THE MCS FOUNDATION

WHAT CAN THE HEAT PUMP SECTOR LEARN FROM SOLAR?

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NOVEMBER 2024

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MCS

Giving everyone confidence in home-grown energy.

With energy costs constantly rising and climate change affecting us all – low-carbon technology has a bigger and bigger role to play in the future of UK energy. MCS is here to ensure it's a positive one.

We are the UK's quality mark for renewable energy technologies like solar panels and heat pumps that are installed in homes and small businesses. Our role is to set clear product and installation standards and protect consumers – giving everyone confidence in home-grown energy.

We are owned by The MCS Foundation, a charitable trust set up to oversee our critical standards work. Any surplus income from our Scheme goes directly into programmes that support the renewable energy sector as we drive towards a Net Zero future.

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The MCS Foundation

Our vision is to make every UK home carbon-free.

The MCS Foundation helps drive positive change to decarbonise homes heat and energy through our work programmes, grants and advocacy.

We support engagement programmes, fund research and facilitate innovative solutions to drive widespread adoption of renewables to help achieve a Net Zero future. In addition, the Foundation oversees the Microgeneration Certification Scheme (MCS) which defines, maintains and improves quality standards for renewable energy at buildings scale.

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Designed by: Jimmy Davies, JimmyDavies.com

Contents

Glossary

BIPV (Building-Integrated Photovoltaics)
A type of solar PV technology that is integrated directly into building materials, such as roofs, facades, or windows, serving as both a power-generating source and part of the building's structure.

DECC (Department of Energy and Climate Change)
A UK government department responsible for energy policy and climate change mitigation, which was active from 2008 to 2016. It was merged into the Department for Business, Energy & Industrial Strategy (BEIS) in 2016.

Department for Business, Energy & Industrial Strategy (BEIS)
A UK government department established in 2016 that combines the responsibilities of the former Department of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS).

BEIS were responsible for policies related to business, industrial strategy, science, innovation, and energy, including efforts to address climate change and promote a low-carbon economy.

DTI (Department of Trade and Industry)
A UK government department responsible for promoting trade, investment, and industry, including energy-related activities, which was active from 1970 to 2007. It was replaced by the Department for Business, Enterprise, and Regulatory Reform (BERR) in 2007, which later became part of BEIS.

Feed-in Tariff (FiT)
A UK government policy mechanism designed to encourage the adoption of renewable energy sources by providing payments to owners of small-scale renewable energy systems, like solar PV, for the electricity they generate and export to the grid. The scheme was introduced in 2010 and closed to new applicants in 2019.

Heating Controls
Devices used to regulate the temperature and operation of heating systems, optimising energy efficiency and comfort. Common types include thermostats, timers, and smart controls that allow users to set specific temperatures or heating schedules for different times of the day.

Inverter
A device that converts direct current (DC) electricity, typically generated by solar panels or batteries, into alternating current (AC) electricity, which is used by most household appliances and the electrical grid.

kWp (Kilowatt Peak)
A measure of the maximum power output of a solar PV system under standard test conditions. It represents the potential power generation capacity of a solar panel or system, typically expressed in kilowatts.

MC4 Connectors
A type of electrical connector commonly used in solar PV systems to connect panels and wiring safely. They are designed to be weather-resistant, durable, and capable of handling the high currents generated by solar panels.

Mounting Equipment
Components used to secure solar PV panels to a building's roof or ground. This includes racking systems, brackets, and other structural elements that ensure panels are installed at the optimal angle and orientation for maximum sunlight exposure and stability.

PDR (Permitted Development Rights)
Regulations in the UK that allow certain building works and changes of use to be carried out without the need for a full planning application. PDR often applies to the installation of small-scale renewables on domestic properties, subject to certain conditions.

Solar Efficiency
A measure of a solar panel's ability to convert sunlight into electricity. It is expressed as a percentage, indicating the amount of solar energy that is converted into usable electrical energy. Higher efficiency means more electricity generation per unit of surface area.

Solar Power Output
The amount of electricity generated by a solar PV module, typically measured in Watts (W).

Foreword

David Cowdrey
Director of External affairs for MCS and The MCS Foundation

Heating our homes and buildings accounts for 17% of the UK's total carbon emissions.

In the face of today's climate emergency, decarbonising those homes and buildings is absolutely essential. To achieve that, we need mass-scale adoption of heat pumps. Heat pumps are being installed faster than ever before in the UK, with 2024 set to be a record year. But even so, we are well behind national targets for installations, and the UK continues to be at the bottom of European league tables for heat pump adoption.

We know that can change. We have seen widespread adoption of small-scale renewable energy with solar PV. Since 2009, more than 1.5 million MCS certified solar PV installations have been carried out across the UK, a remarkable achievement.

So what lessons does the success of solar in the UK offer for the uptake of heat pumps? This report, jointly produced by MCS and The MCS Foundation, looks in detail at that question. Its conclusions are based on a thorough review of solar PV and heat pump development in the UK, with insights from experts in both sectors. One of the crucial messages, repeated again and again in conversations with industry, consumers, and policy experts, is the need for policy and regulatory certainty to provide confidence to the sector and to households. Consumers need to be aware that heat pumps are the future of home heating, and both incentives and advice are needed to support them on their heat pump journey, just as was the case for solar PV.

Providing certainty will ensure installers have the confidence to develop their workforce. Skills needn't be a barrier for heat pump deployment, and this report recommends both policymakers and industry invest in skills development.

Finally, this report recommends that electricity prices should be reduced. Too often we see consumers saying that heat pumps are more expensive than a gas boiler, and saying that this puts them off making the switch. Reducing electricity costs would ensure that a heat pump is always cheaper to run than a gas boiler.
Introducing these policies will remove barriers to heat pump deployment, and be a step forward to ensuring a carbon-free future for all UK homes.

Executive Summary

Domestic heating contributes 17% of the UK's emissions, making its decarbonisation essential for achieving net-zero by 2050.

However, the deployment of heat pumps—the key technology for heat decarbonisation—is significantly off-track, requiring exponential growth to meet critical government targets.

2023 Solar PV vs Heat Pump MCS certified installations in the UK:

183,000
Solar PV installations
2023

39,000
Heat pump installations
2023

In contrast, solar photovoltaics (PV) have become the most widely adopted microgeneration technology in the UK, with just over 183,000 MCS certified installations in 2023, compared to just over 39,000 heat pumps. Additionally, solar PV is now fully commercialised and competitive in the broader market, no longer relying on direct government subsidies, which ended in 2019.

This report provides a comparative analysis of solar PV and heat pump deployment in the UK to examine the factors contributing to the shortfall in heat pump adoption. Crucially, it aims to identify lessons from the development of solar PV that can help accelerate heat pump deployment.

Methodology

The report maps the development of domestic solar PV in the UK using Innovation Theory, which categorises five main stages of commercial maturity of a new technology:

1. **Research and Development**
2. **Demonstration**
3. **Pre-commercial**
4. **Supported commercial**
5. **Commercial**

This report combined the Demonstration and Pre-commercial stages due to their close overlap.

23 semi-structured interviews were conducted with experts from both the solar PV and heat pump industries, alongside a literature review to answer the key research questions:

> What have been the main barriers and enablers of domestic solar PV deployment in the UK?

> Why is domestic heat pump deployment behind solar PV deployment?

Key findings

Section 1 of the report mapped the development of domestic solar in four stages:

1.

Research and Development (1977-1999)
The industry encountered significant barriers to growth, including high upfront costs of solar modules, limited public awareness, and challenges related to installation and grid connectivity.

2.

Demonstration and Pre-commercial (2000-2009)
This stage saw the launch of key demonstration projects and early government schemes for solar PV. They were important in enabling some installations but lacked sufficient funding to support substantial growth in the market.

3.

Supported Commercial (2010-2019)
The introduction of the Feed-in Tariff (FiT) was a turning point for domestic solar PV, driving significant market growth between 2010-2012. However, the sudden changes to FiT rates led to market volatility, with peaks and troughs in installations instead of long-term gradual growth.

4.

Fully Commercial (2019-2024)
Despite the closing of the FiT in April 2019, there was a significant rise in installations between 2022-2023. An unprecedented increase in energy prices resulted in a returned financial incentive to install solar PV. This helped solidify domestic solar PV's position as a commercially competitive technology.

Key lessons

1. Economic Incentives Drive Adoption

The high FiT rates between 2010-2012 made solar PV an economically attractive investment, leading to rapid growth in the market. In 2022, the combination of rising energy bills and reduced installation costs renewed the financial incentive for homeowners to adopt solar PV. Economic factors have been important to the commercialisation of solar PV.

2. Importance of Policy Stability

Consistent and supportive policies are essential for the growth of emerging renewable energy technologies. As illustrated by the solar coaster caused by the poor implementation of the FiT, sudden changes to policy can disrupt the market and slow down progress.

3. Industry Consultation is Crucial for Stable Growth

The lack of industry involvement in the changes to the FiT led to an unsustainable 'solar rush' and subsequent market stagnation from 2016-2021. Engaging industry stakeholders could have helped mitigate these issues by ensuring more stable and sustainable development. This highlights the importance of involving industry in policy planning to avoid volatility and ensure long-term success of policies.

4. Cross-Party Consensus is Vital for Long-Term Policy Stability

The cross-party consensus during the early demonstration and pre-commercial subsidy phase led to key government interventions, such as the publication of the Microgeneration Strategy, the creation of MCS, and the establishment of Permitted Development Rights. This alignment across political lines resulted in considerable policy and regulatory progress for solar PV and demonstrates the value of cross-party support.

5. Role of innovation

Innovation has been key to transforming domestic solar PV into a fully commercialised technology. Incremental improvements in module efficiency and power output, combined with advancements in manufacturing, have significantly reduced installation costs. Additionally, innovations in mounting systems and digital tools have streamlined the installation process.

Why is domestic heat pump deployment behind solar PV deployment?

Heat pumps have remained in a supported commercial stage of maturity since 2014 and are still heavily reliant on government incentives to be competitive.

The report identified several key reasons why heat pumps have not advanced at the same rate as solar PV:

Delayed Policy Interventions

Heat decarbonisation was addressed later, partly due to less stringent early climate targets.

Lack of long-term economic incentive

Solar PV benefited from strong economic incentives like the FiT, which in the early years provided a 10% return. This has not been the case with heat pumps, that have historically been both more expensive to buy and run compared to a gas boiler.

Less reductions in installation costs

Solar PV benefited from significant installation cost reductions between 2000-2013, whereas the same cost reductions have not been seen with heat pumps due to their being a 'transition cost' associated with changes to any heating system.

Public Awareness and Trust

There has been lower public awareness and trust in heat pumps compared to solar PV, partly due to misinformation which has been exacerbated by the media. Choosing to install a Solar PV system (being an add-on technology) is a different decision to a heat pump (being a necessary technology for basic heating needs).

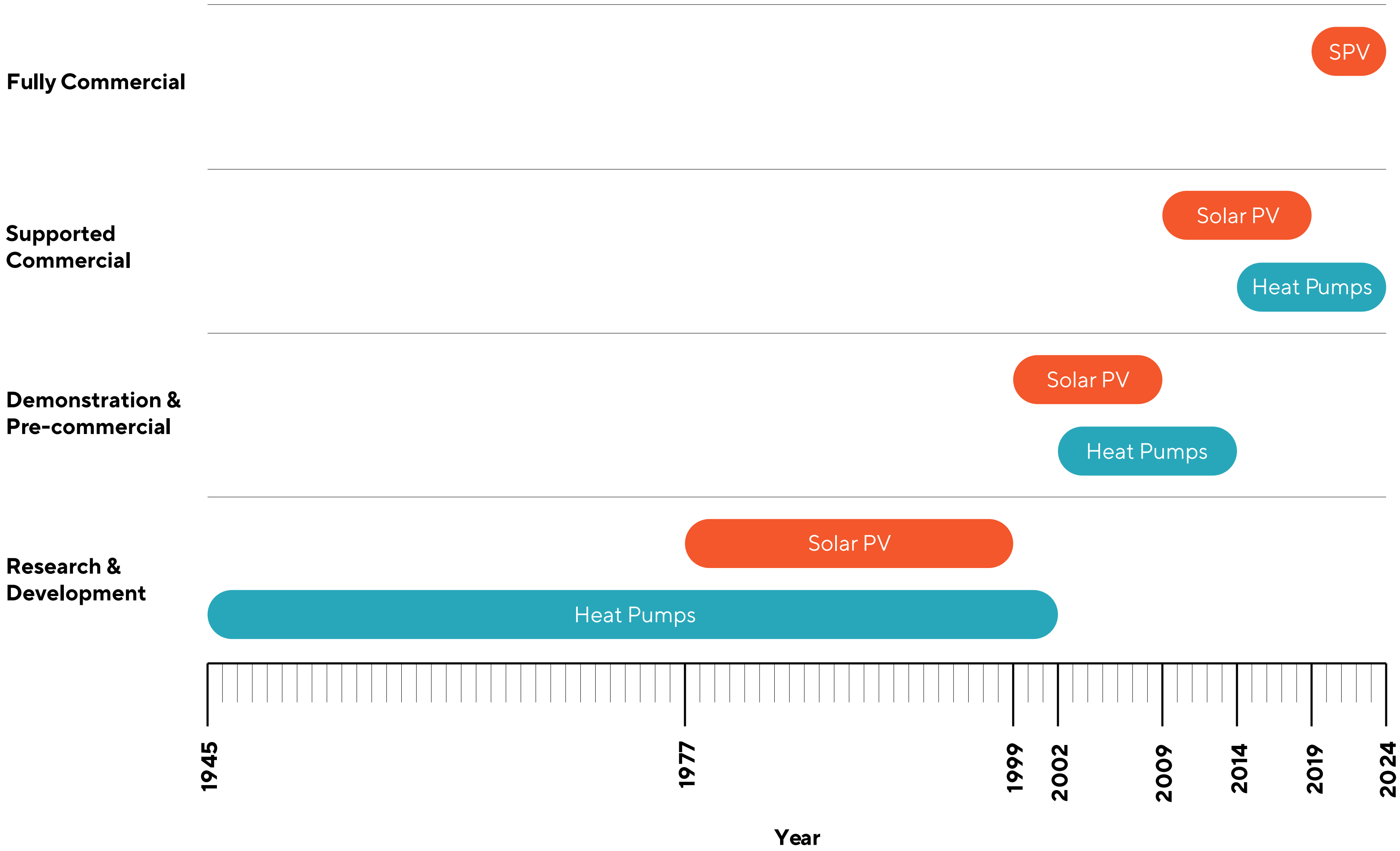
Ineffective Incentive Schemes

The Renewable Heat Incentive for heat pumps was less effective than the Feed-in Tariff for solar PV, leading to slower market growth in the 2010s.

Stronger Lobbying Against Heat Pumps

The heat pump industry faces stronger opposition from the fossil fuel and gas boiler industries, which has hindered policy support for heat decarbonisation.

Figure: *Solar PV and Heat Pumps on the Innovation Theory timeline.*



Recommendations

Clearly there are some unique challenges and opportunities associated with individual technologies, including heat pumps and solar PV. Nevertheless, despite the differences, there are some key lessons that can be derived through this comparison. This report puts forward the following recommendations:

1. **Create an economic incentive for the homeowner by making heat pumps the cheapest form of heating**
   Government must address the price gap of electricity and gas by removing social and environmental levies from electricity and moving them into general taxation. This should be paired with an extension of the Boiler Upgrade Scheme to 2035 to support homeowners with the upfront cost of transitioning their heating system.

2. **Increase consumer awareness and trust of the heat pumps**
   Government should finance a national one-stop-shop in the UK where consumers can get free personalised advice.

3. **Industry should continue to drive innovation to improve standardisation, reduce costs, and broaden the consumer offer.**

4. **Diversify supply chains and support UK manufacturing**
   Government should legislate the Clean Heat Market Mechanism to encourage boiler manufacturers to manufacture and sell heat pumps.

5. **Improve the green finance offer so that more households can transition to low-carbon heating**
   Government should fund a 0% interest Property Linked Finance loan to support homeowners with the upfront purchase of heat pumps.

6. **Long-term policy certainty**
   The Government should implement the following regulations and policies to address barriers and provide long-term certainty:
   - Continue to review the Permitted Development Rights for air-source heat pumps.
   - Announce a ban on all domestic fossil fuel heating systems from 2035.
   - Make a decision on hydrogen for home heating no later than 2026.

7. **Foster cross-party political support for heat pumps**
   The heat pump industry should continue to raise awareness and provide information to MPs across political parties to drive cross-party consensus on this issue.

8. **Support supply chain growth through skills development and stable policy**
   Long-term and stable policy which supports maintained growth is key to provide confidence to stakeholders, including gas heating engineers, to enter the heat pump workforce.

A long-term, policy roadmap to drive heat pump adoption

To conclude, this report examines the evolution of domestic solar PV, from a niche technology in the late 1970s to a fully commercialised technology by 2019.

Significant cost reductions in solar modules, driven by global markets, along with generous FiT rates, led to rapid market growth in the early 2010s. More recently, high electricity prices and the reduced cost of battery storage have further boosted solar PV's financial appeal by shortening payback times. This has helped solidify domestic solar PV as a mainstream, commercially viable technology, even without government subsidies.

However, despite its relative success compared to other microgeneration technologies, the commercialisation of solar PV has not been without significant challenges. Notably, market volatility caused by abrupt changes to the FiT and political uncertainty have hindered steady progress, negatively impacting industry and market growth.

In comparison, the heat pump sector remains dependent on government grants and just over 39,000 were installed in 2023, compared to 183,000 solar panels.

Unlike solar PV, heat pumps have faced delayed policy interventions, fewer long-term economic incentives, and limited cost reductions in installation. Additionally, lower public awareness and trust, issues with the Renewable Heat Incentive, and stronger lobbying from the fossil fuel industry have all contributed to slower market growth compared to solar PV.

Based on this comparison, it is evident that scaling up heat pump adoption will require several key policy and regulatory interventions to address existing barriers. Notably, policies should focus on building public confidence and trust, correcting market distortions to ensure heat pumps become the most affordable heating option, and providing sufficient long-term grants to help homeowners with the upfront costs of transitioning to low-carbon heating. Overall, this analysis illustrates how policy can effectively drive investment and innovation, but also how this progress can be undermined by poor implementation and stop-start approaches. Therefore, a comprehensive, long-term delivery plan is essential to accelerating heat pump deployment in the near term, while also supporting their full commercialisation over the long term.

Introduction

In 2019, the UK Government legally committed to be net zero by 2050. To achieve this, the housing stock will need to decarbonised, as it currently accounts for 17% of all emissions.[1]

In their 2024 progress report, the Climate Change Committee noted that the UK is off-track to meet important interim carbon budgets for heat decarbonisation.[2] The adoption rate of heat pumps, in particular, is significantly behind where it needs to be. Just over 60,000 were installed in 2023,[3] which means there needs to be a ten-fold increase in installations in just four years to meet the government's 600,000 per year target in 2028.

The rollout of domestic grid-connected solar photovoltaics (PV) has in many ways been significantly more successful relative to heat pump rollout. Installations have risen from just two recorded in the 1990s, to over 1.5 million cumulative MCS certified installations by 2024 – around six times the number of heat pump installations. What's more, there were over 183,000 solar PV installations recorded by MCS in 2023, without any direct government financial subsidies.*

With this context in mind, this report aims to analyse the evolution of domestic solar PV in the UK, to understand how it has become the most widely adopted microgeneration technology. In doing so, it aims to determine the key lessons that stakeholders involved in the heat pump transition can learn from the success of solar, answering the key research question: What can the heat pump industry learn from solar PV? To answer this overarching question, a series of 23 semi-structured interviews were carried out with experts from both the solar PV and heat pump industries alongside a literature review.

The unique nature of technology development and adoption is clearly dependant on the time and context in which it develops, which can never be fully replicated.[4] Additionally, there will be unique challenges and opportunities for each individual technology that should be considered in any comparative study. Nonetheless, we believe this original analysis offers a new and valuable perspective of looking at the necessary steps and policy interventions to achieve mass-scale adoption of heat pumps.

10x

Heat pump deployment must **increase ten-fold** in just four years to meet the government's target

*This report only references MCS certified install numbers as there is currently no accurate UK-wide data for non-certified installs.

The 5 stages of commercial maturity of a technology

The first section of this report maps the development of domestic solar PV, and to organise the analysis, it uses concepts put forward by the Theory of Innovation.

This theory encompasses many concepts and frameworks, all aimed at understanding how new technologies, processes or ideas are adopted within societies and markets.[5]

Over the past two decades, this theory has been increasingly used to understand the development of low-carbon technologies. Foxon et al.[6] used a theory of innovation framework to understand the drivers, barriers, and system failures of a variety of renewable technologies. Whilst acknowledging that technology development is often non-linear, with feedback loops between different stages, in the context analysing development over a period of time they put forward 5 stages of commercial maturity and defined them as follows:[7]

1. Research and Development
Includes both 'blue skies' science and engineering/ application focused research. These include both university and industry R&D.

2. Demonstration
Includes early prototypes and is intended to refer up to the point where full-scale working devices are installed—but only in single units or small numbers, and still financed largely through R&D related grants. This is often the preserve of small spin outs or research subsidiaries.

3. Pre-commercial
Intended to capture a fairly broad stage of development, one where multiple units of previously demonstration-stage technologies are installed for the first time, and/or where the first few multiples of units move to much larger scale installation for the first time. Larger players begin to move in, or spin outs must grow rapidly, so investment risks are high at this stage.

4. Supported commercial
The stage where, given generic renewables support measures such as the UK Renewables Obligation, technologies are rolled out in substantial numbers and by commercially oriented companies.

5. Commercial
Technologies can compete unsupported, within the broad regulatory framework.

Domestic solar PV - the four stages of commercial maturity

This report uses these stages to map the development of domestic solar PV in the UK, with one small alteration.

We chose to group together the demonstration and pre-commercial stages, as these stages occurred over a short period for domestic solar PV and were logically paired together. This report therefore breaks down the development of domestic solar in the UK in the following categories and timelines:

1977-1999

Research and Development

In 1977, the UK government started to support research and development into solar systems. Nonetheless, solar PV was more of an academic interest during these years, as it was considered too expensive to be a commercially viable, grid-generation technology. Instead, it was seen as a good 'off-grid' solution for areas that were difficult to connect to the grid. The UK solar industry was heavily influenced by advancements in Germany, where the government were funding grid-connected solar arrays on households from 1990. There were only two known domestic installations in the 1990s, and a large focus during this period was overcoming the barriers of how to connect smaller, decentralised solar PV projects to a largely centralised electricity grid.

2000-2009

Demonstration and Pre-commercial

The first domestic solar PV demonstration project was launched in 2000, followed closely by two early government subsidy schemes. These schemes supported a small number of installations and were designed to evaluate the viability and impact of domestic solar PV in the UK. There was some growth in the market, but this was limited by the government schemes, that only supported a small number of installations.

2010-2019

Supported commercial

The Feed-in Tariff was introduced in 2010, and in the first two years of the scheme, the market saw unprecedented growth. However, sudden changes to the FiT rate led to what was later coined the 'Solar Coaster', with peaks and troughs in installations, instead of gradual market growth. Nevertheless, during these years, there was significant innovation on a global scale which led to cost reductions and improved efficiencies. The significant market growth during this period helped to bring solar PV into the mainstream.

2019-2024

Fully commercial

In April 2019, the FiT closed to new applications and since this point, there have been no direct government financial support for solar PV for the able-to-pay market. Due to energy crisis and significant increases in energy bills, domestic solar PV saw a high uptake in installations in 2023. As a technology, it is now commercially competitive within the broader regulatory environment.

Themes

To organise the key enablers and barriers as well as compare effectively across the different stages of development, we organised the findings into seven themes.

The themes emerged from our thematic analysis of the interview transcripts. To develop the interview questions, we used secondary literature that explored what factors influence energy transitions, and more specifically, what factors can influence microgeneration adoption.

Energy context and external factors

External factors, such as societal, geopolitical and environmental conditions, can impact how new technologies are adopted, in some cases acting as a barrier, whilst in other cases, acting as a catalyst.[8] These can be events on a global scale, or events unique to the individual country. Whilst this report focuses on the development of the UK solar PV industry, it is clear this has not evolved in a vacuum and has been impacted by changes to the global solar PV industry.

Economic factors

Economic factors can influence the development of low-carbon technologies.[9] For example, high upfront costs can be a significant barrier to the uptake of microgeneration technologies,[10] which is often why government subsidies are necessary. This report addresses factors that have influenced the development of solar PV and heat pumps, including upfront costs, running costs, payback periods, and electricity costs.

Public perception and adoption

When considering the successful implementation of any renewable technology, public acceptance and understanding are understood to be critical to mass adoption.[11] This is particularly the case with microgeneration technologies, as it hinges on consumer choice, and therefore trust of the technology.[12]

Technological developments and innovation

Even when the standardised design of technology is achieved,[13] incremental efficiency improvements and developments within the manufacturing processes are important to drive system productivity and cost reductions.[14]

Policy, regulation and standards:

Policy, regulation and standards have been identified as critical to supporting the uptake of low-carbon technologies.[15] These technologies are often more expensive than incumbent options, and there is a significant path dependency associated with fossil fuels that hinders transition. Thus, policy, regulation and standards are critical to supporting the widespread use of low-carbon technologies.

Skills, competence and training:

It is understood that the transition to a low-carbon energy system will require the development of a range of skills.[16] The skills gap is often referenced as a key barrier to the low-carbon heating transition.[17]

Actors

Actors are those that have the power to influence the adoption of things. Different actors can influence energy transitions, either by attempting to protect their vested interests or championing for change.[18] In this report, we refer to any key actors that have influenced the adoption of solar PV or heat pumps in a positive or negative way, at all stages of development.

Summary

To summarise, after outlining the methodology, Section 1 maps the development of domestic solar PV in the four stages of technology maturity to determine what lessons can learnt from its successful commercialisation. Section 2 examines the current progress of heat pump development using the same framework, then Section 3 goes on to investigate why heat pumps have not advanced at the same rate as solar PV, through a comparison of both technologies. Finally, Section 4 outlines recommendations based on the analysis to address existing challenges and promote effective policy measures necessary to achieve mass-scale adoption of heat pumps.

Methodology

To answer the main research question, a total of 23 semi-structured interviews were conducted. This included 13 interviews with solar PV experts and 10 with heat pump experts from diverse backgrounds, including representatives of installers, manufacturers, engineers, energy providers, and policy experts (see Table 1 for details).

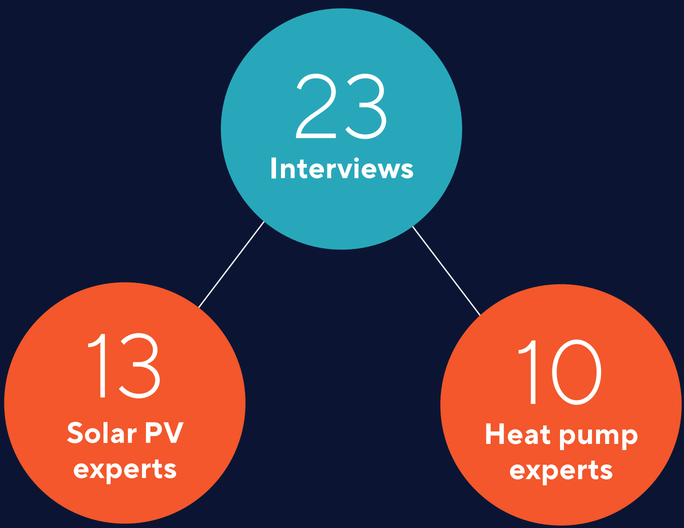


Table 1: *Interviewee roles and counts.*

Type of interviewee	Count
Consultant	7
Distributor	2
Energy Provider	1
Installer	4
Manufacturer	2
Policy	5
Policy / Scientist	1
Sustainable Architect	1
Grand Total	**23**

The interview questions were informed by a literature review on common barriers to solar PV and heat pump deployment. Interviews with solar PV experts centred on the question:

> What have been the main barriers and enablers of domestic solar PV deployment in the UK?

Conversely, interviews with heat pump experts addressed the overarching question:

> Why is domestic heat pump deployment behind solar PV deployment?

Key themes emerged from the interview data analysis, which, when supplemented by a literature review, shaped the main headings of this report. A framework from innovation theory taken from Foxon et al.[19] was also used to determine the different stages of market maturity and structure the analysis.

1. The history of domestic solar PV in the UK

Contents

1977-1999 **Research and development**

Timeline

1977 – The UK Department of Trade and Industry started to officially finance research and development in solar systems.

1981 – BP solar, a subsidiary of British Petroleum, was established, becoming one of the first solar PV manufacturers in the UK. They also carried out important research and development.

1983 – The first grid-connected solar PV array was installed by BP in their Marchwood power station.

1984 – Wind and Solar company set up in the UK. They were one of the first distributors and installers of solar PV.

1990 – Launch of German 1000 Roofs Programme.

1994 – The first domestic solar array connected to the grid – The Vale's Autonomous Home.

1995 – The second domestic grid-connected solar installation - Eco Home Oxford.

1998 – Solar Century was formed, one of the UK's leading solar PV distributors and installers, and an important convening voice for the sector.

1999 – Grid connections standard G77 introduced.

1999 – Launch of the German 100,000 Roofs Programme.

Summary of the R&D stage

Key barriers

1.

Cost

The high costs of solar modules, paired with low electricity bills meant that there was no financial incentive to install domestic solar panels.

2.

Difficult to connect to the grid

Connecting small-scale projects to the grid was a completely new concept and therefore challenging.

3.

Lack of specialised equipment

As solar PV was still in its early stages of development globally, there was limited specialised equipment to facilitate installations.

4.

Lack of political support

Though there was some interest from Government at the time, there was also scepticism around the cost reductions that would have to take place to make solar energy generation cost-competitive.

Key enablers

1.

The establishment of G77

The creation of a grid connection standard was to a key regulatory intervention that helped to streamline the installation process and support an increased number of installations in later years.

2.

The German 1000 and 100,000 Roofs Programme

Important learnings were derived from the German industry around the feasibility and value of small-scale grid-connected solar PV systems.

Energy context and external factors

Solar PV on roofs? – The influence of the German 1000s Roofs Programme

Throughout the Research and Development stage (1977-1999), *"PV was an academic hobby. It was not a commercial end." (Solar PV technical expert).* The British electricity system at the time was largely centralised, made up predominantly of coal- and oil-fired power plants.[20] As one solar interviewee explained, solar PV *"was seen as a very good way of providing power in remote parts of...Africa [or] South America"*, but not considered a competitive grid-connected energy generation technology.

Connecting smaller scale generation technologies to the electricity grid was not something considered by industry or government in the UK until the German 1000 Roofs Programme in 1990. This demonstration programme, launched by the German government, aimed to demonstrate the feasibility and benefits of small-scale grid-connected solar power, supporting the installation of PV systems on the rooftops of 1,000 buildings across the country.[21] The success of this scheme resulted in the launch of the 100,000 Roofs Programme in 1999, which supported 55,00 installations over four years and lead to significant growth in the German solar PV market.[22] One solar expert explained how especially in the early years, the UK solar PV industry were heavily influenced by Germany and these initial demonstration programmes: *"Everyone was very curious from an academic point of view..."*

The first domestic installations in the UK

In the 1990s, there were some domestic standalone installations (not connected to the grid),[23] but only two known domestic grid-connected solar PV installations in the UK, reflecting the very early stages of market development. The first in 1994 was on the house of Brenda and Robert Vale,[24] authors of 'The New Autonomous House' published in 1975. This book put forward a new architectural philosophy; that it is possible to build homes that are good for the planet, give the homeowner more energy autonomy, and that are inexpensive with low- or no bills. The Vale's solar PV installer described how: *"...they wanted to build a self-sufficient house, and they wanted to build it off grid in Nottinghamshire. But it didn't really make sense to try and do it off grid because they'd have to try and store energy from summertime to wintertime...At the same time I'd heard about how people in Germany were looking at connecting solar PV to the grid... I went to a trade show in Europe and met SMA* and heard about their inverters and suggested this to the Vale's as a possibility... Basically [they] said, well, if it's good enough for Germany, it's probably good enough for us and so we managed to install it. "*

Shortly after, Sue Roaf, another architect who has written several books about sustainable architecture, designed and built her Oxford Eco House in 1995. The Oxford Eco House was built with the aim of being a 'low energy' home. Compared to homes of a similar size being built around the same time, with emission intensities of around 6,500 kg CO_2 per annum, the Eco-House Oxford was designed to emit just 148kg CO_2 per annum.[25] The house incorporated 48 photovoltaic modules arranged in 4 vertical rows mounted on a built-up aluminium frame screwed on the roof.

UK manufacturing of solar panels

British Petroleum created the subsidiary 'BP Solar' in 1981, becoming one the leading manufacturers for photovoltaics. Whilst their main manufacturing facilities were in the U.S, Spain and India, they carried out some manufacturing in UK in Aylesbury,[26] whilst their site in Sunbury-on-Thames primarily focused on research and development. At first, the company specialised in solar PV applications where other energy systems offered no practical alternatives including communications, transport signalling, and civil-engineering projects in remote locations.[27] One of first grid connected solar PV installations in the UK was installed by BP Solar on their Marchwood power station in 1983.

The 30kW system was the first project of its kind,[28] and marked the beginning of grid-connected solar PV in the UK. They later installed grid-connected solar panels onto their Sunbury facility, which was used by the Department of Trade and Industry for data collection and monitoring purposes.[29] One interviewee explained how this early commercial R&D was an important enabler of solar PV, as it helped demonstrate the feasibility of grid-connected solar, grow the industry, and spark government interest. They explained; *"BP...helped create an industry."*

*SMA Solar Technology AG is a German solar energy equipment supplier founded in 1981. SMA is a producer and manufacturer of solar inverters for photovoltaics systems with grid connection, off-grid power supply and backup operations.

Economic factors

A breakthrough in design in the 1970s resulted in significant cost reductions to PV module price in the late 1970s to early 1980s.[30] The global cost of cells fell from just over $125 per watt in 1975, to just over $27 per watt in 1981.[31] Nevertheless, despite these significant cost reductions, domestic solar PV installations were still extremely expensive. Several interviewees explained that though solar PV was gaining interest in the UK, *"... it was never really seen...certainly in the short to medium term as being a cost competitive generation technology." (Solar PV expert)*. The Vale's system in 1993 cost £6900/kWp,[32] £14,412 in 2024 prices.[33] In comparison, the average cost of a solar system in 2024 is £1,742 per kWp.[34] In 1993, it was estimated that the payback period was 200 years. Thus, in the R&D stage, a PV system was not cost-competitive within the wider electricity landscape.

Public perception and adoption

Unsurprisingly, there were very low levels of public awareness of the solar PV technology throughout the 1980s, as there were only a handful of installations, most of which were off grid. One founding industry expert in the UK at the time recalled: *"I was approached by a professor in Newcastle, and he said, could you make photovoltaics into building material. My first question was, what on earth are photovoltaics?"* The fact that a buildings engineer had never heard of the technology is indicative of the low levels of awareness of the technology more broadly. Many of the interviewees claimed that though awareness of the technology grew over this period, there was still public scepticism due to the perception that solar generation wouldn't work in the UK due to limited solar irradiance. The only two domestic installations were from two very engaged and eco-aware architects who built these homes with the intention of making them low energy and self-sufficient. Grid-connected solar PV was still too niche, expensive and complex to install to appeal to most homeowners.

Technological developments and innovation

According to one interviewee, the basic solar photovoltaic cell technology has not fundamentally changed, *"the technology that was patented by Bell Laboratories in 1948 ...is basically the same technology [as today]."* However, the efficiency and power output of the modules being manufactured during this period was substantially lower. The efficiency of a solar panel refers to the percentage of sunlight that the panel can convert into usable electricity. Higher efficiency means that a greater proportion of the sunlight striking the panel is transformed into electrical energy, resulting in a higher power output from a given surface area. The best modules on the market at the time only achieved a peak power of 85W, with an efficiency of 13.1%,[35] compared to a solar module on the market in the UK today which has a power output of 445W, with an efficiency of 23.3.%.[36]

The installation process was also much more complex. The direct current (DC) solar connectors first developed by a German company were not widely available. These are specialist electrical connectors that allow panels to be safely connected to cables. Instead, panels had to be hard wired and installed 'live' with black plastic sheeting over them. Though these connectors were invented by a German company in 1996, they did not become standard equipment until 2004.[37] According to one solar installer, this not only made installation harder, but also made it more dangerous. There was also no standardised mounting kit - which is the equipment used to secure the solar modules onto the roof - and therefore each installation had to be customised with standard bits of metal drilled onto the roof. This lack of standardisation made installations more expensive and complex to install. For example, the mounting equipment for the Eco House Oxford reportedly cost £10,000 for a 4kW system,[38] whilst today the mounting equipment for the same size installation costs around £520.[39] Furthermore, mounting equipment available on the market today is standardised and suitable for all roof types.[40] This highlights the progress that has been made in installation efficiency since the R&D stage.

Policy, regulation and standards

Government support for the research, development and promotion of solar technology started in 1977, led by the UK Department of Trade and Industry. This research focused on the design of both photovoltaic systems for energy generation and solar thermal technologies for space and hot water heating.[41] Though the funding amount is unclear, one solar interviewee expert maintained that it was small amounts compared to some European counterparts. Instead, industry relied heavily on findings from German demonstration projects.

The policy and regulatory landscape was not favourable for solar PV during these years. However, there was one important regulatory breakthrough which was the creation of the grid connection standard in 1999. Before this, connecting to the grid was very challenging. Permission was required from local network operators and the decision was at the discretion of local engineers, and by no means certain. It was also very expensive to connect to the grid, which one expert explained is why the few companies installing solar PV at the time focused on off-grid projects. The development of the G77 grid connection standard contributed towards standardising the process, reducing the cost and time it took to connect. This was essential to have in place to support greater uptake of solar PV.

Skills, competence and training

There were no official skills and training for solar PV installation during this period, reflecting the nascent stage of the market. Instead, the technical knowledge and skills required to connect these panels to the grid was heavily influenced by Germany, as was the case for the Vale's installation. The installer had to attend a trade show in Europe to understand how the inverter technology worked and acquire the relevant equipment. Installing solar panels was still a niche skill and connecting to the grid even more specialist.

Actors

Government and industry sceptical about the role that solar PV could play in the energy system.

In the 1990s, various European governments became interested in the PV technology, resulting in several demonstration projects across Europe.[42] According to many of the experts interviewed for this project, the UK Government's perception at the time was that it was an interesting technology, but not something that was at all cost-effective and therefore a potential distraction to centralised energy. Even among climate change advocates, who saw solar as a way to cut greenhouse gas emissions, there was some doubt about the future role of the technology. One interviewee admitted: *"I didn't believe it at the time that it was touted as a thing that was going to, you know, potentially cut costs massively and come to dominate global electricity.... And so, I was kind of a little bit sceptical..."*

Though as one interviewee explained, government interest increased in the 1990s, as a result of the German demonstration projects and a rising commercial interest from actors, including BP Solar.

Conclusions

In the early years of solar PV development, the industry encountered significant barriers to growth, including high upfront costs of solar modules, limited public awareness, and challenges related to installation and grid connectivity. Despite these obstacles, two known domestic installations took place in the UK, as industry took learnings from Germany's successful demonstration projects for grid-connected solar PV. This foundational activity from both commercial and government R&D between 1977-1999 paved the way for future progress, showcasing the feasibility of domestic solar PV and establishing important grid connection standards.

2000-2009 **Demonstration and pre-commercial**

Timeline

2000 – The first solar PV demonstration project launched in the UK.

2000 – The Finance Act – reduced VAT from the standard 17.5% to 5% for Energy Saving Materials, including solar PV systems.

2001 – A Photovoltaic Government Industry Group set up. The group made a series of recommendations to Government to support the growth of solar PV.

2002 – Renewables Obligation - Government ordered all energy suppliers to generate some of their energy from renewables to ensure that by 2010 10% of electricity was generated from renewable energy.

2003 – The 'Merton Rule' was introduced by the London Borough of Merton in 2005 requiring all new major developments to use onsite renewable energy to reduce annual CO_2 emissions by a set percentage, typically 10-30 %. The Merton Rule was taken up by 150 other local authorities.

2006 – The Zero Carbon Homes Bill was introduced by the Labour government and committed that from 2016 all homes would be 'zero carbon' ready.

2006 – The Energy Review: Energy Challenge – The UK government committed to reducing CO_2 emissions by 60% compared to 1990 levels.

2006 – The Microgeneration Strategy published by the UK Government.

2006 – The Low Carbon Buildings programme was launched.

2008 – The Climate Change Act signed, and a new governmental department was formed; the Department of Energy and Climate Change (DECC).

2008 – Solar PV, solar thermal, ground and water source heat pumps added to Permitted Development Rights.

2008 – The Microgeneration Certification Scheme was set up, a quality assurance scheme for small-scale renewables.

Summary of the demonstration and pre-commerical stage

Key barriers

1.

Cost

Installing PV was still expensive, approximately three times per kWp compared to 2024 installation costs, and even with government support it was not cost-competitive.

2.

Lack of awareness and consumer support

Domestic solar PV was still a new technology, and high upfront cost, long payback periods, and lack of trust were factors impacting consumer adoption.

Key enablers

1.

Cross-party support for microgeneration technologies

Key policies and strategies were established during this period that supported future uptake, most importantly the Microgeneration Strategy in 2006.

2.

Demonstration projects and early support schemes

These schemes supported the uptake of a small number of solar PV installations and demonstrated to government the feasibility of domestic solar PV.

3.

Establishment of Permitted Development Rights

This streamlined and simplified the installation process for domestic installations.

4.

Campaign from the solar industry

The campaign from the solar industry during this period was critical to them securing increased government financial support for the supported commercial stage (2010-2019).

"...we'd always said that the government, both here and in the EU, need to get a huge market in order to drive down the cost [of]...semiconductors at the time, microchips and things. If you make enough of them, it's highly automated and therefore you drive down the cost. That's exactly what the Chinese did."

Energy context and external factors

Climate change targets became more ambitious

Climate change targets between 2000-2009 were considerably more ambitious than had been seen previously in the R&D years (1977-1999). The 2003 white paper, 'Our Energy Future – Creating a Low Carbon Economy,' was a key milestone which set a long-term target to reduce CO_2 emissions by 60% by 2050 compared to 1990 levels.[43] Five years later in 2008, the UK legally committed to reduce CO_2 emissions by 80% compared to 1990 levels.[44] As the carbon intensity of the grid was still very high at the time, with mostly gas used to generate electricity,[45] government acknowledged the importance of putting in place a range of measures to support renewable energy generation in the UK.[46] This had a positive impact on the policy and regulatory landscape for solar PV (see policy, regulation and standards).

China started to dominate solar cell manufacturing globally

Though there was still some UK manufacturing during this stage (2000-2009), by 2008, China was the leading producer of solar cells in the world.[47] One of the key factors driving down solar module prices between 2001-2009 was improvements to manufacturing and economies of scale from increased global demand.[48] One interviewee described how: *"...we'd always said that the government, both here and in the EU, need to get a huge market in order to drive down the cost [of]... semiconductors at the time, microchips and things. If you make enough of them, it's highly automated and therefore you drive down the cost. That's exactly what the Chinese did."*

Though relying on foreign supply chains has its risks (as seen in the Fully commercial years), progress in global supply chains had a positive impact in driving down costs in the domestic solar PV market in the UK.

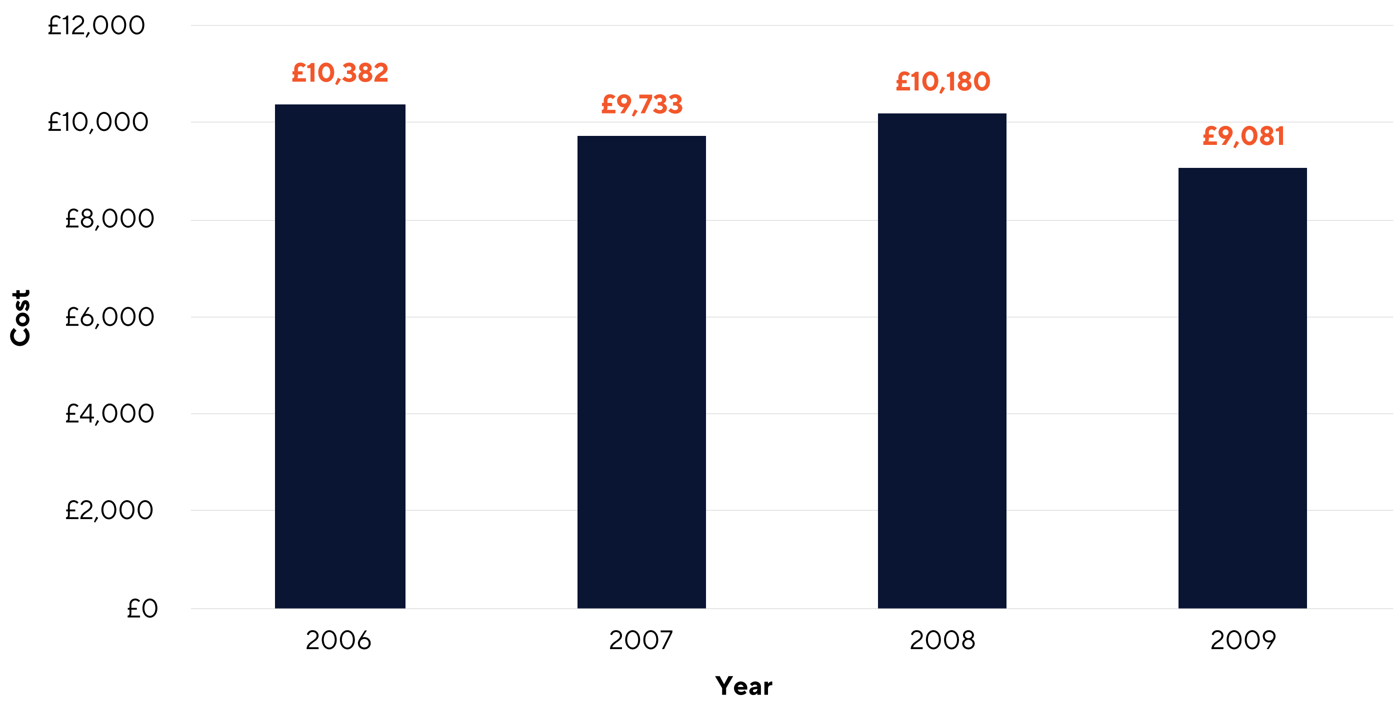
2008

by 2008, China was the leading producer of solar cells in the world

Economic factors

The cost of installing solar PV systems was still very high in the demonstration/pre-commercial stage of development. ***Figure 1*** shows the cost of installation per kWp from 2006 to 2009 in 2024 prices. Installations were four to five times more expensive than today, where a homeowner can install a solar system for an average £1,742 per kWp. As a result, without government support, upfront costs and payback times were still too high for domestic solar PV to be competitive within the wider market. According to one interviewee, *"the payback period with the...[Low Carbon Buildings Programme grant] was still something like 15 to 20 years, so it was difficult to make commercial sense."*

Figure 1: *The price of a domestic solar PV installation per kW from 2006-2009 inflation adjusted. [Data sourced from: DECC [49]].*



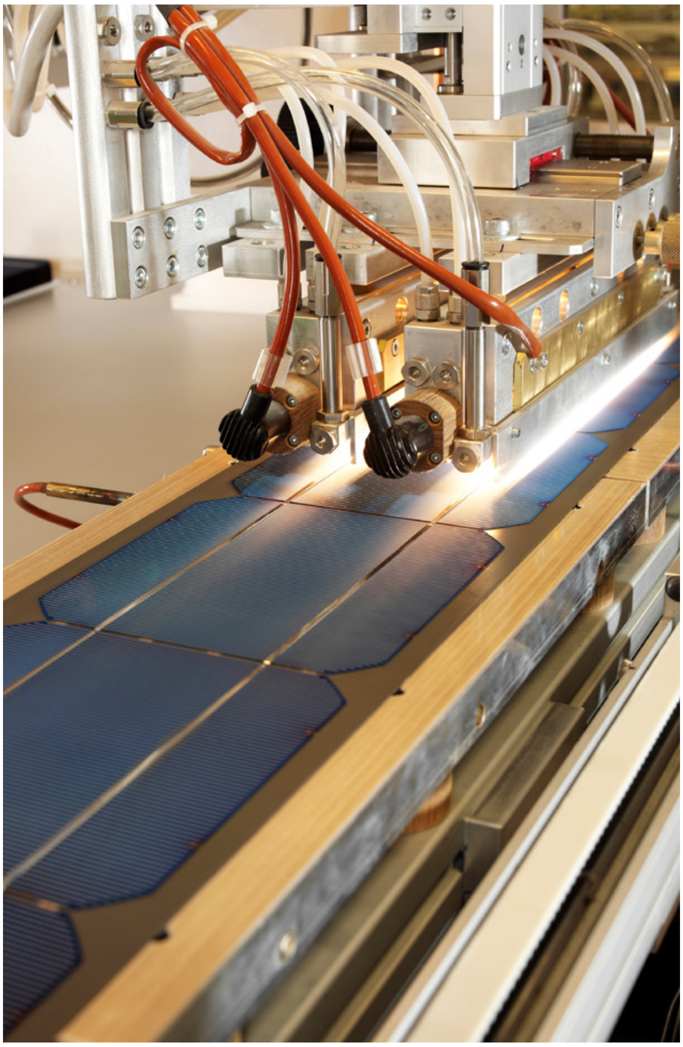
Public perception and adoption

Though there was growing public awareness and support for renewable energy generation and solar PV more broadly,[50] in the early 2000s domestic solar PV was still considered an 'innovative' technology.[51] Solar systems remained largely unattractive to the majority of homeowners due to the high upfront costs, the long payback times and a general lack of trust in the technology's performance.[52] According to several interviewees, anecdotally they suggested that those installing domestic solar PV were still predominantly households who were motivated by environmental reasons. One interviewee who was installing domestic solar PV at the time recalled a typical demographic for the early adopters as retired individuals who were often driven by altruistic motives rather than financial gain.

Nonetheless, according to another interviewee the early government support schemes for solar PV between 2003-2009, succeeded in creating some public interest in the technology – and subsequently many of the grant schemes for solar PV were oversubscribed (see Policy, Regulation, Standards).

Technological developments and innovation

Improvements to the efficiency of the PV modules and manufacturing processes between these years helped to drive down module costs.[53] Furthermore, R&D initiatives continued to explore innovative solar PV technologies, in particular building integrated technologies. In the early 2000s, Solar Century, a manufacturer and distributor, designed and manufactured solar tiles.[54] At the time, there was a growing number of solar PV distributors in the UK and by 2008, 31 companies supplied solar PV equipment, which could be the modules, inverters, or the mounting equipment.[55] However, one installer noted that there was still a lack of choice for equipment, and as a result, *"you couldn't go into a distributor and say I want this to go with that and that; it didn't exist."* The installation process had improved since the R&D stage, but a lack of equipment and standardisation meant that installations were still more complex than today.



Policy, regulation and standards

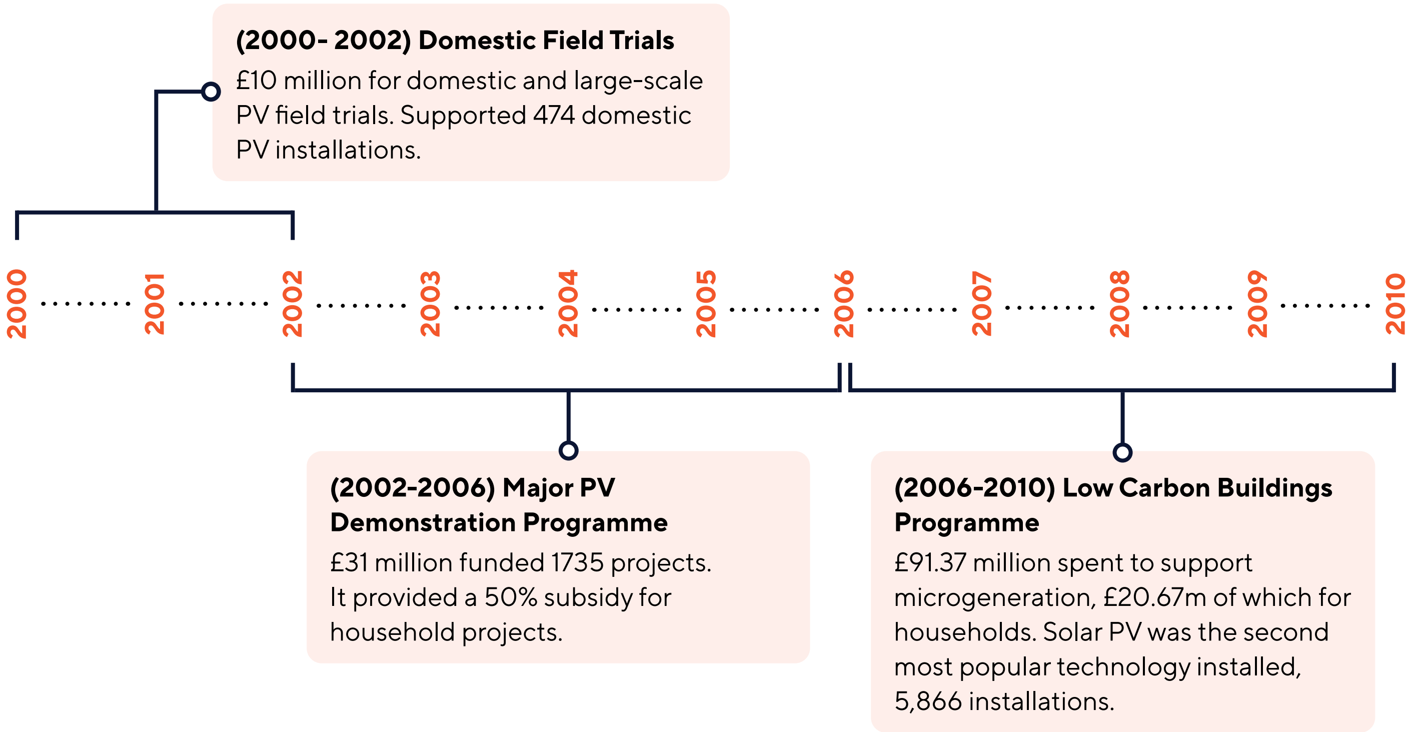
Demonstration and early market support schemes

In 2000, the Domestic Field Trial (DFT) was launched by the Department of Technology and Industry (DTI) - the first demonstration project for solar PV. This helped inform the Photovoltaics in Buildings – Guide to Installation of PV systems (2002), the first comprehensive manual intended to inform on the effective and safe installation of PV systems in buildings. The DFT was followed by the Major PV Demonstration Programme (2002), which provided upfront grants to households to install solar PV. These programmes were aimed at monitoring the performance of PV systems in domestic buildings, providing insights into system design, installation practices, and effectiveness in various conditions.[56] The Low Carbon Buildings Programme (LCBP) was launched in 2006, a government scheme which provided grants for a range of microgeneration technologies. It covered on average a third of the installation cost for a solar PV system, with 5,866 solar PV systems installed in total.[57]

The early demonstration and support schemes were critical for early development of the domestic solar PV market in the UK, especially as the upfront cost of installation was still high. However, the impact was limited, as the schemes only supported a few thousand installations between 2000-2009. Importantly, the grant pot for the LCBP was too small to support the growing demand for the scheme, and as a result it was often oversubscribed to.[58] One interviewee noted that: *"The main problem with it was the funding wasn't sufficient to meet the demand… [so] the way they used to do it was they would allocate a certain amount of money per month and once that money had gone, you couldn't actually apply until the beginning of the next month. So, you can imagine what started to happen. The money would go in literally 12 hours or something and then you've got all these potential customers waiting around…"*

This made it challenging to grow the industry in any meaningful way as *"you can't plan your business on that sort of model." (Solar PV expert)*. According to one expert, it became clear within industry that to grow demand for domestic solar PV and drive the necessary innovation and economies of scale, it would require significantly more government funding, along with a better-designed scheme implemented over a longer timescale.

Government supported schemes



The Merton Rule increased solar PV uptake in new builds around the UK

The Merton Rule was first adopted by the London Borough of Merton in 2003. It required new developments to generate at least 10% of their energy needs from on-site renewable energy sources, which included solar thermal, solar PV and micro wind. This pioneering planning policy gained significant traction across the UK and by 2008, more than 150 local authorities had adopted similar policies.[59] According to many of the solar experts interviewed, the Merton Rule was an important catalyst for solar PV on new builds and *"it [the Merton Rule] spread like wildfire across Britain."*

The government launched the Microgeneration Strategy

The regulatory landscape for domestic solar PV progressed significantly between 2000-2009. The Microgeneration Strategy was published in 2006,[60] which reflected the positive political appetite for small-scale renewables at the time. The strategy acknowledged the significant role that these technologies could play, suggesting that they could provide 30-40% of the UK's electricity needs by 2050. It set out a clear plan to support increased rollout, including increasing financial incentives, improving the regulatory landscape, increasing public awareness, and creating a technical and standards certification scheme.

Several of these policy commitments were enacted in this stage of development. Firstly, microgeneration technologies were added to the Permitted Development Rights in March 2008, removing the need for planning permission in some instances. Thousands of installations all requiring planning permission would have slowed adoption rates and necessitated significant local council capacity, as identified in the strategy. Removing this administrative barrier was critical to allow for growth in installations that would take place in future years. Furthermore, in 2008, the government established the Microgeneration Certification Scheme, a quality assurance scheme responsible for certifying both installers and microgeneration products. This initiative was important in maintaining high standards within the solar PV industry and safeguarding the integrity of government funding.[61] Finally, in 2008 the UK Energy Act was enacted, which laid the primary legislation for the Feed-in Tariff (FiT) scheme. As the next section will explore in detail, this was a tariff-based financial support policy that helped rapidly grow the PV industry.

Skills, competence and training

Some vocational training providers began offering courses that provided the necessary technical skills and knowledge for the installation and maintenance of solar PV systems. One of the first training courses founded during this period was the City and Guilds 2372 in 2004.[62] It provided installers with a foundation in solar PV technology, installation techniques, and safety standards. However, formal training was still relatively limited, and the Microgeneration Strategy recognised the need to develop skills and training in renewable energy technologies to support future growth in the industries.

Actors

Solar campaigns during this period were critical to advancing the solar PV industry in the UK

According to one interviewee who worked in public affairs at the time, it was evident that advancing domestic solar PV would require substantial government support to stimulate market growth and reduce costs. They also explained that *"it was so obvious that in order to win a Feed-in Tariff, we had to campaign as if our lives depended on it..."* Consequently, there was an 18-month campaign from 2008, during which Solar Century, an installer and distributor, played a leading role. Several interviewees highlighted the importance of this campaign in securing the FiT.

Cross-party support for microgeneration technologies

The political landscape for small-scale renewables became increasingly positive, due to cross-party support. David Camerion, the Conservative party leader at the time, used the 'Power to the People' campaign to enhance the Party's popularity, while Conservative shadow energy minister Greg Barker was very supportive of microgeneration technologies. As one interviewee explained: *"The particular set of circumstances were Cameron detoxifying the Tory party in opposition and using environment very much as a tool in order to achieve that. A Labour Party, that was still relatively progressive, had a very strong leader in the Energy Department in Ed Miliband. Pressure from the Tories on Labour in the run up to an election compelled [Labour] to...improve their green offer. It sort of empowered Ed Miliband to force the government to get into a better position. And so as a consequence, there was a sort of vying of environmental credentials between those two parties at the time..."*

This suggests that political will and support are significant factors that impact technology development. As shown, cross-party support can help bring about the implementation of government policies and regulations that are essential to encourage the uptake of low-carbon technologies.[63]

Conclusions

This stage saw the launch of key demonstration projects and early government schemes supporting solar PV. These schemes were important in raising awareness of the technology and supporting a larger number of installations than had been seen previously, but lacked sufficient funding to support substantial growth in the market. Increased political interest in climate change and microgeneration technologies led to significant strides in the policy and regulatory landscape for solar PV, including the incorporation of these technologies into PDR. These developments were critical to support increased uptake in the supported commercial years (2010-2019).

Improvements to efficiency and manufacturing processes led to some cost reductions in global module prices, but upfront cost of domestic installations remained a barrier, and the technology still mostly appealed to an environmentally engaged demographic.

"It was so obvious that in order to win a FiT, we had to campaign as if our lives depended on it."

2010-2019 **Supported commercial 'Feed-in Tariff'**

Timeline

2010 – Launch of the Feed-in Tariff.

2011 – The UK's first 'solar power plant' installed in Cornwall.

2012 – The Feed-in Tariff rate was cut from 54.17p per kWh to 25.05p for arrays between 0-4kWp installed in existing buildings.

2013 – The Solar Roadmap was published which set out four guiding principles which formed the basis of the UK's solar PV strategy.

2015 – The Zero Carbon Homes Bill was scrapped by the Conservative government.

2016 – Department for Business, Energy and Industrial Strategy was established.

2019 – The Feed-in Tariff closed.

Summary of supported commercial stage

Key barriers

1.

Cuts to the Feed-in Tariff

Changes to the FiT rates led to a boom-and-bust cycle in installations during these years instead of gradual market growth. For example, there were 888,587 installations between 2010-2015, followed by just 188,587 installations between 2016-2019.

2.

Skills

The fluctuations in solar PV demand between 2010-2019, driven by changes to the FiT, created uncertainty for the industry, making it difficult to invest in and develop long-term skills.

3.

Political volatility

Political support for climate-related issues became less favorable during this period, particularly from 2015, when several environmental schemes were scrapped. Compared to other political concerns like rising energy prices, climate change was not viewed as a 'bread-and-butter' issue.

Key enablers

1.

Feed-in Tariff

The generous rate of the Feed-in Tariff, originally 54.17p for installations between 0-4kWp, led to a rapid growth in the sector between 2010-2012.

2.

Reduction in solar module costs

Automation of manufacturing, alongside incremental improvements to efficiency and power output led to significant global cost reductions in the PV cells.

3.

Increased consumer awareness

The significant growth in the market thanks to the FiT increased consumer awareness and confidence in the technology.

Energy context and external factors

2010

In 2010, the UK was gradually emerging from a severe global financial recession

The UK was in a recession, and this had an impact on fiscal policy decisions

In 2010, the UK was gradually emerging from a severe global financial recession. The years between 2010-2014 were marked by a government policy of austerity, with unprecedented cuts to public funding.[64] The Government faced significant limitations in providing direct financial support to renewable technologies, including domestic solar. As a result, many schemes aimed at supporting renewable technologies were paid for by electricity suppliers and then claimed back via domestic electricity bills, instead of being directly financed through general government spending. This meant that unlike the grant schemes in the pre-commercial stage (2000-2009), there was no maximum spending budget and therefore no cap on the number of households that could apply for funding.

2015

The May 2015 general election resulted in a victory for the Conservative Party

2015 end of the coalition and 'cut the green crap'

The May 2015 general election resulted in a victory for the Conservative Party and the end of the Conservative-Liberal Democrat coalition that had run from 2010-2015. David Cameron's 'cut the green crap' comment, reportedly made in 2013, signalled a shift in the UK Government's approach to environmental policies. Cameron, who in the lead up to the 2010 election had positioned himself as a champion of environmental issues, faced pressure to reduce energy costs for consumers and businesses amidst economic challenges.[65]

The comment was interpreted as an intention to scale back on green initiatives perceived as financially burdensome. In contrast to the demonstration and pre-commercial stage (2000-2009), the political landscape worsened for climate-related policies, and several important policies were scrapped, including the Zero Carbon Homes Bill, which would have required all new developments to be 'zero carbon ready' from 2016. This could explain why there was significant inconsistency of government support for solar PV during these years (see Policy, regulation, and standards).

Growth in solar PV capacity around the world led to improvements in production and cost reductions in modules.

Growth in solar PV capacity around the world led to improvements in production and cost reductions in modules.

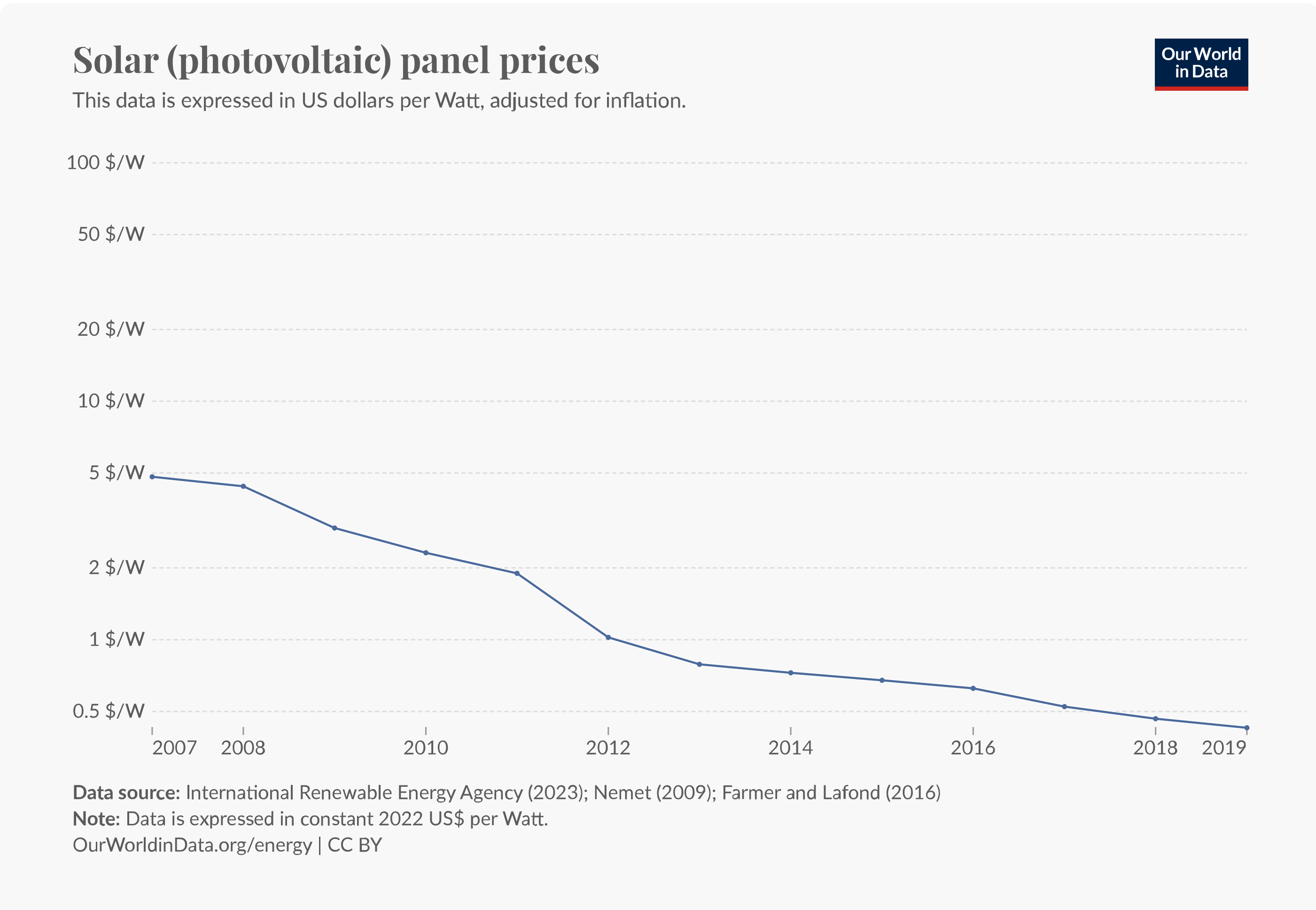
The global market for solar PV expanded exponentially during these years (2010-2019). In 2009, the global installed capacity for solar PV was just over 23GW, and by 2019 this had increased to almost 600GW.[66] Many European countries had market support policies (Feed-in Tariffs) in place,[67] and this helped to drive incremental improvements to the PV technology, and drive down costs,[68] as seen in ***Figure 2***.

By the 2010s, most manufacturing had stopped in the UK, with BP solar closing their British factories in 2014. Global manufacturing had come to be dominated by China, who had successfully automated the process of manufacturing, as one solar expert highlighted:

"…. It was by then recognised that China was going to lead the world in this. Germany tried to do this and failed. They didn't create enough market and enough subsidy so that costs were significantly greater. Spain tried the same. BP tried the same, but they were just too late… the result is that most of the European manufacturers disappeared."

It is estimated that in 2010 the module made up 45-60% of the cost of a domestic solar PV installation in the UK.[70] Global manufacturing price reductions, therefore, had a direct impact on domestic installation costs in the UK, and led to a significant decrease in installation costs between 2010-2013.

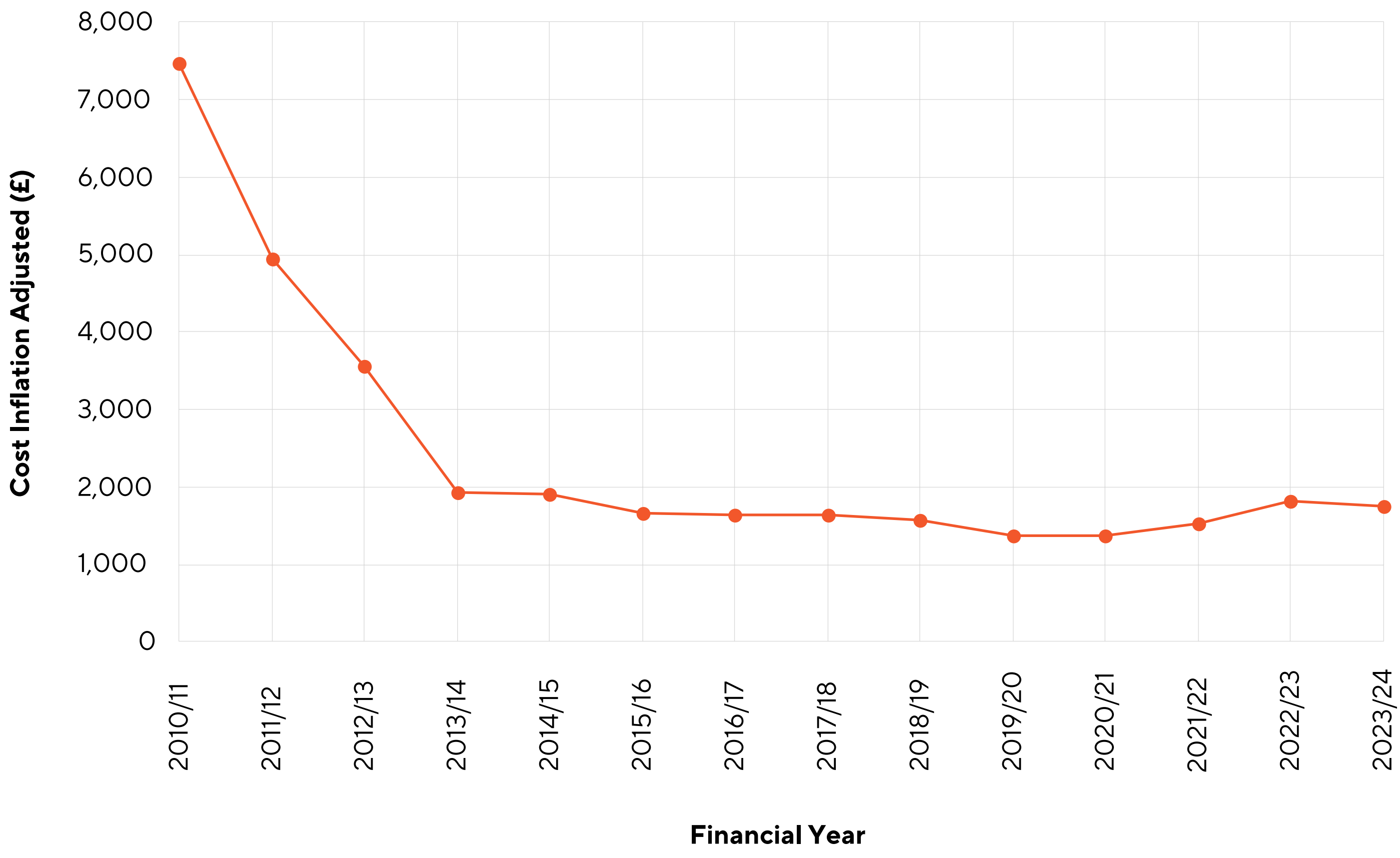
Figure 2: *The global price ($/W) of solar photovoltaic 2007-2019 ($/W). [Source: Our World Data[69]]*



Economic factors

2010 marked a turning point for the economics of domestic PV systems in the UK. Due to the wholesale cost reduction of modules, there was a roughly 50% reduction in UK installation costs between 2010 and 2012, illustrated in ***Figure 3***. Concurrently, electricity prices rose by about 15% during the same period,[71] reducing payback times for solar investments. These external economic factors, coupled with the generous Feed-in Tariff (Fit) rates available from 2010 to 2012, made installing solar PV not just economically viable but also a highly lucrative investment, at an approximate rate of return of 10%.[72] All of the interviewees tied the significant growth in the solar PV market in the early 2010s to the financial incentive created by the FiT.

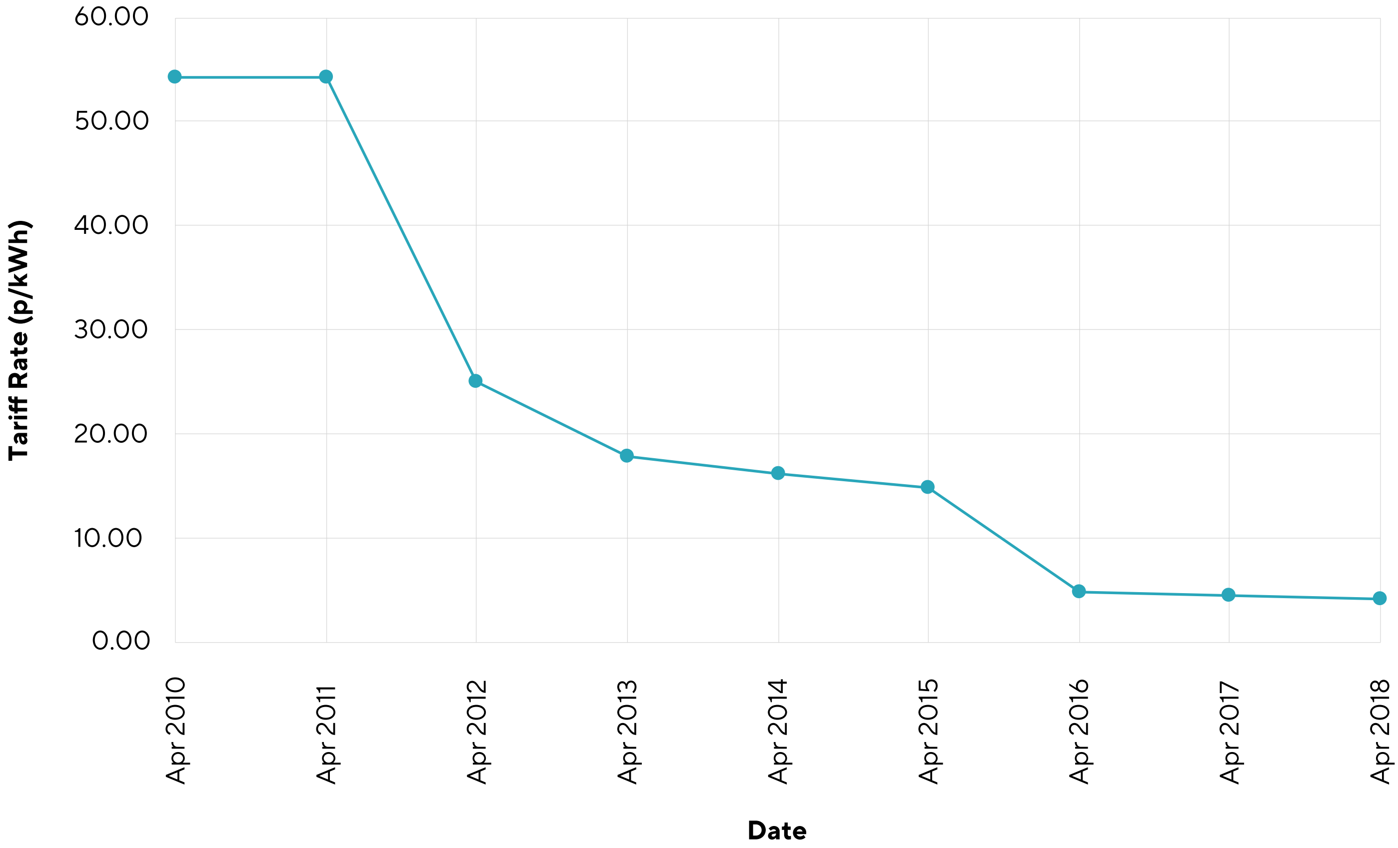
Figure 3: *Cost of small-scale solar PV installation per kWp for each financial year between 2010/2011 – 2019/2020 adjusted for inflation using 2024 prices. [Data sourced from: DECC and Gov UK.[73]]*



In the first two years of the scheme, the rates were extremely generous set at 54.17p per kWh for solar PV arrays up to 4kWp installed in existing homes.[74] However, the FiT rate was cut by more than half in April 2012 to 25.05p per kWh, and then again in January 2016 from 13.18p to 4.81p per kWh, as seen in ***Figure 4***. Simultaneously, the cost of installing solar panels plateaued in 2013/14. As a result, the return on investment decreased, dampening the economic incentive to invest in solar PV.[75]

One solar interviewee explained that after the FiT rates were cut drastically, *"no matter what you said to a person...it was a 20-year return again... So, it just didn't make sense."*

Figure 4: *The FiT rate (p/kWh) for a 0-4kW solar PV system between April 2010 to April 2018 installed in an existing property. [Data sourced from: Ofgem*]*



*Note that from April 2013, there were three different FiT rates available (Higher, Middle, Lower) based on the energy efficiency of the property. This graph shows the higher tariff rate to demonstrate the best possible tariff rates for solar PV installations. www.ofgem.gov.uk/publications/feed-tariff-fit-tariff-table-1-april-2019

Public perception and adoption

There was significant growth in the market between 2010-2019 with cumulative MCS certified installations increasing from just 1,239 in 2009, to over one million cumulative MCS installations in 2019.[76]

According to one solar PV expert, this expansion in the market resulted in an increased awareness and confidence in the technology, helping to bring solar PV into the mainstream. They described how: *"In the early days of the FiT, you didn't really know anyone who had it. So, you didn't have anyone to compare it with. But now our old Fred or Betty down the road's got it and you trust their judgement...now people are pretty comfortable with it other than a few naysayers."*

The early years of the FiT also transformed the demographic of those investing in the technology, attracting a more financially motivated group of adopters.[77]

The peaks and troughs in installations which were correlated with changes in the FiT rates, suggests that the financial incentive has been a significant factor in determining adoption from homeowners. As one interviewee explained, *"for most people, the decision has to at least wash its face in economic terms."*

Technological developments and innovation

Improvements to the solar cell technology led to cost reductions and improved efficiencies

Incremental improvements to the solar module resulted in a 30% efficiency increase, from 14.7% in 2010 to 19.2% in 2019.[78] This helped to drive down cost of solar modules and improve the payback periods – the more efficient the solar panel, the higher the solar production over the lifetime.[79] There were also improvements to power output, including the development of half-cut solar cells around 2014. By cutting the cells in half, the electrical current within each cell is halved, which reduces resistive losses and increases the overall energy output of the solar panel. This makes half-cut cells particularly beneficial for installations where shading is a concern or where maximum efficiency is required from a limited space. The half-cut cell innovation can increase power by up to 20Wp per cell.[80] One interviewee explained how manufacturers have even started putting glass in between the half cells, to reflect light from the ground, which also helps to increase efficiency.

The FiT, which led to rapid market growth between 2010-2012, also led to improvements in the installation process. One interviewee noted that everything changed after the FiT, with more wholesalers and distributors entering the market offering a wider range of mounting kits and installation accessories. Unlike the earlier years of development where each installation was customised, this helped bring about greater standardisation which improved installation processes. Government financial incentives and grants can be a driving force for innovation in low-carbon technologies, as it reduces the economic risk and encourages investment in the sector.[81] This was clearly the case in the early years of the FiT. However, one solar expert remarked that cuts to the Feed-in Tariff to some extent hindered the rate of innovation, particularly in aesthetic improvements.

Policy, regulation, and standards

The Feed-in Tariff (FiT)

THE DESIGN OF THE FEED-IN TARIFF

- **Guaranteed payments**

  Under the FiT scheme, participants received payments for the electricity they generated and used themselves, as well as for any surplus electricity they exported to the grid. These payments were guaranteed for 20 years and were index linked.

- **Generation tariff**

  This was a fixed payment per kilowatt-hour (kWh) of electricity generated by the renewable energy system, regardless of whether it is used on-site or exported to the grid.

- **Export tariff**

  In addition to the generation tariff, participants received a separate payment for the excess electricity they export to the grid. This rate is typically lower than the generation tariff but provided an additional revenue stream.

- **Eligibility and certification**

  Only MCS certified solar panels were eligible for the scheme, and they had to be installed by MCS certified contractors.

- **Funding**

  The costs of the FiT scheme were borne by electricity suppliers, who were required to make payments to renewable energy producers. These costs were then passed on to all electricity consumers through their energy bills.

The FiT was launched in 2010, and closely followed the design of the German scheme which had been implemented several years beforehand. Though Germany was not the first country to implement a FiT globally, one interviewee explained that *"the German scheme...set the model for Feed-in Tariff schemes across Europe."*

The aim was to encourage upfront investment in renewable generation technologies by guaranteeing the homeowner a return on initial investment. It was initially set at a generous rate of 54.17p per kWh for solar PV arrays up to 4kWp, and 47.25p for installations up to 10kWp.[82] As one interviewee put it, *"Their view was, we're so far behind Germany we've got to set it very high."*

As a result, the scheme sparked a rapid growth in the market within the first two years from 1,239 MCS certified installations per annum in 2009, to 203,129 in 2011. Both industry and Government had underestimated the solar panel cost reductions that would take place between 2010-2012,[83] and as a result, many of the interviewees referred to these two years as 'the solar PV gold rush', as homeowners and businesses sought to benefit from the attractive returns. One solar expert explained: *"We always said if you get the Feed-in Tariff right, this technology will take off, and in fact, the only thing we got wrong was the extent to which the cost of installations would fall. So, we were very conservative with a small 'c' about where pricing might end up."*

The 'solar coaster'

The implementation of the FiT received considerable criticism from all interviewees working in the industry at the time. Concerned about the sustainability of this growth and the potential for runaway costs, the Government reduced the tariff rates to curb the rapid increase in installations.[84] Instead of steady market growth between these years, the cuts to FiT rates lead to a boom-and-bust bust pattern of installations. For example, there were over 26,000 solar PV installations in March 2012 before the rates were changed, and then just under 5,500 in April 2012.

There were some mixed views, but for the most part experts agreed that the FiT was probably set too high to begin with and *"...if they'd been more realistic... might have lasted for longer and led to a better, more sustainable growth of the industry."* (Solar PV expert).

Many interviewees felt that their insights and expertise could have contributed to more effective and efficient policy design.

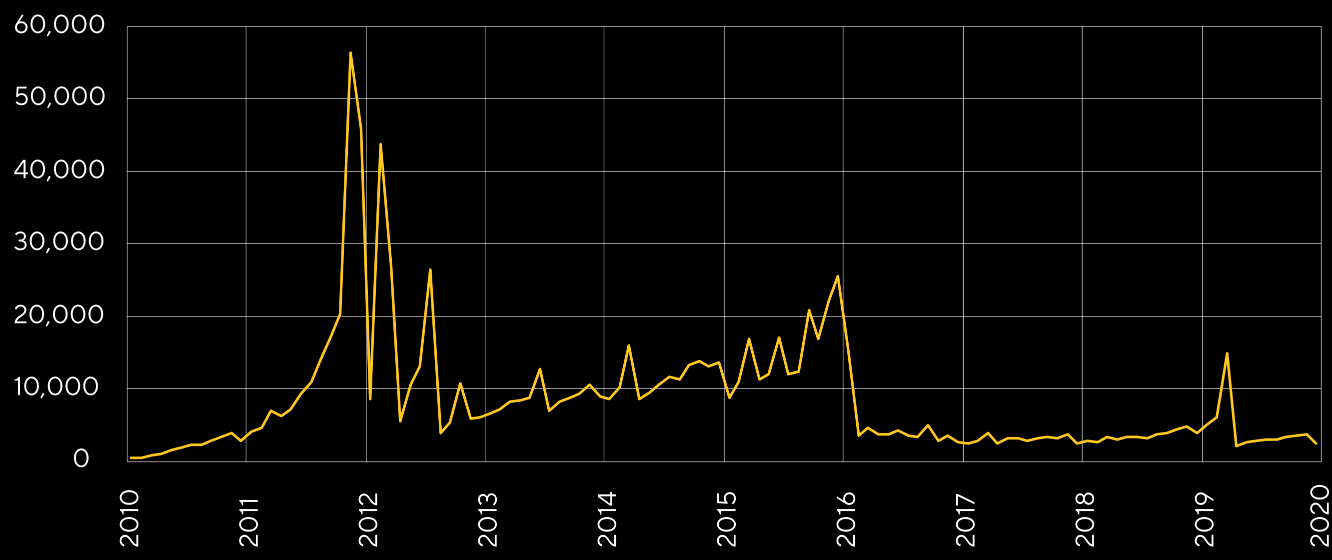
One expert described: *"...there was never any attempt to bring in the industry for sort of confidential discussions about how you reduce the FiT rate perhaps more quickly than had been envisaged because nobody realised that the price of solar was going to come down so much...And that would have been a very sensible discussion to have... but we never had it."*

They went on to explan that despite the relative success, there were many years where the UK missed out on the opportunity to grow the solar PV market further. *"So, 13 years on, we're just about back to where we were 13 years ago is one way of looking at it...Well, it is great, but what about the wasted years in between..."*

Nevertheless, despite the shortcomings of the scheme, between 2010-2019, there was a unanimous feeling that *"it did, in a very jumpy way push solar into the mainstream."* (Solar PV Expert)

Figure 5: *Installations over time graph, showing solar PV data from the MCS Data dashboard[85] between 2010 - 2019. [Sourced: 29 July 2024.]*

MCS

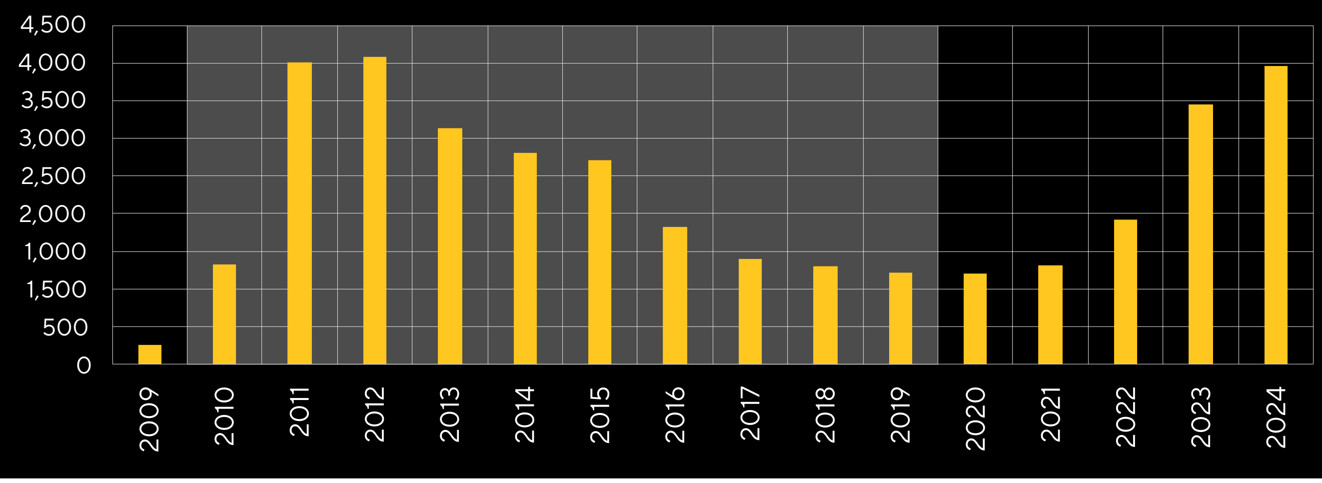


Skills, competence and training

The FiT had a significant impact on the solar industry and it directly supported the creation of roughly 25,000 jobs in the first two years.[86] However, the cuts to the FiT were equally as impactful, as it is predicted that they the initial cuts resulted in a 42% decrease in employment, with many companies being forced to close.[87] Similar patterns are seen in the MCS data, with a rapid rise in the number of contractors becoming certified between 2010-2012, and then a significant number leaving the scheme between 2012-2019, as seen in ***Figure 6***.

According to one interviewee, the lack of market certainty and the boom-bust nature of installations between 2010-2019 made it challenging for the solar industry to grow gradually and invest in long-term skills development: *"...the FiT was great as a design, but the implementation was pretty awful and eventually when they did remove it completely, it destroyed the industry for four years. And so, you had a lot of highly skilled people in the industry, and they had to go and find something else."*

Figure 6: *Graph of certified MCS contractors from 2009 to end of May 2024. [Sourced: MCS Data 31st May 2024.]*



Actors

Concern in Government about rising electricity prices impacted the FiT

According to one solar expert, the Government levied the FiT on electricity bills assuming that only dedicated environmentalists would be interested in the scheme. Nevertheless, solar PV installations in the first year were more than double what DECC had anticipated.[88] Thus, the decision to cut the FiT rates was partly driven by concerns that continued high uptake of the scheme would lead to noticeable increases to energy bills. As one interviewee put it, *"energy prices is a very bread and butter issue. Climate change, certainly in 2013 was very much not [a bread and butter issue], arguably still not."*

Conclusions

The introduction of the FiT was a turning point for domestic solar PV, driving significant market growth between 2010 and 2012. Falling global module prices, combined with a small rise in electricity costs, made solar PV a financially attractive option for the first time. This surge in growth raised consumer awareness, built confidence, improved installation processes, and supported industry expansion. However, changes to FiT rates caused market volatility, leading to peaks and troughs in installations between 2010-2019, instead of steady, long-term growth.

2019-2024 **Fully commercial**

Timeline

2019 – Google launched Project Sunroof in the UK.

2020 – Covid and lockdown for most of the world.

2021 – The blockage in the Suez Canal impacted shipments of solar equipment impacting the supply chain and therefore cost of solar panels.

2022 – Russia's war on Ukraine.

2022 – 0% VAT on Energy Saving Materials.

2023 – The UK Department of Energy Security and Net Zero (DESNZ) was set up.

2023 – The Solar PV Taskforce was reestablished by the UK government.

Summary of the fully commerical stage

Key barriers

1.

Upfront cost

Despite the significant cost reductions in installations since the R&D stage, upfront cost is still a barrier to a proportion of households in the UK.

2.

Supply chain challenges

Since 2019, problems with the supply chain have caused a slight increase to installation costs. There have also been some ethical concerns associated with relying heavily on one country for the supply of modules.

Key enablers

1.

The Energy Crisis

The surge in electricity prices driven by the energy crisis created a strong economic incentive to invest in solar again, despite the absence of direct subsidies following the closure of the FiT scheme.

2.

Widespread consumer trust in the technology

There is now widespread consumer trust and confidence in the technology, as well as a heightened awareness of energy related issues.

3.

Ease of installation and improvements to the technology

Several incremental improvements to the technology have resulted in more efficient solar panels and improved installation processes.

4.

The battery storage revolution

Since 2019, domestic battery storage systems and EVs have been emerging rapidly due to cost reductions. This has strengthened the financial benefit of solar PV, by increasing self-consumption rates.

Energy context and external factors

The energy crisis and Russia's war on Ukraine

Wholesale gas prices in the UK rose significantly in October 2021 due to a combination of factors. The initial rise was driven by the rapid global economic recovery following the COVID-19 pandemic, which sharply increased demand for energy.[89] There were also supply constraints, exacerbated by a colder-than-usual winter across the Northern Hemisphere.[90] Russia's invasion of Ukraine in February 2022 created a perfect storm, causing gas prices, and subsequently electricity prices, to reach record highs by early 2023. The UK, which imports about half of its gas,[91] was particularly vulnerable to these international market dynamics.[92] While the energy crisis had many negative social and economic impacts,[93] many of the solar experts considered it as an important contributor to the rise in domestic solar PV installations between 2021-2024. Energy security became an increasingly important issue for energy suppliers, who have begun to diversify their product offerings for small-scale renewables. *"Those that were slow back 11 years ago are moving quicker than others now within the industry."* (Solar PV expert).

The solar industry in the UK has been impacted by global supply chains

Between 2019-2024, global external events caused fluctuations in solar PV module prices, and this had an impact on domestic installation costs in the UK causing a slight rise from £1,369 per kWp in 2019, to £1,742 in 2024. Someone working in the solar industry explained: *"Manufacturing of PV modules, it's quite sensitive to price fluctuations. We've had a lot of supply chain issues the last couple of years…there was the ship that got stuck in the Suez Canal. There was a various supply chain hiccups [that] happened and COVID, of course, was another big one."*

Furthermore, the ethics of solar panel manufacturing in China have become an increasingly pressing concern within industry over the past several years, primarily due to reports of forced labour practices.[94] Solar Energy UK, the national trade association, is actively rallying the industry to enhance transparency protocols within the solar panel supply chain.[95] One interviewee explained how there is united feeling amongst industry members of the need to address this concern:

"We're trying to get our house in order. It's difficult because the Chinese government denies that there's any issue and pretty much all the suppliers and modules are Chinese, and they can't very well take on their own government to provide us with information. But they are offering more transparent supply chains now and we have to pay a bit of a premium for products that have that transparency, but we're willing to do that."

Whilst the UK industry has previously benefited from global solar PV supply chains, with the major cost reductions in solar modules between 2010-2012, this highlights the consequences of relying too heavily on an undiversified supply chain that is dominated by one country. According to one interviewee, in response to this, the European Union have announced the European Solar Charter which aims to support more manufacturing in Europe to help improve the stability of the supply chain.[96]

Rising electricity grid challenges

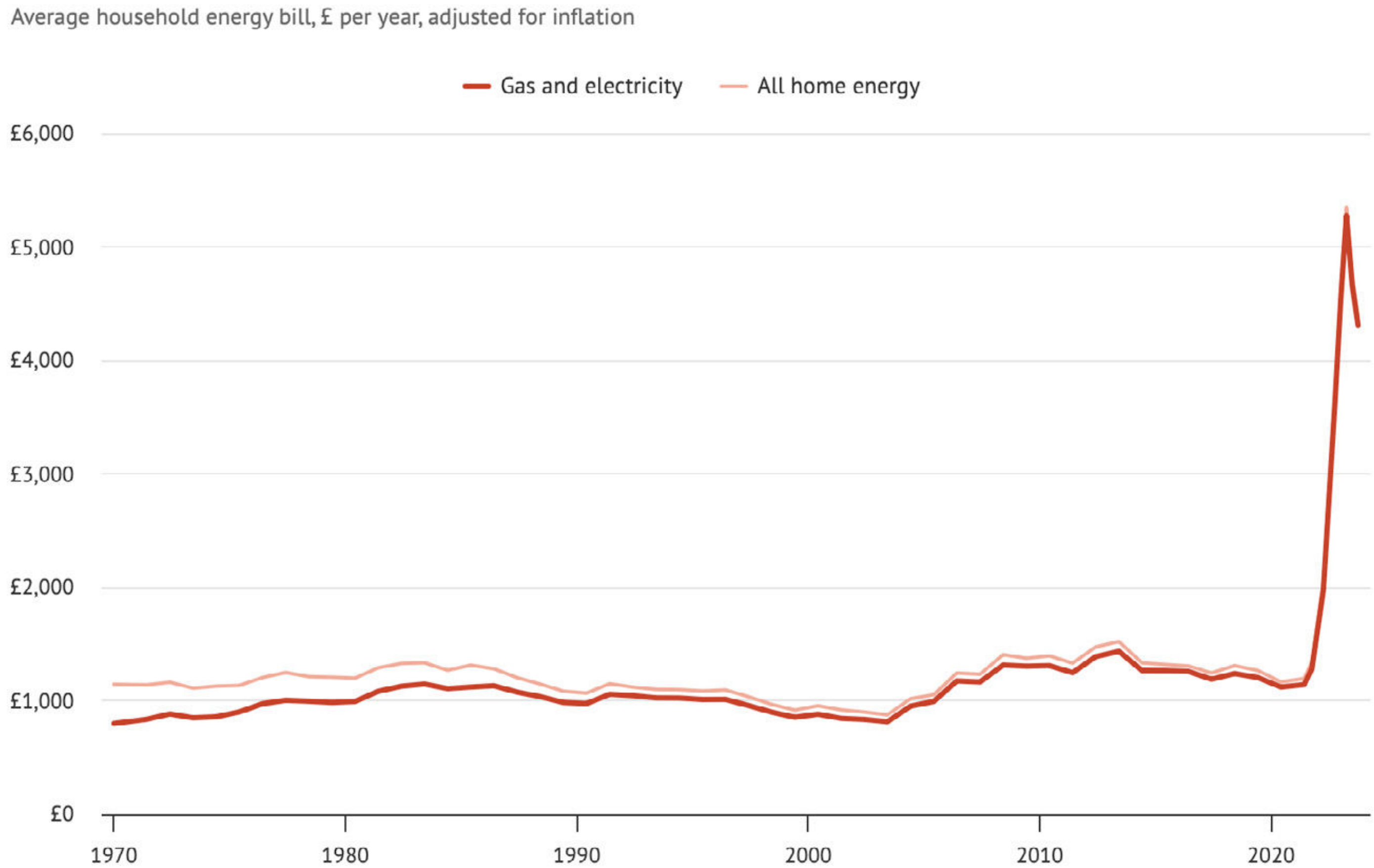
Many of the solar experts noted that grid capacity concerns have started to surface in the past few years. Whilst this has not directly been a barrier to uptake of solar PV in the domestic sphere, many explained that grid capacity issues could pose a significant barrier in future years. Consequently, both the transmission and distribution networks will need strategic reinforcement over the following few years to facilitate net zero by 2050[97] and support the mass-adoption of microgeneration technologies, including solar PV.[98]

Economic factors

Unprecedented rise in energy bills

When adjusted for inflation, it was calculated that between 2021-2023, households' bills reached unprecedented levels, as seen in ***Figure 7***.

Figure 7: *Average households energy bill, £ adjusted for inflation (Source – Carbon Brief)*[99]



This resulted in the return of a strong economic incentive to install solar PV systems, despite the lack of direct government subsidies. There has been a gradual rise in installations from 2021, peaking in 2023 as seen in ***Figure 8***. One interviewee explained how *"solar's always had that cash advantage one way or another, either extraordinarily high subsidies or extraordinary high electricity price relative to the cost of the modules."*

In addition, the rapid decrease in battery storage costs, which have decreased by more than 90% in less than 15 years,[100] increased the affordability of installing both solar PV and battery storage together. This once again enhanced the financial offer of solar PV without the FiT, enabling households to store surplus solar energy, reducing imports and exports to the grid: *"...you're now able to virtually double your self-consumption rate of your PV system, PV prices are tumbling still and... batteries are now emerging in microform...this is the perfect storm."* (Solar PV expert).

Figure 8: *MCS certified solar PV installations over time showing solar PV data from the MCS Data dashboard[101] between 2019 - 2024. [Sourced: 16th August 2024]*

Upfront cost can still be a barrier for some households

Despite the recent drops in the price of solar PV, many interviewees noted that the upfront cost is still a barrier to uptake for many homeowners. Though there has been a rise in 'green loans' and 'green mortgages', green finance uptake for small-scale renewables is still relatively low, partly because of the limited range of products to suit different customers.[102]

Improving the green finance offer, with a wider range of options, could help broaden the demographic of people who can afford an installation. As one interviewee put it: *"There's a certain type of customer who can install PV thanks to finance, if we could open that up and give more opportunities, that will drive deployment."*

Improving the green finance offer, with a wider range of options, could help broaden the demographic of people who can afford an installation

Public perception and adoption

According to many of the interviewees, for several years there has been widespread trust of the solar PV technology because of rapid market growth during the FiT years (2010-2019). Since the FiT, it is not uncommon to know at least one person who has installed a solar PV system, and this has reinforced confidence in the technology. Furthermore, many of the solar experts claimed that since the energy crisis there has been a heightened public awareness and engagement with energy related issues, as one explained: *"Since the Ukraine war...people have become more aware of those sorts of things [energy issues] and the costs of the of solar's come down to the point where it's easier to make those choices."*

Unlike the FiT years (2010-2019), where economic factors were the most significant in driving consumer demand, there was a shift in consumer adoption patterns in this period, whereby it was not only seen as a good financial investment, but also a way to improve energy security and reduce carbon emissions: *"[the] energy crisis has been a huge driver. Also, people's awareness and consciousness around environmental issues. People are also concerned about financial gain, although it's becoming less of an economic decision..."* (Solar expert).

One interviewee explained this heightened engagement with domestic solar PV and energy could have a positive impact in influencing households to invest in other microgeneration technologies, including heat pumps, as these systems function well together: *"With a million and a half homes with solar and another 200,000 getting solar every year... they are much more ready for [a] heat pump because you can self-use. You can use your own solar and you can bring your heat pump running costs down and do very clever stuff with tariffs and then add batteries."*

Technological developments and innovation

Incremental improvements to the technology

Though the solar PV technology has not changed greatly since R&D stage (1977-1999),[103] the incremental innovations and improvements to the design have been a critical in driving cost reductions and improving efficiency.[104] For example, since 2019, there has been a shift from polycrystalline to monocrystalline solar cells, with monocrystalline becoming the more dominant technology.[105] Monocrystalline panels, made from single-crystal silicon, offer higher efficiency and better low-light performance due to their uniform structure. In contrast, polycrystalline panels, made from melted silicon crystals, have lower efficiency due to increased electron resistance. Advances in production and cost reductions have further driven the popularity of monocrystalline panels.[106] Additionally, a different type of cell known a 'N-type' solar cells, treated with phosphorus, have been gaining popularity. These are more efficient and less prone to degradation than the more common P-type cells, which are treated with boron. Initially more costly and complex to manufacture, advancements have made them more accessible since around 2021.

Although still a minority in market share, N-type cells are projected to comprise 50% of the market by 2031, indicating a significant shift from P-type cells.[107] What's more, one interviewee expressed that *'the solar industry has a lot of technical advancements to go.'* They explained that the industry is likely to see further improvements in efficiencies, aesthetics, products and prediction of energy and consumption. Our expert's future innovation predictions included new products like solar PV in suspension paint; solar blinds; and printed solar.

The battery and electric vehicle revolution

Since the FiT ended in 2019, there has been a significant rise in uptake of domestic batteries and electric vehicles (EVs). Since the introduction to the MCS scheme, battery storage has shown consistent growth both in terms of installations and registered contractors, becoming the third biggest technology behind solar PV and heat pumps.[108] Upon analysis of MCS data, it was found that 98% of battery installations are occurring at an address that also has a PV system.[109] Domestic batteries and EVs have transformed the solar energy landscape by significantly increasing self-consumption rates of on-site solar energy generation.[110] By storing solar energy generated during the day, households can maximise their use of renewable energy, reducing their energy bills. One solar PV expert explained: *"So, if you try to make it work [solar], even with the dear [energy] prices, it's a long payback period... As soon as you put a battery in, it completely changes it. The other thing that's happened is electric vehicles coming along the same as batteries..."*

The added value of solar PV in recent years, therefore, is its compatibility with other technologies, including batteries, EVs, and heat pumps. With electricity demand for home heating projected to quadruple by 2050,[111] the value of domestic PV systems is likely to increase. As one interviewee remarked: *"Today you actually use very little electricity in the UK since the biggest energy consumer in the home is heating your home...So, all of a sudden the potential value of solar doubles, because you now have twice as much that you can produce yourself."*

The digitalisation of the sales process

The installation process for domestic PV has improved significantly since the R&D years. There are currently 131 solar PV wholesalers and distributors in the UK,[112] compared to just 4 in the early stages of development.

Therefore, there is more standardised mounting equipment available, specialised equipment such as MC4 connectors, and a variety of different panels for different roofs.[113] The installation process became even more streamlined in the fully commercial stage, with the launch of Project Sunroof. This is a software tool developed by Google in 2019 to assist installers and homeowners by determining the solar energy potential of individual rooftops. This has been critical in streamlining the sales and installation process for installers, as *"...with the software that's out there now you can design a system and do all the calculations without visiting the property."* (Solar PV expert).

Policy, regulation and standards

Market-led levers

In April 2019, the FiT closed and, in its place, the Smart Export Guarantee (SEG) was established. As with previous changes to the FiT, this led to an initial peak in installations before the closure and then a crash throughout 2019, as the SEG was considerably less generous. The SEG is a market-driven policy which means that instead of government directly funding the policy, energy suppliers with over 150,000 customers are mandated to offer SEG tariffs,[114] which allows households to sell their surplus power back to the grid.

Comparatively, between 2019-2024 the number of innovative tariffs offered by energy suppliers voluntarily has increased, especially in the past two years. These tariffs are often linked with microgeneration technologies, including heat pumps and EVs, and reward consumers with cheaper electricity in off-peak times. *"[These types of offers] make it really economic for consumers to invest in the solar, and the battery."* (Solar PV Expert).

Locally led government schemes

Locally led government schemes and the Electricity Company Obligation (ECO) have played a meaningful role in supporting domestic solar PV adoption between 2019-2024. The Local Authority Delivery (LAD) scheme and the Home Upgrade Grant (HUG) were aimed at improving the energy efficiency of low-income and low-energy performance homes.

The Social Housing Decarbonisation Fund was aimed at decarbonising social housing, while ECO requires large energy companies to fund energy efficiency improvements in low-income houses. **Table 2** shows the number of solar PV installations installed under the different schemes, with a total of 59,122.

For many of the local authority led schemes, most notably LAD2, solar PV installations made up a significant proportion of the total measures installed. When asked why this was the case, one expert explained: *"There's quite low disruption involved with putting solar panels in and that works very well, especially with the first and middle local authority delivery schemes because they had quite short lead times...if it's just external work and a resident doesn't need to leave the house, that's very attractive for local authorities...and their providers to be organising solar installs rather than deeper insulation works, which would basically be very difficult to do in a sort of a 9-month window."*

Though the regulatory landscape is positive for solar PV in the UK, it is not mandated for new builds

To enhance the adoption of domestic solar PV systems, many interviewees noted that new build homes should be built with solar panels. Given the Government's commitment to constructing 1.5 million homes over the next five years,[116] mandating solar PV on new builds has the potential to virtually double the domestic market from new build homes alone.

Table 2: *Number of solar PV installations under locally led government schemes and the Electricity Company Obligation between 2020-present day. [Sources: HULA Release June 2024, SHDF Release May 2024; analysis by James Dyson, E3G.[115]]*

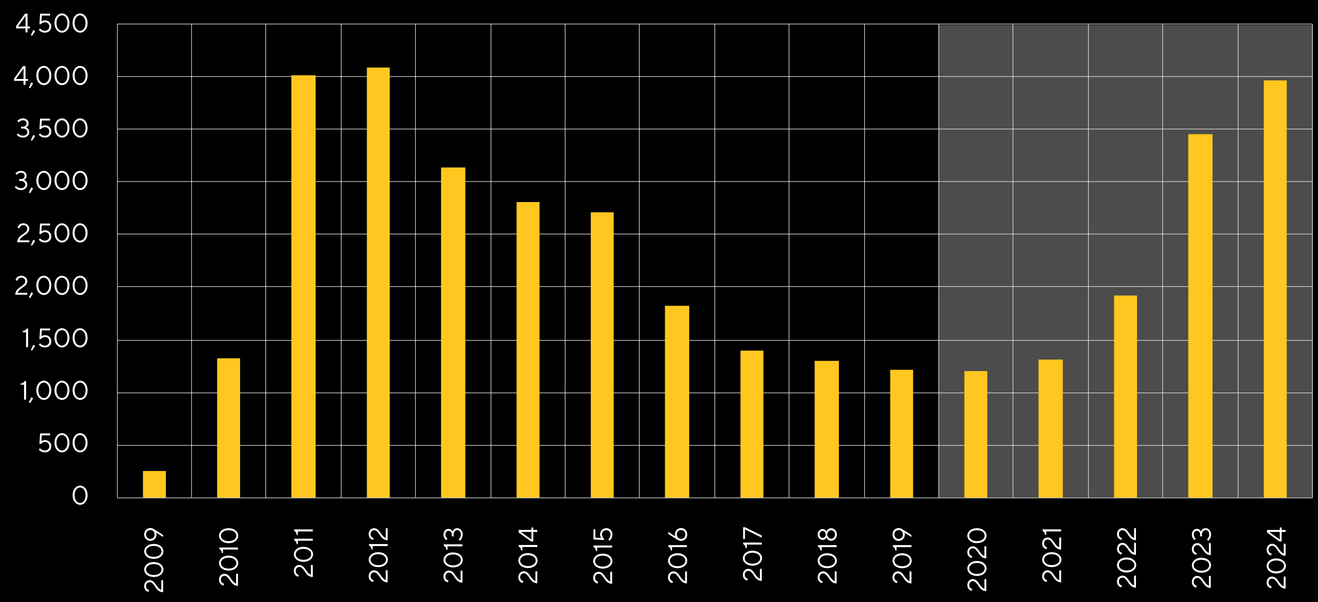
Scheme	Dates of scheme	Number of measures installed	Percentage of total measures
LAD1	August 2020 - March 2021	6,734	28%
LAD2	April 2021 - December 2021	11,743	43%
LAD3	April 2022 - March 2023	10,140	38%
SHDH1	February 2021 - January 2023	3,137	10%
SHDH2	April 2023 - March 2025	1,255	17%
HUG1	April 2021 - March 2022	1,709	27%
HUG2	April 2022 - March 2024	904	35%
ECO3	December 2018 - March 2022	135	0.01%
ECO4	April 2022 - March 2026	23,365	5%

Skills, competence and training

As shown in ***Figure 9***, the number of MCS certified solar PV installers has increased significantly between 2020 and 2023, reflecting the growth in installations during this period. As seen during the FiT, the number of installers closely reflects the demand in installations, suggesting that the solar PV supply chain can step up in response to growth in the market and an increase in demand. Nevertheless, one interviewee commented on the industry's general lack of skills and training development since the R&D stage, attributing it to the culture of 'on the job training.': *"Most people are trained when they join a company who's already [in the sector], they're trained... on the job. That doesn't help new people to enter, perhaps so much. So, it'd be good if there was more [training]"*

Many interviewees noted that to support continued growth of domestic installations in the future, there would be a need for more installers and better training provision.

Figure 9: *Graph of certified MCS contractors from 2009 to end of May 2024. [Sourced: MCS Data 31st May 2024.]*



Currently over
3,500
Solar PV certified contractors
May 2024

1,453
Solar PV certified contractors
joined the scheme in 2023

Over
400
Solar PV certified contractors
certified for PV have joined the scheme this year

Actors

Following the Ukraine war, the previous Conservative Government increased its focus on renewable energy and energy security, and there has been political support for solar PV. The British Energy Security Strategy, published in April 2022, highlighted the urgency of increasing renewable energy capacity to improve energy independence and security. The strategy aimed to increase the UK's solar capacity from 14 GW to 70 GW by 2035, reflecting a significant shift towards renewable energy to mitigate reliance on imported fuels.[117] This positive momentum has continued since the election of a Labour Government, who have set up Great British Energy and importantly committed to decarbonise the electricity grid by 2030.

Conclusions

With the closure of the FiT in April 2019, domestic solar PV entered its fully commercial stage of maturity. Despite the absence of direct government subsidies, there was a noticeable increase in installations between 2022-2023. This was driven by high electricity prices, which restored the financial incentive to invest in solar PV. The energy crisis also heightened consumer awareness of energy related issues, which had a positive impact on adoption. These external factors, combined with progress made from the FiT years — including increased consumer awareness, trust, and improved installation processes — resulted in a significant number of installations in 2023, cementing solar PV as a commercially competitive technology.

Summary

Key lessons learnt from the commercialisation of domestic solar PV

In the early stages of domestic solar PV development, adoption was limited and the technology faced significant barriers. This included high installation costs, challenges associated with connecting to the grid, limited political interest, and a lack of public awareness.

However, key policy and regulatory interventions helped to overcome these challenges, including the introduction of the G77 connections standard and the inclusion of domestic solar in Permitted Development Rights.

Early demonstration and government support schemes helped to showcase the feasibility of small-scale solar PV and increase consumer interest and demand. The turning point for solar PV was the introduction of Feed-in Tariff (FiT) in 2010, which rapidly accelerated deployment in the first two years of the scheme. At the same time, global reductions in module prices, driven by economies of scale and improvements to manufacturing, further reduced costs and spurred market growth in the UK.

However, changes to the FiT rates, without proper consultation with industry, led to a boom-and-bust pattern in installations, resulting in many installers and businesses being forced to leave the industry between 2016-2021. Since the FiT officially ended in 2019, the energy crisis has played a key role in boosting the solar PV market. Rising energy costs have provided strong economic incentives for households to install solar PV systems, even without direct government subsidies. This has been compounded by the recent falls to battery storage prices, which has made installing solar PV even more financially compelling.

What We Can Learn:

1. Economic Incentives Drive Adoption

The high FiT rates between 2010-2012 made solar PV an economically attractive investment, leading to rapid growth in the market. In 2022, the combination of rising energy bills and reduced installation costs renewed the financial incentive for homeowners to adopt solar PV. Economic factors have been important to the commercialisation of solar PV.

2. Importance of Policy Stability

Consistent and supportive policies are essential for the growth of emerging renewable energy technologies. As illustrated by the solar coaster caused by the poor implementation of the FiT, sudden changes to policy can disrupt the market and slow down progress.

3. Industry Consultation is Crucial for Stable Growth

The lack of thorough industry involvement led to an unsustainable "solar rush" and subsequent market stagnation from 2016-2021 caused by cuts to the FiT rates. Engaging industry stakeholders could have helped mitigate these issues by ensuring more stable and sustainable market development. This highlights the importance of involving industry in policy planning to ensure long-term success of policies.

4. Cross-Party Consensus is Vital for Long-Term Policy Stability

The cross-party consensus during the early demonstration and pre-commercial subsidy phase led to key government interventions, such as the publication of the Microgeneration Strategy, the creation of MCS, and commitment to the FiT. This alignment across political lines resulted in considerable policy and regulatory progress for solar PV and demonstrates the value of cross-party support.

5. Role of innovation

Innovation has been key to transforming domestic solar PV into a fully commercialised technology in the UK. Incremental improvements in module efficiency and power output, combined with advancements in manufacturing, have significantly reduced installation costs. Additionally, innovations in mounting systems and digital tools have streamlined the installation process.

→ These lessons highlight the importance of supportive, long-term policies and innovation in the successful commercialisation and scaling up of microgeneration technologies in the UK.

2. In what stage of commercial maturity are heat pumps?

This section examines the development of the heat pump industry in the UK, following the same stages used to map the progress of domestic solar PV.

The history of heat pumps in the UK is unsurprisingly less comprehensive, due to most of the progress taking place in the past decade. The aim of this section is to provide a high-level overview rather than a detailed analysis, to pinpoint what stage of commercial maturity heat pumps are compared to solar PV. It focuses on the key policy and regulatory milestones, whilst Section 3 analyses in more detail the economic, social, technological, and external barriers to heat pump deployment through a comparison with solar PV.

1945-2022 Research and development

The first heat pump in the UK was installed in Norwich in 1945 by John Sumner,[118] a water-source system that used the neighbouring river to heat Norwich City Council buildings. Sumner also installed a closed-loop ground source heat-pump into his home in the 1950's. Despite the efficiency of the system in the council building, heat pumps were not widely adopted in the UK due to the relatively low cost and abundance of fossil fuels, such as coal and North Sea gas.[119]

A transition from coal to gas powered central heating took place in the late 1960s, and in 20 years, 85% of domestic properties had adopted gas central heating.[120] Consequently, domestic heat pumps received very little attention during this time. Instead, technological advancements took place outside of the UK, including improvements to the operation and efficiency of the technology.[121]

Some adoption of heat pumps for domestic heating took place in Europe in the 1970s, notably in Scandinavia. These countries, who used oil to heat their homes, were particularly impacted by the oil crises in the 1970s. Consequently, the governments of these countries put in place comprehensive policy support aimed at helping households to transition away from oil to other forms of heating, including heat pumps.[122]

2003-2014 **Demonstration and pre-subsidy**

The demonstration and pre-subsidy years saw the introduction of policies to promote domestic heat pumps. In 2003, Clear Skies was launched, a grants programme which supported 473 ground-source heat pumps. [123] Interestingly, air-source (ASHPs) were not included, as they were not considered a viable option for domestic heating, according to one interviewee. The Low Carbon Buildings Programme (2006-2010) did offer grants for both technologies, though only 1,573 ground-source and 1,461 ASHP were installed.

Some other important regulatory steps were taken between 2003-2013. Notably, the Microgeneration Certification Scheme was set up in 2008, which created product and installations standards for heat pumps. This was particularly important as one key finding from the UK demonstration trial by the Energy Savings Trust underscored the importance of proper sizing and system design to ensure optimal performance. This demonstration project took place from 2008 to 2013 to understand the efficiency, cost-effectiveness, and suitability of heat pumps in-situ (in properties). Overall, the demonstration provided valuable data that informed subsequent policies and support mechanisms for heat pump technology in the UK.[124] In particular, the EST recommended that customers use an MCS certified installer to ensure high quality and optimised systems.[125] Heat pumps were also added to the Permitted Development Rights; ground-source and water-source were added in 2008, at the same time as domestic solar PV. Air-source heat pumps were not added to PDR until 2011, when the MCS published MCS 020, a standard that provides a noise assessment to determine the sound pressure from the heat pump.[126]

The Green Deal was another UK government initiative launched in January 2013 to help homeowners and businesses finance energy efficiency improvements, including renewable energy installations, with no upfront cost. Instead, the costs were recouped through savings on energy bills under the "Golden Rule," which stipulated that the expected savings must be equal to or greater than the costs of the improvements.[127] However, the Green Deal struggled with low uptake and was criticised for its complexity and high interest rates. Instead of becoming a long-term policy initiative, it closed for new funding in July 2015, just two years after being launched.[128]

The domestic Renewable Heat Incentive (RHI) was due to be introduced in 2012 to go alongside the Green Deal.[129] However, the RHI was delayed, in part due to reservations in DECC that it would follow a similar pattern to the FiT between 2010-2012.[130] According to one interviewee, the UK government were concerned that there would be another 'gold rush', so chose to delay the scheme. This delay was not well received by the heat pump industry, who had spent six months preparing for the introduction of the domestic RHI.[131] However, the Renewable Heat Premium (2011-2014) was brought in as an interim measure.[132] This provided an upfront grant to homeowners and supported 14,000 heat pumps in total over the three years.[133] In addition to government funded schemes, the Electricity Company Obligation was launched in 2013 which necessitated energy suppliers to fund energy efficiency measures for low-income households.[134] Though heat pumps were technically eligible for the scheme, in the first iteration almost all heating measures were gas boiler replacements or heating controls.[135] Thus, it did not have a significant impact on the heat pump market.

To conclude, this stage saw an increase in policy and regulatory activity to support heat pump adoption in the UK. Nevertheless, the impact of these schemes was limited in some cases due to poor implementation and short-termism, and as a result only a limited number of heat pumps were installed.

2014-2024 **Supported commercial**

In 2014, heat pumps entered their supported commercial stage of maturity with the introduction of the domestic RHI. Like the FiT, this scheme was designed to incentivise a greater adoption of low-carbon heating technologies. However, it was not levied onto energy bills, and instead was financed by the Treasury and only guaranteed payments for 7 years (instead of 20 years) based on the amount of renewable heat the homeowner's property made (per kWh).[136] Despite running for 8 years, closing to new applicants on 31st March 2022, the scheme did not support the same growth to the heat pump market as the FiT did for the solar PV market. Section 3 (Policy, regulation and standards) will look in more detail about the reasons for this.

Towards the end of the RHI, the Government launched the Green Homes Grant (2020), offering vouchers to cover part of the cost of installing energy-efficient improvements and low-carbon heating technologies, including a £5,000 voucher for a heat pump. The Green Homes Grant scheme faced various administrative challenges, including delays in voucher processing and contractor availability, leading to lower-than-expected uptake. As a result, the scheme was closed to new applications on 31 March 2021, much earlier than initially planned.[137]

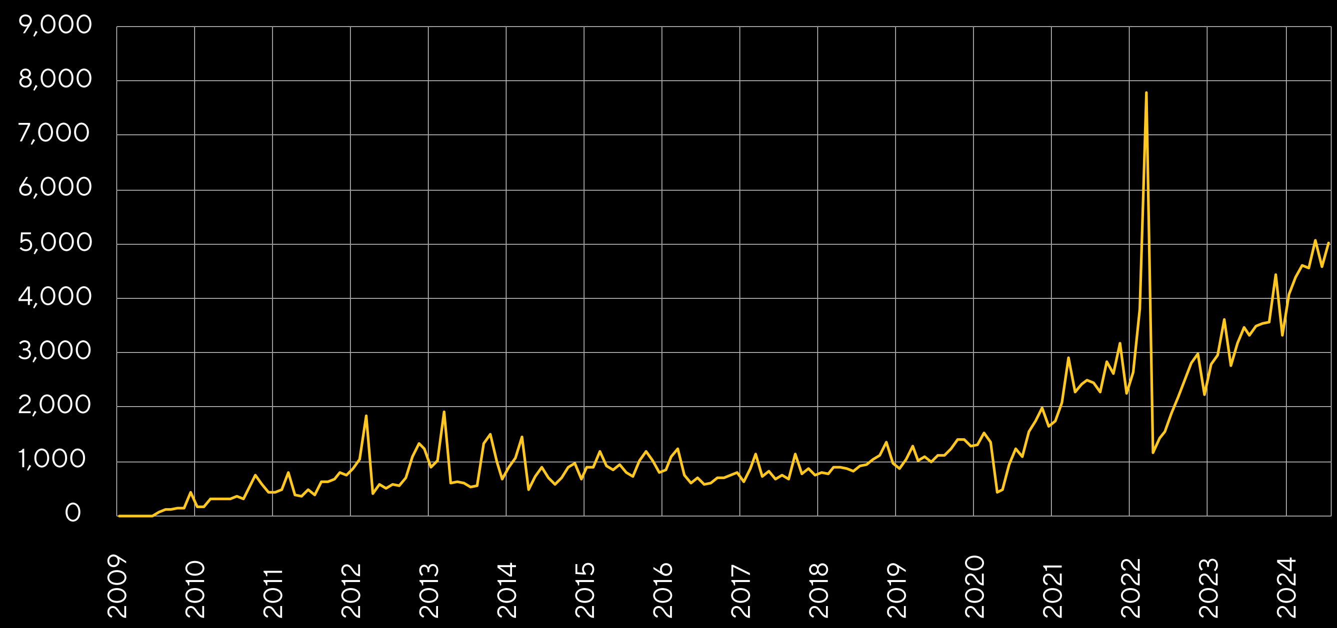
In October 2021, the UK Government published the Heat and Buildings Strategy and set an ambitious target to install 600,000 heat pumps per year by 2028.[138] This triggered a number of policies designed to support heat pump rollout. Importantly, the government introduced the Boiler Upgrade Scheme, launched in May 2022. Homeowners could receive an upfront grant of £5,000 for an air-source, and £6,000 for a water/ground-source heat pump. In October of 2023, the BUS scheme increased the grant to £7,500 for both air- source, water-source and ground-source heat pumps.[139]

The Clean Heat Market Mechanism (CHMM) is another proposed policy within the Heat and Buildings Strategy. Initially scheduled for April 2024, it requires large companies selling fossil fuel heating systems to also sell a proportion of heat pumps.This policy was designed to increase the number of heat pump sales year on year, eventually supporting 400,000 heat pump sales in 2028.[140] However, the implementation of the CHMM was delayed by the previous government until April 2025, and has not yet been confirmed by the new Labour government, elected in July 2024. Other key policies include the publication of the Heat Pump Investment Roadmap in March 2022, outlining UK government's broader strategy to support the growth of the heat pump sector. The Heat Pump Ready Programme was also launched in 2022 which provided innovation funding for projects that address technical and financial barriers, create new tools and technologies, and support trials to accelerate the deployment of heat pumps. Furthermore, Energy Saving Materials – including heat pumps – were zero-rated for VAT to help address the high upfront costs.[141]

Locally delivered schemes have also supported heat pump adoption in this stage. These include the Social Housing Decarbonisation Fund (SHDF), the Home Upgrade Grant (HUG), and the Local Authority Delivery Scheme (LAD). However, data on the number of heat pumps installed through these schemes is not always widely available, and their overall contribution has been relatively low. For example, the LAD scheme only delivered 1,898 heat pumps,[142] highlighting the limited impact of these initiatives in driving large-scale heat pump deployment to date. This was also seen with the early iterations of the ECO scheme, which primarily supported gas boiler replacements. Heat pumps were technically eligible for the scheme, but 96% of 'Other Heating' measures consisted of heating controls.[143] However, important progress has been made in ECO4 due to a shift towards supporting more renewable heating technologies, including heat pumps.[144] Importantly, renewable heat and microgeneration technologies are now separately captured in the data. This shift has resulted in the support of nearly 26,000 renewable heating systems,[145] most of which we expect to be heat pumps.

To conclude, since 2021, there has been several new Government policies to support heat pump rollout. As shown in ***Figure 10***, this has resulted in a steady growth to the market between 2021-2024, culminating in a record 39,268 MCS certified heat pumps installed in 2023. Recent changes to the BUS scheme have had a significant impact, with a 75% increase in applications in February 2024 compared to February 2023.[146] Despite this recent progress, domestic heat pumps are still in their supported commercial stage of development in the UK. This means that they still require government market support to be competitive. What's more, despite a record number of installations in 2023, this only equates to around 6% of the Government's 600,000 per year target, and in comparison, roughly 1.75 million gas boilers are still being sold in the UK.[147] Unlike domestic solar PV, which saw significant growth in the market in the early 2010s, the market has remained largely static since the RHI was introduced, with a maximum monthly peak of 7,776 just before the RHI closed. The UK needs the heat pump market to increase exponentially in the next few years if we are to meet the 2028 target.

Figure 10: *Installations over time graph, showing heat pump data from the MCS Data dashboard[148] between 2009 - 2024. [Sourced: 29 July 2024.]*



39,268

A record 39,268 MCS certified heat pumps installed in 2023

6%

Despite a record in 2023, this only equates to around 6% of the Government's 600,000 per year target

7,776 *(March 2022)*

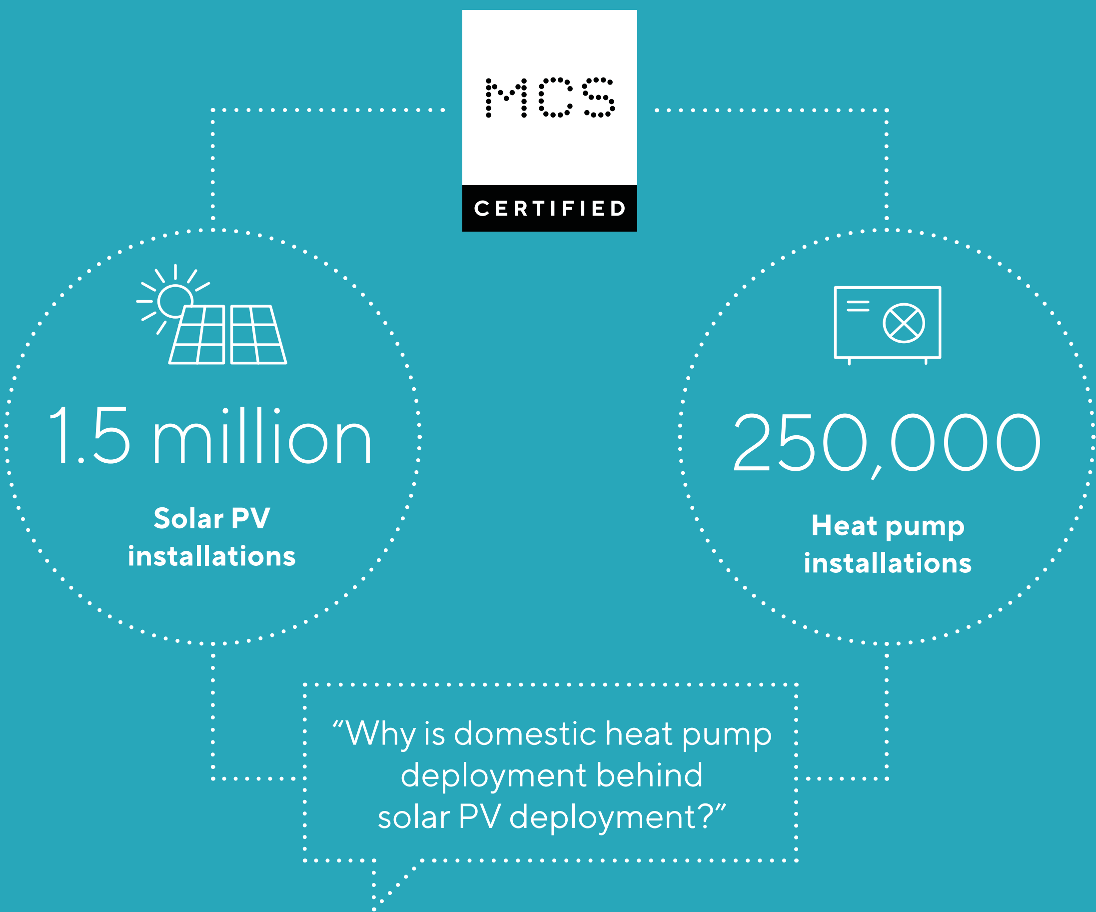
Maximum monthly peak of 7776 installations before the RHI closed

3. Why is heat pump deployment behind solar PV?

Section 1 mapped the development of solar PV from R&D to full commercialisation in 2019, and Section 2 analysed heat pump development using the same framework.

Despite the first heat pump installation in the UK taking place forty years before the first grid-connected solar installation, heat pumps have not advanced past the supported commercial stage.

This means that they still require direct government financial support to be competitive within the wider heating market. Furthermore, there has been 1.5 million MCS certified solar PV installations, compared to 250,000 heat pump installations. This section aims to address the second research question to understand 'Why domestic heat pump deployment is behind solar PV deployment?"



Energy Context and external factors

The global market for heat pumps matured much earlier than solar PV

At the turn of the century, the global market for solar PV was still very small, with 1.23GW of solar energy capacity worldwide, compared to over 1000GW in 2022.[149] In contrast, one interviewee explained how the basic heat pump technology was already mature in the UK in 2000, used in commercial buildings for air-conditioning. Equally, the technology was growing in popularity for domestic heating in Scandinavian countries like Sweden and Norway.[150] One interviewee explained, *"there was a lot of fat to come out of solar PV manufacturing, which is why the price of PV modules has reduced so much..."*

This has not been the case for domestic heat pumps as *"the technology has been mature for decades."* As a result, the installation cost of domestic solar PV has decreased significantly since the first installation in 1994, whereas the same cost reductions have been far less dramatic for heat pumps. This partly explains why heat pumps still require government subsidies, whilst solar PV has succeeded in becoming fully commercialised since 2019.

Electricity decarbonisation preceded heat decarbonisation in the UK

In the early 2000s, climate change targets were much less stringent and in the 2002 Energy Review there was still an assumption that gas would play an important role for home heating in the 2050 energy system.[151] One policy expert explained how *"as the carbon budgets tightened up, it became more obvious that you had to do something on heat."* This was especially the case after the UK signed the Climate Change Act (2008), in which the Government committed to reduce emissions by 80%. Heat decarbonisation has often been referred to as "the Cinderella of energy policy," with many related policies being implemented later than those focused on decarbonising energy generation. Importantly, the supported commercial stage for heat pumps was four years later than for domestic solar PV, with the implementation of the domestic RHI in 2014, compared to the FiT in 2010. This could explain why solar PV is further along the technology development timeline, as key policies were implemented several years before heat pump policies.

Economic factors

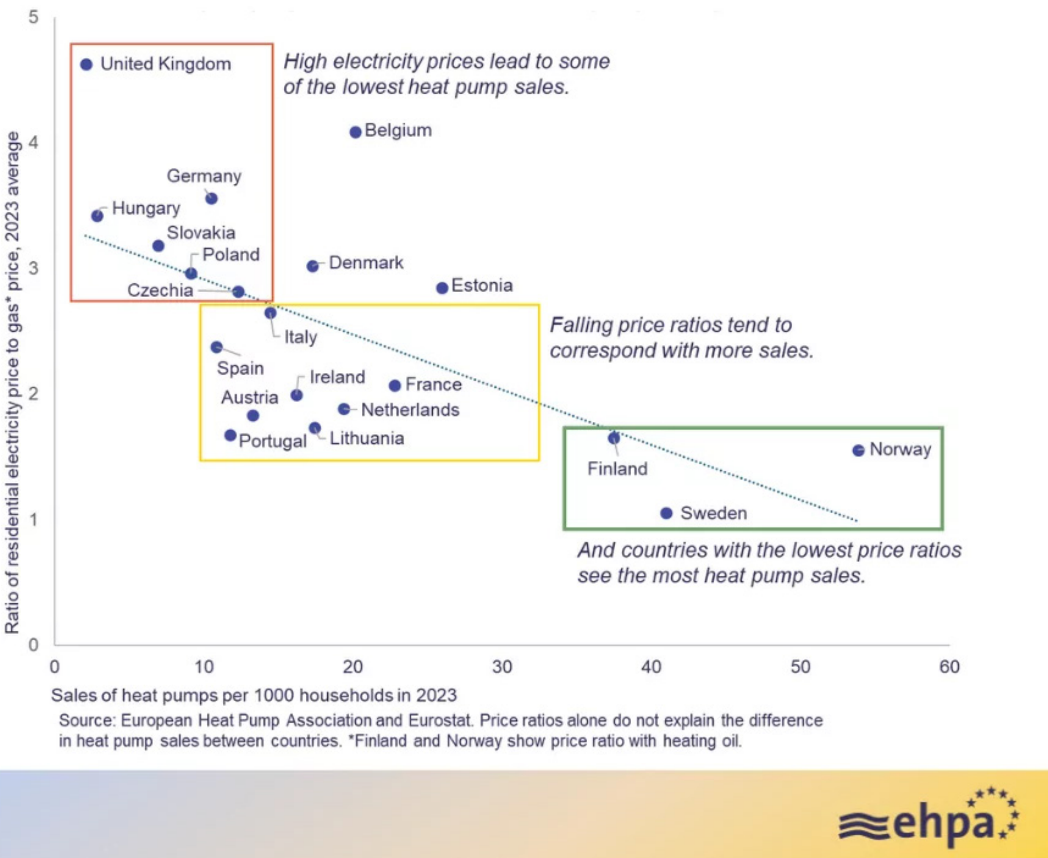
The financial incentive for heat pumps has been lacking compared to solar PV

Economic factors were identified as key drivers of solar PV deployment, including high FiT rates, upfront cost reductions, and rising electricity prices. All of these factors have resulted in there being a financial incentive to invest in solar PV. In contrast, heat pumps have lacked a comparable financial incentive. They have a higher upfront cost than other fossil fuel heating systems,[152] and until the recent energy crisis, they were likely to increase a household heating bill due to the high cost of electricity compared to gas in the UK.[153] One interviewee explained:

"...if the financial incentives were there just like they were with solar then we can easily make customers comfortable with the switch. But right now, we do expect customers to save money, but it's still such a tight space with electricity being so expensive and gas being so, so cheap. So, it's not an easy choice for the consumer whereas it should be a no brainer."

There is seemingly a correlation between heat pump adoption and a country's spark gap – the ratio between electricity and gas prices. The European Heat Pump Association produced a graphic showing that countries with the highest spark gap also see fewest heat pump installs (see ***Figure 11***).[154]

Figure 11: The y-axis plots the spark gap of a country (0-5), whilst the x-axis plots the sales of heat pumps per 1000 households in 2023. [Source: European Heat Pump Association.][155]



The lack of financial incentive for heat pumps could explain why they have not moved past the supported commercial stage. Even with government subsidies and grants, there has not been an economic incentive to switch from gas heating, as installing a heat pump costs more, and in the past, may have also increased annual heating bills.[156]

Hardware costs vs transition costs

According to several interviewees, the overall installation cost of domestic solar PV is predominantly linked to hardware costs – the modules, the mounting equipment and inverters. In 2010, it was estimated that 45-60% of the overall cost was made up of the module costs.[157] Therefore, when hardware costs decreased significantly between 2010-2012, consumer installation costs decreased accordingly. In contrast, one heat pump installer explained: *"Changing your gas boiler to a heat pump is generally a four-day job. A much larger share of the total sum of the installation actually relates to the man hours that are put in versus solar, where most of the money is actually for the hardware."*

This has resulted in there being much less dramatic cost reductions for heat pump installations over the same period. There is an initial 'transition cost' associated with connecting or changing the pipes, changing any radiators, and adding a hot water tank. This 'transition' cost is present with a shift to any new heating system, as was seen in the UK when home heating was transformed from coal to gas central heating from the 1960s.[158] The same interviewee explained how this transition has for the most part already taken place in Sweden and therefore, for homes that are about to replace their heat pump for the first time: *"...all the piping stuff has already been done, so actually getting rid of an old heat pump and replacing it with a new one is also a one-day job...But to get there, we need to transition the houses first."*

Many heat pump experts felt that at least some cost reductions from economies of scale and improvements to the efficiency of the supply chain could be achieved in the future. However, heat pumps could require government grants for a longer period than domestic solar PV to cover the 'transitional' cost, before they become fully commercially viable. This is especially the case if we are to succeed in installing 600,000 heat pumps per year, as upfront cost is still a significant barrier to adoption.[159]

Alongside government support, a diverse range of product offerings are starting to emerge in the market, including 'heat as a service',[160] where homeowners do not pay the upfront cost and instead just pay a monthly service charge for heating. These types of offers are likely to be increasingly important levers to facilitate adoption.

Photo credit: Vaillant Group

Public perception and adoption

Lack of awareness of the heat pump technology

A key difference that has contributed to the lower uptake of heat pumps compared to solar PV is the disparity in consumer awareness. According to the 2012 government public attitudes trackers, nearly half (47%) of respondents had never heard of an air-source heat pump, whereas solar PV had the highest level of public support among renewable technologies, with 83% expressing support[161] Whilst the awareness of heat pumps has increased over the past decade - with one in four people planning to get a heat pump as their next heating system - even in Spring 2024, only 9% of the public claimed they knew a lot about low-carbon heating, and only 25% a fair amount.[162] Many of the heat pump experts remarked how PV systems are simply more visible and that has helped normalise the technology, whereas this has not been the case with heat pumps: *"...it is about familiarity and about perception, and the fact that most people are still not yet exposed to heat pump technologies, or at least they think they're not. Of course, they are because they've got them all over their house, every shop they go into, every hotel room they go into, every office they go into - heated and cooled by heat pumps pretty well. So, they are massively exposed, but they don't realise it."*

Another heat pump policy expert added that solar PV is simply an easier technology for consumers to understand: *"People conceptualise PV differently because you put it on your roof and it makes something... Whereas a heat pump; it technically...extracts more heat from the environment than solar panels extract from light, but you don't see a product coming out of it. You don't see electrons or your meter going around, you just see a box in the garden using energy."*

Uncertainty and lack of trust are two important factors that can negatively impact consumer adoption of microgeneration technologies.[163] This is compounded by a lack of comprehensive advice for homeowners and there have been calls to introduce a government-funded one-stop-shop to address this, where every homeowner can access personalised advice.[164]

Consumer confidence: The media – misinformation around heat pumps

While some solar experts noted that misinformation about solar PV in the media has been prevalent to some extent in the past, misinformation regarding heat pumps has been significantly worse, especially over the past decade. One policy expert explained how: *"heat pumps are subject to a vitriolic campaign of misinformation from right wing media... [who are] desperately chasing clicks [on the internet] because that's the only way they make the business model stand up."*

This in part explains why there are so many untrue myths about heat pumps in the UK,[165] that have simply not been prevalent for domestic solar PV. Solar panels are an additional 'fit and forget' technology, whereas heating is a necessity. Thus, reliability is an important factor for any type of heating, including gas boilers.[166] As one solar PV installer put it, *"If solar fails you, you've got the grid, therefore, you've got no risk. If a heat pump fails in December...they're [the homeowner] cold. People get passionate about it."* Interviewees suggested that adopting low-carbon heating therefore requires more engagement and trust from the consumer compared to installing solar panels, which they perceive to involve less risk. Early studies into consumer adoption of microgeneration technologies demonstrated that risk is an important factor influencing homeowners.[167] Several heat pump interviewees explained how the untrue myths around heat pumps, exacerbated by the media, have had a negative impact on public perception and trust of heat pumps, ultimately affecting homeowners' willingness to adopt.

Untrue myths around heat pumps, exacerbated by the media, have had a negative impact on public perception and trust of heat pumps

Technological developments and innovation

Transitioning to a new heating system for the first time is more technologically complex than adding a new solar PV system

One heat pump expert used the analogy that the installation process for solar panels is like putting a bandage on an arm, whereas heat pumps are more like open heart surgery.

Installing a solar panel generally requires both a roofer and an electrician and can usually be fitted within a day. This is not the case with heat pumps, as one installer explained: *"You need somebody who's really good at selling because you need to sell it. Then you need a surveyor to survey it. Then you need a designer to design it. You then need a heat pump installer to install it. And you need an electrician to do the electrical aspect...And none of these are the same person. Before you've done any of the admin, you've got five skill sets needed."*

Heat pumps are still a bespoke installation, whereas solar panels have become more standardised

Since 2000, there has been less innovation in the heat pump industry compared to solar industry, although this is has started to change in the past few years. One interviewee observed that whilst solar PV has become a relatively standardised technology, due to the development of specialist equipment and modules that suit different roofs, heat pumps have by and large remained a bespoke installation. They explained, *"it's very technical.... And it's got to be designed to work in [the] worst case scenario."*

They argued that the development of high temperature heat pumps, that distribute water through the radiators at higher temperatures, could result in less distruptive installations as there is more chance of being able to keep the existing heating system, including the emitters. One heat pump manufacturer added to this that in the future they predict there will be "different variants of heat pumps, which we haven't seen yet." Nevertheless, the lack of standardisation and innovation in the heat pump industry in the UK over the past two decades could explain why solar PV has become more competitive earlier than heat pumps.

Policy, regulation and standards

The Renewable Heat Incentive vs the Feed-in Tariff

The RHI was the government's scheme for supporting domestic low-carbon heating from 2014 to 2022. The policy was intended to be implemented in 2012, shortly after the FiT,[168] but government were wary of a gold rush similar to that seen in the early years of the FiT. As a result, the domestic RHI was delayed and, when launched, was much less generous.[169] It offered payments over seven years, instead of twenty, intended to cover the initial upfront cost of the installation. The result of this was *"[it] didn't actually give you a sweetener really. It just meant that you weren't paying anything more than you otherwise would have paid"(Heat pump expert).*

This was unlike the early years of the FiT, where homeowners were getting a 10% return on investment (ROI) for their solar PV systems.[170] Even with the cuts to the FiT in 2012, there was still a 4% ROI. Additionally, another significant shortcoming of the RHI was that it was heavily skewed towards biomass boilers. One interviewee described: *"We in the heat pump sector thought through our discussions with DECC...that we'd aligned the subsidy support tariffs appropriately to the costs. And then literally at one minute to midnight these new tariffs appeared. Biomass tariff way up in the stratosphere. So, the RHI came along, and the heat pump market was cut in half overnight."*

Ultimately, the RHI did not support the same growth in the heat pump market as the FiT had succeeded in doing, as shown in ***Figure 12*** and ***Figure 13***.

Figure 12: *Solar PV installation numbers in the first four years of the Feed-in Tariff. [Data sourced from MCS Data dashboard on 13th August 2024.]*

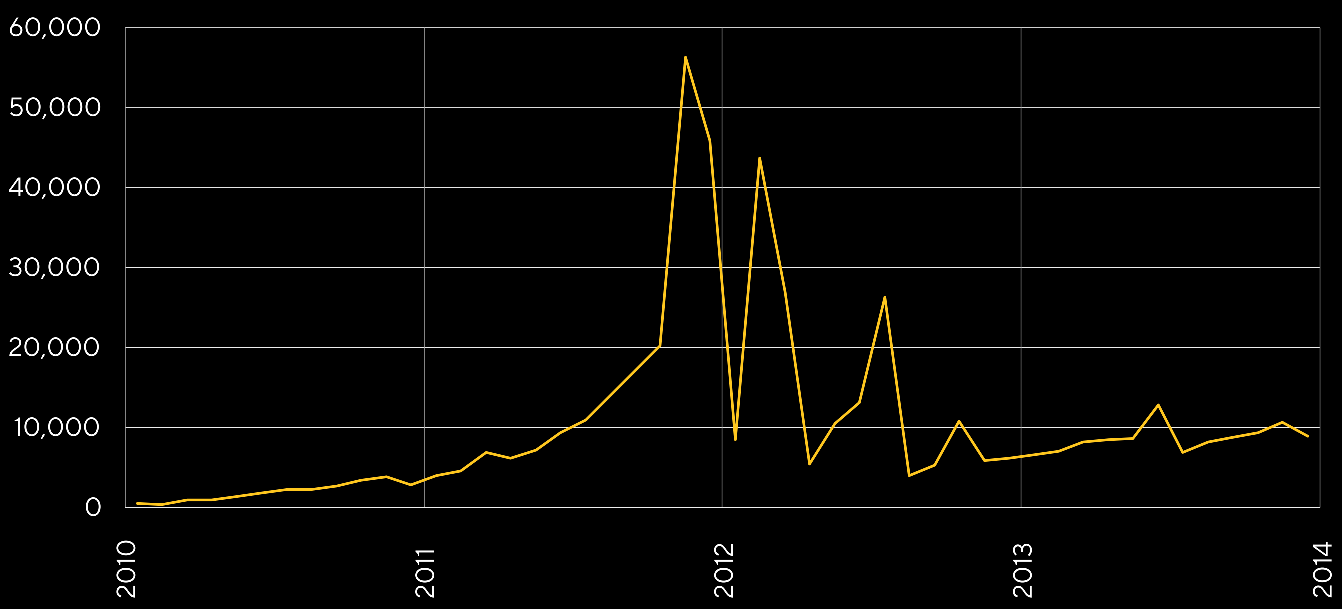
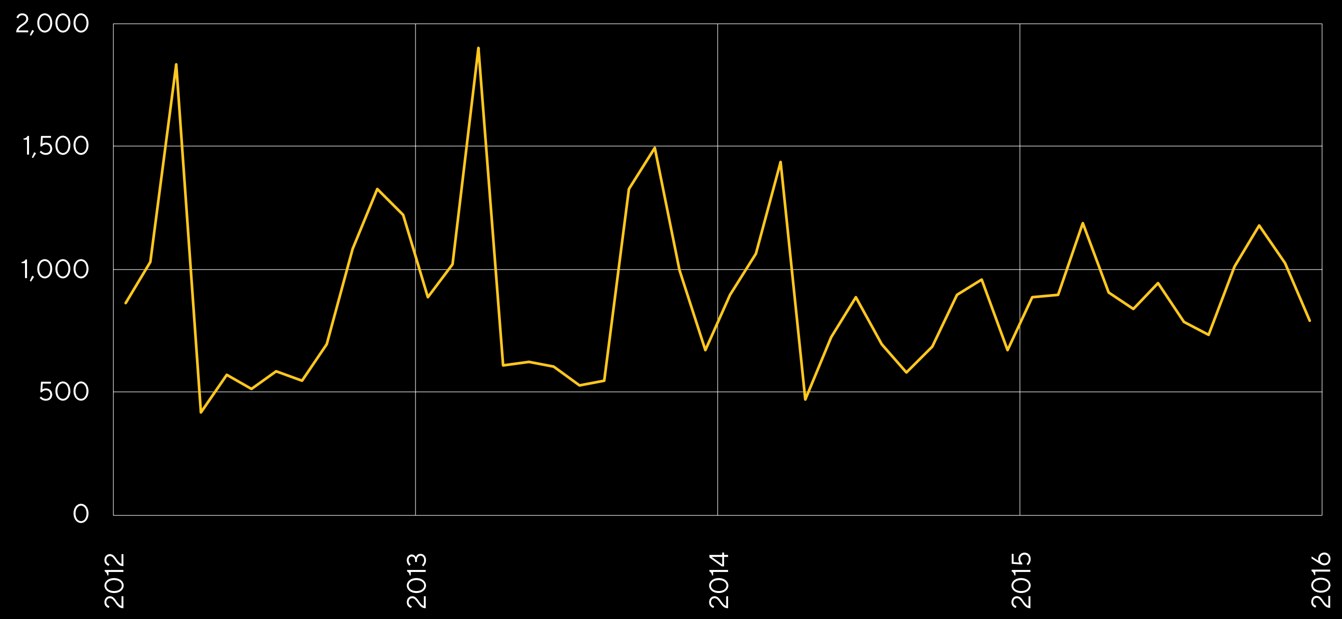


Figure 13: *Number of heat pump installations in the first four years of the Renewable Heat Incentive. [Data sourced from MCS Data dashboard on 13th August 2024.]*



As was shown in the solar PV development section, the FiT had wide ranging impacts, most notably driving innovation in the installation process and raising consumer awareness of the technology. ***Figure 12*** shows that in the first two years of the FiT scheme (2010-2012), almost 400,000 solar PV arrays were installed, compared to just over 30,000 heat pumps in the first two years of the RHI. This in part could explain why there has not been the same innovation in the heat pump industry over the same period. The market did not grow at the speed and scale of the solar PV industry, and therefore there was less of an incentive for businesses to enter the market and drive innovation.

Planning permission – PDR

Generally, it is not necessary to get planning permission to install domestic solar PV, apart from in conservation areas or on listed buildings. However, the Permitted Development Rights (PDR) rules for air-source heat pumps have started to become a barrier to adoption, particularly in terraced properties where space is limited according to a CEO of a heat pump company. Whilst they are currently taking the strategic decision to support households through this process, they acknowledge the difficulties of this: *"We spend weeks of administration on a single installation. Right now, we're picking up the bill on it, so any customer we sell to who require planning permission, which is 50% of customers, we lose money... in practice that makes us very different from the local plumber...because they are absolutely not resourced to spend many weeks on sending architects out to do elevation drawings and to sort of ping pong back and forth with the council that all want different things in different formats, at different times."*

What's more, according to a heat pump policy specialist, the PDR rules for planning permission are not based on any kind of scientific reasoning but instead were simply "plucked out of the air". This type of regulatory barrier has not been prevalent for solar PV since the demonstration and pre-commercial stage (2000-2009). The previous Government recently consulted on changes to PDR, acknowledging these barriers and proposing changes to address them.[171] Thus, it is possible that these restrictions will be removed by the new Labour government in the foreseeable future.

Skills, competence and training

While both sectors have suffered the damage of policy uncertainty and market fluctuations, according to one solar installer, it has been fairly easy for electricians to both enter and leave the market to *"go back to something else that [is] equally lucrative."* Though one heat pump installer explained that *"transferring the skill set from gas to heat pumps... isn't that difficult"*, there is currently competition for skills with the gas boiler industry. Unlike the FiT, the RHI did not result in significant market growth of the heat pump sector, and thus historically there has not been an incentive for gas engineers to switch, *"gas engineers have got, I believe this false belief that they've got career for life, working with gas, even if they're 20 or 30 years old."* (Heat pump expert). Furthermore, the average age of a gas boiler engineer in the UK is 50-60,[172] and a lot are near the age of retirement and do not see that the transition will impact them. One policy expert described the value they could bring to the industry: *"We do need [them] because I think they have a lot of experience they can pass on to a new generation, but they also have quite a lot of, like weight in terms of talking about where the industry might go."*

Furthermore, even for those who have the qualifications to install heat pumps, there are practical challenges for SMEs or 'one-man band' heating engineers to fully transition to the heat pump sector. Currently, these groups can install a gas boiler extremely easily and usually within one day. With the skills required to install a compliant heat pump, one heat pump expert explained that it is simply easier and more lucrative for them to continue to install gas boilers. These challenges highlight the importance of long-term policy and regulatory certainty in driving skills development in the heat pump sector.

Actors

Lobbying against heat pumps has been much stronger than lobbying against domestic solar PV

The lobby against heat pumps has been much more prevalent than for domestic solar PV. In particular, hydrogen for heating has been a significant distraction in the low carbon heating space.[173] In the UK, approximately 1.75 million gas boilers are installed annually,[174] and the widespread adoption of heat pumps would mark the end of a multi-billion-pound industry. As a result, lobbyists from the gas and oil industries work in Westminster with the primary aim to continue business as usual by advocating for hydrogen heating.[175] The UK Government is set to make a firm decision in 2026, but this has created uncertainty not only for industry, but for homeowners as well. For example, recent investigations have been carried out by the Competition and Markets Authority (CMA) into the potential miss-selling of 'hydrogen-ready boilers'.

The concern is that hydrogen heating is being marketed as available now, despite this not being the case.[176] As well as the potential to mislead consumers, uncertainty around hydrogen heating is likely to delay policies for the electrification of heat, including heat pumps. This could be another explanation as to why heat pump policy has been often been delayed compared to solar PV policy.[178]

Heat decarbonisation has been less politically palatable than electricity generation decarbonisation

We do not need every household in the UK to have solar panels, but we do need every home to transition to some form of low-carbon heating. This makes heat decarbonisation more politically challenging. The Government is reluctant to be seen as forcing consumers into making changes,[179] which makes a ban on new fossil fuel heating systems politically unpalatable according to one interviewee. This underscores why there has been a lack of political buy-in for heat decarbonisation. It involves complex, long-term investments with no easy wins, necessitating substantial government support. One policy expert described it:
"As a kind of emissions and climate measure, I don't think heat has ever found something where people in power could think ...I'll leave a legacy."

Many policies to forward heat decarbonisation, including the rebalancing of electricity and gas prices, have been considered politically challenging.[180] Despite continued evidence from industry that this particular policy is important in supporting heat pump adoption,[181] it has been continuously delayed.

4. What can the heat pump industry learn from the success of solar PV?

1. A financial incentive for the homeowner
2. Consumer trust and awareness of the technology
3. Incremental efficiency improvements and technological innovations
4. Diversified and robust supply chains
5. Green finance
6. Cross-party political support
7. Long-term supportive policy and regulation
8. Supply chain growth through skills development and stable policy

1. A financial incentive for the homeowner

In the two periods where domestic solar PV reached the highest number of installations, in 2011, and in 2023, there was a noticeable financial incentive to invest. In the first instance, the generous rates for the FiT resulted in high returns on investments. The second, record-high electricity prices, combined with low installation costs, resulted in their being an economic incentive to invest without government subsidies. Government must make heat pumps the cheapest form of heating, so there is an economic incentive for the homeowner to switch. They must also support consumers with the initial 'transition cost' which is required when switching any heating system.

Recommendations:

- Government must address the price disparity of electricity and gas by removing social and environmental levies from electricity and moving them into general taxation.
- Government should extend the Boiler Upgrade Scheme until 2035.
- Government should extend 0% VAT of energy saving materials until 2035.

2. Consumer trust and awareness of the technology

Lack of trust was a barrier to adoption in the early stages of solar PV development, but this was overcome in the FiT years, where significant market growth led to greater visibility and helped solidify solar PV as a mainstream technology. Heat pumps are not as widely familiar to the public than solar PV and have suffered from widespread misinformation from the media. Consequently, industry and government must raise awareness, improve trust and streamline the consumer journey.

Recommendations:

- Government must finance a national one-stop-shop in the UK where consumers can get free personalised advice, support and information on the best low-carbon heating technology for their home.
- Government must finance a professional marketing campaign to raise awareness of why it is necessary to transition to low-carbon heating and the different options.
- Industry and energy suppliers must strengthen the consumer journey for installing a heat pump. This should consider the sales process, the upfront cost, the installation stage, and consumer protections.

3. Incremental efficiency improvements and technological innovations

Incremental improvements to the solar PV technology, installation, and manufacturing processes have been key to solar PV reaching full commercialisation. In the future, the heat pump industry must continue to drive innovation to improve efficiency, standardisation, and reduce costs.

Recommendations:

- Industry should continue to drive innovation to give rise to a greater standardisation of installation, an increase in the variety of products, and improvements to the efficiency that help drive down cost.

4. Diversified and robust supply chains

One lesson learned from the rollout of domestic solar PV in the UK is the risk associated with relying on a monopolistic supply chain, where manufacturing predominantly occurs in a single country. Ethical or political issues within this supply chain can disrupt the entire industry in the UK. To mitigate these risks, it is crucial to establish some manufacturing within the UK.

Recommendations:

- Government should legislate the Clean Heat Market Mechanism to encourage boiler manufacturers to transition to sell and manufacture more heat pumps.

5. Green finance

Even though domestic solar PV has reached full commercialisation, upfront cost can still be a barrier for a proportion of households. Equally, even with government grants and support schemes, the upfront cost of heat pumps could be a barrier for households. Improving the green finance offer will be critical in the future to allow more households to access heat pumps.

Recommendations:

- Government should introduce zero interest rate Property Linked Finance (PLF) loans. Upfront costs for renewables would be covered in full and paid back via a service charge applied to the property, rather than attaching loan payments attached to the individual.
- Banks, financial institutions, and energy suppliers should continue to strengthen their green finance portfolio, by offering a range of products and services to appeal to a wide range of homeowners.

6. Cross-party political support

The history of solar PV demonstrates that cross-party political support is an important driver of policy and regulation. When political actors are supportive, key policies and regulations are established, fostering growth and innovation. This was evident during the demonstration and pre-commercial years of the PV industry, where bipartisan backing of microgeneration technologies led to the introduction of several supportive policies, including the FiT.

Conversely, the 'cut the green crap' stance saw many of these schemes being watered down, highlighting how the lack of political consensus can impede progress and undermine the stability needed for the sector's advancement. For widespread heat pump adoption, we need a long-term strategy with cross-party commitment to ensure that essential policies are maintained and not rolled back on over time.

Recommendations:

- The heat pump industry must continue to raise awareness and provide information to MPs across political parties to drive cross-party consensus on this issue.

7. Long-term supportive policy and regulation

The 'solar coaster' highlights the importance of consistent policy and the drawbacks of stop-start financial incentives. Poor implementation of the FiT led to peaks and troughs in installations between 2010 and 2019, disrupting steady market growth and undermining industry confidence. To support mass-scale heat pump deployment, a stable, long-term policy plan is essential to build sector confidence, attract investment, and demonstrate to the public the direction of travel for domestic heating in the UK.

Recommendations:

- The new Government should continue to review and rapidly implement changes to the Permitted Development Rights for air-source heat pumps, removing the 1m from a boundary rule, and other measures that block installations.
- The Government should announce a ban on all domestic fossil fuel heating replacements from 2035. This timescale allows time for a transition but would reinforce the Government's net zero goals and provide long-term certainty.
- Government must make a decision to move away from hydrogen for heating and focus support on low-carbon technologies that are proven and are commercially available now.
- The Government should legislate the Future Homes Standard no later than 2025, requiring all new build homes to be zero-carbon ready.

8. Supply chain growth through skills development and stable policy

The history of solar PV has shown how microgeneration industries can expand rapidly to meet increased demand. However, it was noted that skills development in the future will be necessary to support increased growth in the sector. Equally, to achieve the government's 600,000 heat pump installations per year by 2028, it is predicted that we need more than 33,000 full time installers. This is at least a three-fold increase of the approximate 11,000 individuals in the UK that currently have qualifications.[182]

Recommendations:

- Long-term and stable policy which supports maintained growth is key to provide confidence to stakeholders, including gas heating engineers, to enter the heat pump workforce. Increasing supply is counterproductive if there is not the demand to sustain the workforce.
- To build a sustainable heat pump supply chain, we need to attract more talent by raising awareness of the diverse, impactful career opportunities in low-carbon heating. This requires clear communication of career pathways, real-world examples, and targeted outreach.

Conclusions

This report has mapped the development of the domestic solar PV in its four stages of commercial maturity to understand the key triggers that enabled it to transition from a niche technology in the Research and Development stage (1977-1999) to a fully commercialised technology in 2019.

The analysis shows that several key factors contributed in a positive way to the development of solar. These include:

- Key regulations, like the G77 connections standard and Permitted Development Rights, helped streamline the installation process by reducing the need for planning permission from local councils to connect to the grid and install solar panels on rooftops.
- Cross-party political support in the early 2000s was critical for pushing through important policies and strategies, notably the Microgeneration Strategy, which laid out a long-term plan to reduce barriers and support the adoption of microgeneration technologies.
- Early government schemes, such as the Low Carbon Buildings Programme, supported initial installations, proved the feasibility of the technology, and helped spark interest in the solar PV technology.
- Cost reductions in module prices, driven by improvements in global manufacturing and economies of scale, led to significant cost reductions between the 1990s and 2015. This has enabled solar PV to become economically competitive in the broader energy market by reducing payback periods.
- Generous FiT rates between 2010-2012 led to rapid market growth, from just over 9,000 annual installations in 2009 to over 200,000 annual installations in 2011. This created 25,000 jobs in the first two years. This rapid growth also helped establish solar PV as a more mainstream technology, increasing consumer awareness and confidence.
- Innovation in the installation process, alongside incremental improvements and technological innovations, helped standardise solar PV installations.
- External factors, such as the energy crisis in 2022/23 and the resulting rise in electricity prices, shortened payback times and restored economic incentives to invest in solar PV, even without direct government subsidies. The concurrent cost reductions in battery storage installations were also critical in enhancing the financial appeal of solar PV.

Nevertheless, despite reaching full commercialisation in 2019, this has not been achieved without significant challenges.

One of the most notable changes was the poor implementation of the FiT scheme. The initial FiT rates between 2010-2012 had been set high, leading to rapid market growth and what has been coined 'the solar gold rush'. However, the sudden reduction in rates created a boom-and-bust cycle, with installations peaking between 2010 and 2015, reaching 882,693 installations, and then plummeting to just 188,587 installations between 2016 and 2019. The changes to the rates, which were implemented with little consultation with the solar PV industry, led to a period of uncertainty and instability. This volatility made it difficult for businesses to plan for the long term, and many MCS-certified contractors left the market from 2012-2020, resulting in a loss of skills and capacity. Further compounding the challenge was the political environment during the mid-2010s.

In 2013, Prime Minister David Cameron's government shifted its stance, with the infamous "cut the green crap" rhetoric, signalling a reduced political commitment to green initiatives. Key renewable energy schemes were scaled back or eliminated, and concerns were raised that high levels of uptake of schemes like the FiT could increase electricity bills for consumers.

The market volatility caused by these policy changes highlighted several key challenges:

- **Lack of industry consultation:** The rapid changes to the FiT were implemented with minimal input from the solar PV industry. Many stakeholders believed that this lack of consultation led to poorly designed policies that failed to account for market realities, resulting in extreme fluctuations in installation rates, impacting industry confidence.

- **Political uncertainty:** The fluctuating levels of political support for solar PV created an unpredictable environment for investment. The shift away from supportive policies in the mid-2010s underscores the need for cross-party consensus to ensure consistent policy support for renewable technologies.

- **Impact on long-term skills development:** The erratic policy landscape and resulting market volatility made it challenging for the solar PV industry to invest in skills development and workforce training. After the cuts to the FiT in 2012, the number of MCS certified contractors gradually declined, and the sector has only recently begun to recover to pre-2016 levels of capacity.

With this in mind, key lessons can be been learnt from the positive and negatives associated with the rollout of solar PV. These include:

- **Economic Incentives Drive Adoption:** The high FiT rates between 2010-2012 made solar PV an economically attractive investment, leading to rapid growth in the market. In 2022, the combination of rising energy bills and reduced installation costs renewed the financial incentive for homeowners to adopt solar PV. Thus, economic factors have been important to the commercialisation of solar PV.

- **Importance of Policy Stability:** Consistent and supportive policies are essential for the growth of emerging renewable energy technologies. As illustrated by the solar coaster caused by the poor implementation of the FiT, sudden changes to policy can disrupt the market and slow down progress.

- **Industry Consultation is Crucial for Stable Growth:** The lack of industry consultation during the design and implementation of the FiT led to an unsustainable "solar rush" and subsequent market stagnation from 2016-2021. Engaging industry stakeholders could have helped mitigate these issues by ensuring more stable and sustainable market development. This highlights the importance of involving industry in policy planning to avoid volatility and ensure long-term success of policies.

- **Cross-Party Consensus is Vital for Long-Term Policy Stability:** The cross-party consensus during the early demonstration and pre-subsidy phase led to key government interventions, such as the publishing of the Microgeneration Strategy, the creation of industry standards, and commitment to the FiT. This alignment across political lines resulted in considerable policy and regulatory progress for solar PV and demonstrates the value of cross-party support.

- **Role of innovation:** Innovation has been key to enabling domestic solar PV to reach full commercialisation in the UK. Incremental improvements in module efficiency and power output, combined with advancements in manufacturing, have significantly reduced installation costs. Additionally, innovations in mounting systems and digital tools have streamlined the installation process.

This analysis also identified some persistent challenges that still need to be addressed for domestic solar PV to reach mass scale adoption:

- Upfront costs continue to be a barrier for a proportion of homeowners. As a result, more appealing and innovative green finance solutions will be necessary in the future to broaden accessibility.

- Installing solar PV in all new homes presents a significant opportunity to double the market by 2029.

- Strengthening the traceability of the supply chain is important to ensure the ethical procurement of solar panels in the future.

- Grid connection issues have become increasingly prevalent, indicating a need for significant infrastructure upgrades to support continued rollout in the future.

Despite solar PV's successful commercialisation, challenges to mass adoption remain, including high upfront costs, supply chain traceability, and grid capacity limitations

Implications for Heat Pump Adoption

Heat pump adoption is significantly behind that of solar PV, with just over 39,000 MCS installations in 2023 compared to 183,000 for solar PV.

Heat pumps remain in their supported commercial stage of development, still relying on government support to be competitive within the wider heating market. This report examined the reasons why heat pumps have fallen behind solar PV in terms of deployment and commercial maturity, identifying the following key reasons:

- Heat decarbonisation was addressed later, partly due to less stringent early climate targets and delayed policy interventions.
- Solar PV benefited from strong financial incentives like the FiT, making it a more attractive investment. In contrast, heat pumps have lacked a similar financial incentive, as they are more expensive to buy than gas boilers, and historically, have also been more expensive to run due to the high price differential between electricity and gas.
- The cost of installing solar PV has decreased significantly due to reductions in hardware costs. In contrast, there is a 'transitional' cost associated with changing any heating system. Consequently, the upfront cost of heat pump installations remains high due to high labour costs.
- Public awareness and trust of heat pumps has historically been much lower than for solar PV. This has been exacerbated by misinformation in the media, which has contributed to lower adoption rates.
- The Renewable Heat Incentive (RHI) for heat pumps was less effective than the FiT, leading to slower market growth in the 2010s. It has only been recent changes to the Boiler Upgrade Scheme, a properly designed and appropriately implemented scheme, that has triggered steady growth in the market.
- The heat pump industry faces stronger lobbying against it compared to solar PV, particularly from the oil and gas industries. This has resulted in delays to policy support for heat pumps, as hydrogen for heating is being advocated as a viable solution to home heating.

To overcome these challenges, the heat pump sector must learn from the successes and setbacks of solar PV. Key lessons include:

- The importance of stable, long-term policy frameworks that provide confidence to industry.
- Introducing economic incentives that make heat pumps more financially attractive to homeowners, similar to the FiT for solar PV.
- Implementing public awareness campaigns to build consumer trust and drive adoption.
- Addressing practical barriers such as:
  - Reducing installation costs through innovation.
  - Improving the green finance offer to make the technology accessible to a wider range of households.
  - Enhancing skills and training programs to build a robust workforce.
  - Revising regulatory frameworks like Permitted Development Rights and ensuring grid readiness.

Recommendations

Based on the comparative analysis, this report puts forward the following recommendations:

1. **Create an economic incentive for the homeowner by making heat pumps the cheapest form of heating**
Government must address the price disparity of electricity and gas by removing social and environmental levies from electricity and moving them into general taxation. This should be paired with an extension of the Boiler Upgrade Scheme to 2035, to support homeowners with the upfront cost.

2. **Increase consumer awareness and trust of heat pumps**
Government should finance a national one-stop-shop in the UK where consumers can get personalised advice, support and information of what the best heating technology is for their home.

3. **Industry should continue to drive innovation to improve standardisation, reduce costs, and diversify the consumer offer.**

4. **Diversify supply chains and support UK manufacturing**
Government should provide grants to support more UK-based heat pump manufacturing and legislate the Clean Heat Market Mechanism to encourage boiler manufacturers to sell and manufacture heat pumps

5. **Improve the green finance offer to allow more households to transition to low-carbon heating**
Government should fund a 0% Property Linked Finance loan for heat pumps.

6. **Address the regulatory barriers to heat pumps**
The Government should continue to review the Permitted Development Rights for air-source heat pumps, announce a ban on all domestic fossil fuel heating systems from 2035, and make the decision to move away from hydrogen for heating.

7. **Foster cross-party political support for heat pumps**
The heat pump industry should continue to raise awareness and provide information to MPs across political parties to drive cross-party consensus on this issue.

8. **Invest in long-term skills development**
To build a sustainable heat pump supply chain, we need to attract more talent by raising awareness of the diverse, impactful career opportunities in low-carbon heating. This requires clear communication of career pathways, real-world examples, and targeted outreach.

Overall, the path to mass adoption of heat pumps in the UK will require a coordinated effort involving stable government support, economic incentives, industry innovation, and strong public engagement. By applying the lessons learned from solar PV, the UK can accelerate the rollout of heat pumps and eventually support its full commercialisation.

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