Industrial Strategy Challenge Fund: Prospering from the Energy Revolution

Final Evaluation Report

August 2023

Ipsos & Technopolis Group

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Contents

List of tables

List of figures

Glossary

BAU	Business As Usual
BEIS	Business Energy and Industrial Strategy
CfD	Contract for Difference
CR&D	Collaborative Research and Development
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSR	Demand Side Response
EDiT	Energy Digitalisation Taskforce
EDT	Energy Data Taskforce
ERIS	Energy Revolution Integration Service
ESC	Energy Systems Catapult
ESO	Electricity System Operator
EV	Electric Vehicles
FCA	Financial Conduct Authority
FCR	Field-Citation-Ratio
FiT	Feed-in-Tariff
IRR	Internal Rate of Return
ISCF	Industrial Strategy Challenge Fund
IUK	Innovate UK
MEDA	Modernising Energy Data Access
MEDApps	Modernising Energy Data Applications
Ofgem	Office of Gas and Electricity Markets
P2P	Peer to Peer Trading
PFER	Prospering from the Energy Revolution
R&D	Research and Development
SaaS	Software as a Service
SEG	Smart Export Guarantee
SLES	Smart Local Energy Systems
TCR	Targeted Charging Review
ULEV	Ultra-Low Emission Vehicles
V2G	Vehicle to Grid

Executive Summary

Ipsos MORI, together with Technopolis, were commissioned in 2018 to undertake an impact evaluation of the Prospering from the Energy Revolution Industrial Strategy Challenge Fund programme (PFER). An evaluation baseline was established in Summer 2020 and an interim report was produced in Summer 2021. This report summarises findings from the final evaluation of PFER.

This report draws on the framework of indicators and metrics that were agreed with the Programme Team in 2019 as part of the process of developing an overarching evaluation plan. A mixed method approach was used to establish the evaluation baseline of the PFER Challenge, including an in-depth analysis of programme documentation, a review of secondary data, and surveys of organisations that had applied for PFER funding.

ISCF PFER Challenge overview

The PFER Challenge was launched in 2018 with a budget of £102.5m to develop innovative local energy systems that combine distributed energy technologies, storage, and market arrangements to provide cheaper, cleaner, and more resilient energy services for consumers. By 2023, PFER aimed to prove scalable local business models that can unlock 10 times more investment than business-as-usual, create real-world proving grounds for new products and services, and establish UK leadership in integrated energy provision. PFER set out to achieve these objectives through funding for large-scale Demonstrator projects, novel Smart Local Energy System (SLES) business models developed by Concept and Future Design and Detailed Design studies, R&D funding competitions, and funding to facilitate data sharing and access across the energy sector to develop novel applications and products through the Modernising Energy Data Access (MEDA) and Modernising Energy Data Access Applications (MEDApps). PFER also established a national interdisciplinary research and innovation capability in SLES that provided research, tools and project assistance to roll out a ‘whole-system’ approach across the energy sector (EnergyREV and ERIS).

Challenge Context

Prior to 2018, the energy policy and regulatory environment lacked specific provisions and guidance for implementing place-based approaches. Such approaches were not considered or incorporated within mainstream policy or regulation, resulting in a landscape that did not facilitate or enable viable place-based business models effectively. As a result, there was little to no recognition of, or evidence to support the unique characteristics, potential benefits, and requirements of place-based approaches in the context of achieving net-zero objectives.

In the UK, investment in place-based approaches was quite limited, largely due to the lack of recognition and understanding of the significance of such approaches, as well as the absence of clear policy or regulatory frameworks to support them. As a result, the financial commitment towards these approaches was not substantial enough to facilitate widespread development of SLES. While investment in companies with potential to contribute to SLES reached c. £437m in 2015, annual investment from 2010 to 2014 did not surpass £200m. Following changes to the national planning policy framework (which effectively banned onshore wind investment) in 2015, investment in SLES companies tailed off in the years leading up to PFER.

Collaboration across the component parts of a SLES in the UK was disjointed and siloed. There was a lack of integrative mechanisms and comprehensive strategies encompassing all parts of the system.

Hence, the interaction was limited and often, the different parts operated independently of each other rather than functioning as a cohesive unit.

Before 2018, energy system data and digitalisation were in its nascent stages. While there was recognition of the potential benefits of open data and digitalisation, its adoption across the energy sector was limited. The tools for harnessing data for insight, prediction, and automation were not yet mature, and the infrastructure to support wide-scale digitalisation was undeveloped (for example, the smart meter rollout was significantly lower than initial targets set). The true value of data was yet to be fully realised in terms of optimising energy networks, improving customer experience, and aiding in the transition towards renewable energy resources.

Furthermore, distribution-level flexibility markets were not well-established or widespread in the UK prior to PFER. The concept and mechanisms to facilitate such markets were still in the developmental or exploratory phase during this period.

At the same time, by 2018, a clear opportunity was visible across the public and private sector of the potential to integrate clean technology assets in a place - technology which largely existed and rapidly reducing in cost - and to add emerging digital intelligence techniques to effectively join up the local system under novel business models and financing. This was the opportunity that the PFER programme aimed to take advantage of to help businesses and places across the UK to prosper from the decarbonisation journey.

Throughout PFER's lifetime, there have been several external factors that have both necessitated changes to the existing centralised energy system and affected viability of place-based approaches. In 2019 the UK became the first major economy in the world to pass a law to bring all greenhouse gas emissions to net-zero by 2050. Since then, it has made several pledges to reach this target including generating all electricity from clean sources by 2035. Additionally, ongoing considerations around the policy and regulatory framework for local energy approaches have meant there remains uncertainty around the revenue streams of SLES models, for example the Review of the Electricity Market Arrangements and the Targeted Charging Review, the latter of which has substantially changed the incentives for some business models funded through PFER.

Several other factors, including significant adoption of SLES-enabling infrastructure and technologies in Great Britain, COVID-19 and the war in Ukraine have also influenced the wider context within which PFER has been delivered, such as the wider smart meter rollout and increases in energy retail prices.

Evaluation findings

1.1.1 Build UK leadership in integrated energy provision

PFER is understood to have contributed to building significant momentum around 'local' energy and local planning for delivering Net-Zero. Several projects have plans in place to further their local energy plans with support from government. This underscores the expanding magnitude of place-based strategies previously non-existent before the inception of PFER. Several notable examples of this include the West Midlands (RESO) and Greater Manchester's GM-LEM, projects, both of which will continue building on their SLES designs via devolution funding agreements. Meanwhile, the LEO and ESO projects are perceived to have impacted Oxford's net-zero agenda, while ERIS' Net Zero Go has stimulated notable enthusiasm amid Local Authorities for building successful, local zero carbon initiatives.

PFER has significantly increased understanding and created a substantial evidence base around SLES. PwC research showed that place-based approaches could save approximately £137bn in investment costs and generate an extra £431bn in energy and social benefits. Meanwhile, EnergyREV research emphasised that system savings from scaling up SLES could range from £1.2bn to £2.8bn / yr compared to not implementing SLES.

Critical findings derived from the spectrum of projects and PFER's research consortium have pinpointed the principal policy and regulatory obstacles that must be overcome to facilitate the expansion of SLES. Through targeted engagement with regulators and policymakers, PFER has influenced several policy initiatives that have supported the scale-up of SLES. Examples include

- The Strategic Innovation Fund's collaborative delivery between Ofgem and Innovate UK.
- Ofgem's requirement for networks to publish their digitalisation strategies and abiding by the best practice guidance developed by the Energy Data Taskforce . Supporting this aspect of SLES, PFER's Icebreaker One (MEDA) project led to the creation of an open energy data architecture and platform, which gained significant momentum across the energy sector with aims to open energy data access that could enable further integrated energy provision.
- Innovate UK's interaction with the broader energy sector led to the sharing of PFER insights, which influenced Chris Skidmore's Independent Review of Net Zero and advocated for local Net Zero deliverance.
- These insights also directly impacted critical Ofgem consultations on local energy institutions, governance, and distributed flexibility. ERIS, PFER's technical energy market specialists, also had a substantial impact on building capacity and capability in the sector which was previously seen as a key barrier to delivering SLES models, especially in supporting local authorities in their energy planning and in developing the Net Zero Go toolkit.

Structural changes to the energy market are still required to spread value fairly and incentivise sustainable and commercially viable business models for distributed flexibility that operate across multiple vectors (i.e., energy, heat and transport).

1.1.2 Unlock investment and economic opportunities in local integrated energy systems

PFER was effective in supporting firms to leverage follow-on private investment and develop their products and services. Firms awarded PFER funding raised £1.26bn in external funding between 2019 and 2021, of which £94m to £225m was estimated to be directly attributable to the programme. Three technology developers involved in Demonstrator projects have also been acquired by energy suppliers, indicating that assets in battery storage and energy systems management are likely to be commercialised. PFER's engagement with the National Infrastructure Bank has been influential in developing a due diligence framework aiding in de-risking investment in portfolios of other locally integrated net zero projects like SLES. Many of the PFER funded projects have since received follow-on public funding to expand on their SLES models, including for example within Greater Manchester to deliver Daikin air to water heat pumps for social housing across Manchester. More generally, PFER has led to work by PwC, UK100, Green Finance Institute, and 3Ci to understand and coordinate finance for net-zero projects. This includes quantifying private sector investment needed, studying barriers to this investment and providing guidelines for local authorities on net-zero funding and ways to bring public and private capital together.

1.1.3 Create real world proving grounds to commercialise new products and services

PFER has made substantial progress towards technology development and the commercialisation of new products and services across its portfolio, generating significant economic impacts among programme participants. PFER funding has been particularly effective in supporting firms increase their turnover, generating an additional £68m in income estimated to be directly attributable to the programme. PFER funding has led to 26 IP rights being awarded to projects across the PFER portfolio, supporting the commercialisation of seven SLES technology products within the programme's lifetime, including a 50MW battery storage system in Cowley, and integration assets developed under the ESO and LEO projects. PFER's Icebreaker One project was a key success of the programme which led to the creation of an open energy data platform used by key players in the industry. Its creation has already fuelled interest within industry to open energy data access, going some way in addressing some of the major challenges facing innovators.

Several barriers to SLES technology development persist, in particular access to household energy and network datasets needed to formulate new optimisation products and services, readiness of the market to adopt new technologies, and complexity of the system that make it difficult to sell the benefits of new disruptive technologies, particularly for large-scale integration software with multiple revenue streams.

1.1.4 Prove investable, scalable local business models

All business models improved their CRL through the programme, making good progress towards commerciality. However, most are currently unable to prove investability and scalability without ongoing policy and regulatory reform to change incompatible market structures. Nevertheless, PFER has generated important evidence around the barriers facing SLES market actors and has contributed to the wider narrative around place-based approaches to Net-Zero. PFER's ESO demonstrator successfully proved its investment case and has plans to replicate part of their PFER-funded ESO demonstration (notably missing the heat element as the heat pumps installed under the project were unable to connect to the project's transmission-based Optimisation and Trading Engine). PFER's project LEO and ReFLEX demonstrators require further demonstration work to commercialise their business models before replication plans can be developed.

The viability of PFER-funded business models relies heavily on the wider regulatory environment. Initially, market design didn't consider local needs and preferences, making it difficult for PFER projects to access benefits of consumer flexibility. This impacted the value signals for flexibility trading and feasibility of revenue streams, as well as integration of flexibility services with network management systems, limiting SLES viability. Despite this, PFER's Demonstrator and Detailed Design smart local energy systems are projected to deliver savings on both GHG emissions and consumers bills with projected greenhouse gas savings ranging from 2% to 108% and user bill savings of up to 57%, indicating significant wider environmental and societal impacts.

Acknowledging the value of SLES to energy systems and better capturing its value is required to drive future adoption of new SLES models. Whilst the wider regulatory and policy framework has started to acknowledge this, various key reviews such as REMA are still underway – hence there remains uncertainty around how SLES business models can be scaled.

Conclusions and Recommendations

Creating resilient, comprehensive business models is essential for the UK's energy systems to undergo a significant transformation towards achieving our objectives of carbon reduction and promoting clean growth. PFER's impact can be seen in the change in scale and momentum in delivering place-based approaches from before the programme was launched. Findings from across the PFER Challenge have highlighted the potential of SLES in delivering better outcomes for markets and consumers that can also provide environmental benefits. The investment community have shown interest in key aspects of SLES markets where there are well-developed commercial offerings or products that have real use-cases. The primary issues facing market actors delivering novel SLES markets relate to market structures and regulation. Until further changes to the wider policy and regulatory structures are enacted, it is unlikely that the true value of SLES can be fully unlocked, which is likely to have strong implications for additional investment in new models being rolled out more widely, and the UK's ability to deliver on its Net Zero strategy to reduce its greenhouse gas emissions while delivering positive outcomes for end consumers.

To continue the progress made by PFER and encourage the rollout of SLES solutions, recommendations are provided throughout this report. Innovate UK, DESNZ and Ofgem should consider the findings contained within this report alongside the recommendations provided in the wider research and evaluation reports commissioned by Innovate UK to provide a strong vision for energy transformation. In particular this should address the role of decentralised energy, and address the main policy and regulatory barriers highlighted by the Demonstrator and Detailed Design projects that are ultimately driving barriers to accessing finance and skilled workers. Moreover, future government-funded programmes of a similar nature should replicate elements from the PFER programme's design to streamline project delivery and maximise value-add from the interdisciplinary aspect of the programme.

1 Introduction

Ipsos MORI, together with Technopolis, were commissioned in 2018 to undertake an impact evaluation of the Prospering from the Energy Revolution Industrial Strategy Challenge Fund (PFER). An evaluation baseline was established in Summer 2020 and early outcomes presented in September 2020. This report sets out the final assessment of the outcomes of the Challenge.

1.1 Evaluation objectives

The aim of the impact evaluation was to provide a comprehensive view of the outcomes of the PFER Challenge to date. The evaluation questions defined in the Terms of Reference comprise:

- To what extent did the Challenge prove investability, scalability and replicability of SLES business models?
- To what extent did the Challenge lead to additional investment in local integrated energy systems and UK businesses?
- Was the Challenge able to create real-world proving grounds to accelerate new products and services?
- To what extent did the Challenge contribute to UK leadership in integrated energy provision?

1.2 Methodology

We adopted a mixed-method approach including:

- An analysis of IUK programme documentation, including project monitoring information, exploitation plans and stage gate documents to understand progress made by projects and issues faced.
- An analysis of publicly available statistics on the performance of the UK SLES-enabling infrastructure sectors was used to set the Challenge in context and provide further evidence of results.
- Econometric analysis of secondary data using sources from the Office for National Statistics and Pitchbook, to establish programme-level economic and investment outcomes.
- In-depth case study interviews were completed with 35 individuals responsible for projects funded through the programme, covering Demonstrator projects, Detailed Design projects, Innovation Accelerator projects, Modernising Energy Data Access and Applications, as well as ERIS and EnergyREV. These case studies investigated progress made against the initial project objectives and realisation of the outcomes outlined in the Theory of Change (see Figure 2.1).
- The evaluation was supported by consultations with 15 stakeholders internal and external to the programme to provide views on its results and explore how the context in which it was delivered has evolved. Consultees included Innovation Leads responsible for strands of the programme, members of the programme’s Advisory Board and Investment Panel, and broader policy and regulatory stakeholders in the smart local energy system ecosystem.

1.2.1 Limitations of the evaluation

For this stage of the evaluation, several specific limitations have resulted in a delay in some expected endline benefits of PFER being observable:

- **Timings of this report**: At the time of drafting this report, the large-scale demonstrators were still in the final phases of their demonstration period. This has meant that some findings from the demonstrator competition have not been reported here.
- **Impact of COVID-19 –** The pandemic has introduced a number of delays to PFER, including a slow-down of planned energy asset installations. Whilst the PFER team has responded to this flexibly and the Demonstrators and Detailed Designs funded projects have been granted the extension they requested, this has pushed back timings of the large-scale demonstrators. A reduced demonstration period for these projects has consequently pushed back some benefits that were expected to materialise in time for this final evaluation.
- **Timescales to impact –** Some medium-term outcomes and long-term impacts of PFER are not observable yet, thus the final evaluation focussed on an assessment of progress towards such long-term results. Figure 2.1 (PFER Theory of Change) highlights the stage at which the PFER programme is at in terms of observable outcomes.
- **Policy and Regulatory factors –** A dynamic regulatory and policy landscape has created continued uncertainty regarding the future market design and regulation of the energy sector in the short-term. This has dampened investor interest and constrained commercial exploitation at this final evaluation stage. Examples of this include Government policies surrounding heat and buildings, hydrogen, managing the energy crisis and bill levies.

1.3 Structure of this report

The rest of this report is structured along the following sections:

- **Section 2** gives an overview of how PFER has evolved from when it was first devised and discusses key developments in the wider context of PFER. It also provided an updated Theory of Change for PFER.
- **Section 3** provides a final update of key evaluation metrics.
- **Section 4** discusses the broader outcomes of PFER generated through PFER's key knowledge enhancement groups.
- **Section 5** discusses the programme-level outcomes of the programme in relation to systems change and environmental and economic outcomes.
- **Section 6** discusses the technological progress made by PFER funded firms and progress made in commercialising SLES technologies.
- **Section 7** discusses progress made by PFER towards commercialising SLES business models.
- **Section 8** provides our final evaluation conclusions and recommendations.

2 Challenge Overview and Context

This section describes the changes in landscape for the development, demonstration, and wider adoption of SLES since PFER was launched in 2018. The section draws on a review of the literature and public statistics available charting the recent evolution of the sector and technology area. This section also outlines recent developments of the programme.

2.1 Background

PFER was launched in 2018 with the aim of developing and proving new ways of intelligently combining distributed energy technologies with novel market arrangements that deliver consumer-centric business models in a particular location or area, that are cheaper, cleaner, scalable, investable, and resilient for the long-term. Smart local energy systems, if widely adopted, could result in system-level cost savings of around £1.2bn per year by enhancing the flexibility of electricity consumption through demand-side response (DSR) and facilitating the use of local energy storage and generation.[1]

The programme committed £102.5m to demonstrate integrated intelligent local systems which can deliver power, heat and transport to customers in cost-effective, innovative ways. Its objectives are to:

- By 2023, prove[2] investable, scalable local business models using integrated approaches to deliver cleaner, cheaper energy services in more prosperous and resilient communities that also serve to benefit the energy system as a whole.
- Unlock 10x future-investment in local integrated energy systems versus business as usual in 2020s.
- Create real world proving grounds to accelerate new products and services to full commercialisation.
- To build UK leadership in integrated energy provision.

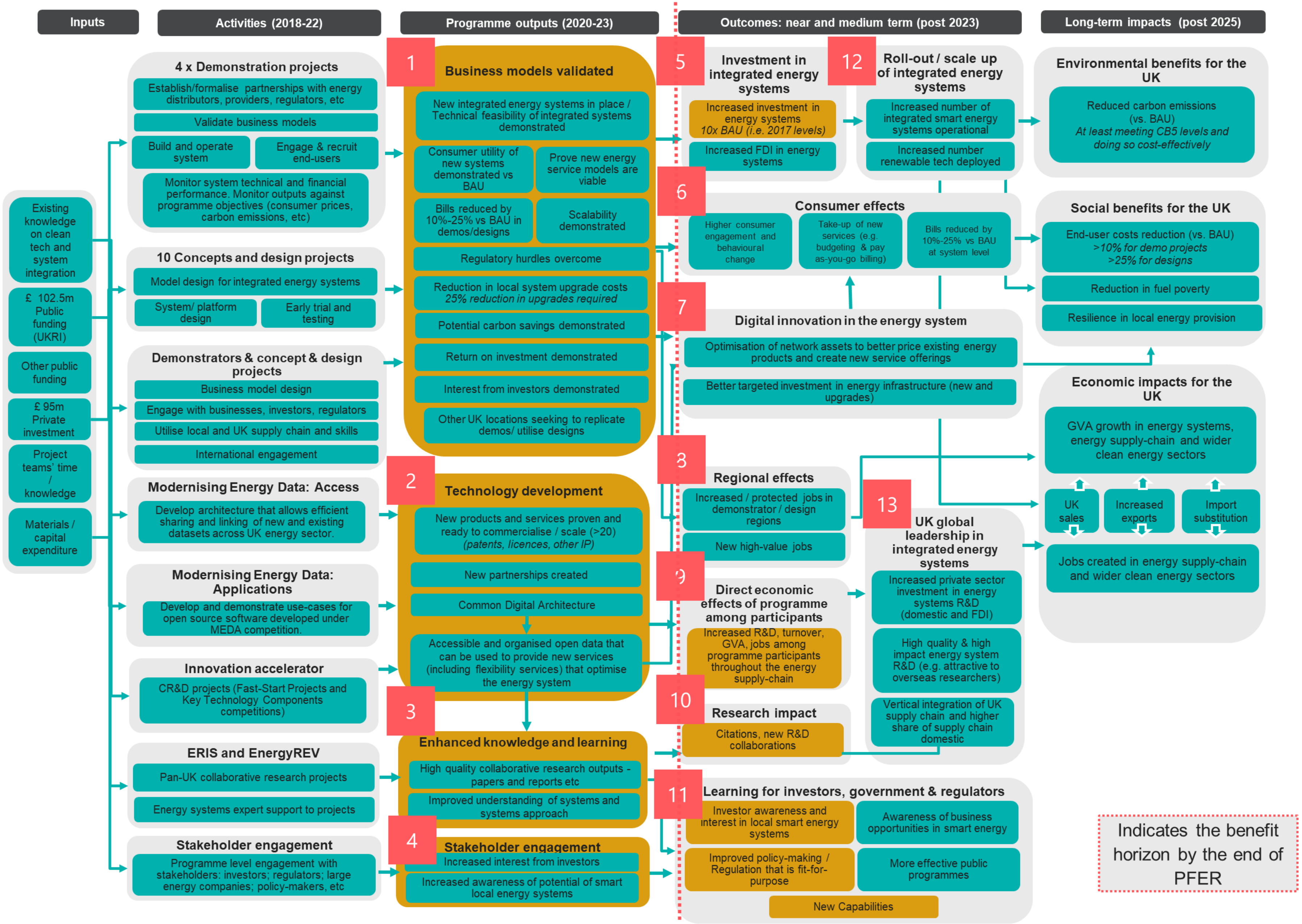
PFER addressed these objectives by bringing together real-world demonstrations in three locations across the UK, supporting Concept and Future Design and Detailed Design studies in places across the UK, a programme of R&D designed to address technology gaps, coordination of national interdisciplinary research and innovation capability in smart local energy systems (SLES), whilst creating national leadership in taking a 'whole-system' approach. PFER also funded activities to facilitate data sharing and access across the energy sector and to develop novel applications and products using this data.

A logic model representing the outputs, outcomes and long-term impacts expected from the PFER Challenge is presented overleaf (see Figure 2.1). The remainder of this report assesses the PFER Challenge's progress in achieving both its main objectives and the expected outputs and outcomes. It is to be noted that we might expect continued outcomes and impacts to continue to develop in the future

[1] M. Aunedi, T. Green (2020) Early Insights into System Impacts of Smart Local Energy Systems.
[2] As per the PFER Business Case, 'proving' business models is defined as developing a business model which integrates local energy markets in way consumers find financially rewarding and easy to engage with, and the finance community wish to scale and replicate across the UK.

since many of these are dependent on wider rollout of SLES models post 2023 which was always anticipated to take place after the funding programme was finished.

Figure 2.1: PFER Theory of Change



2.2 Contextual developments

There have been a variety of developments in the wider context for the programme that have influenced the delivery of the programme and its results.

2.2.1 Market design and policy framework

There is significant residual uncertainty around the long-term energy market design model and policy framework and how this should evolve to achieve net-zero targets. This uncertainty presents a significant barrier to testing the commercial viability of SLES business models.

Wider government policy has continued to focus on the energy sector's contribution to progressing towards Net Zero. The recent Net Zero strategy[3] sets out detailed plans to achieve this and explicitly highlights the opportunity that SLES have in delivering net-zero energy while delivering against local priorities across different sectors of the economy. There has also been increased recognition of systems approaches in work by BEIS and Ofgem including the net zero strategy and the independent net zero policy review 'Mission Zero' by Chris Skidmore in 2022. The Energy White Paper[4] set out an initial conversation on wider reforms to the electricity market and provided some initial ideas on future market design. Place-based energy planning was also recognised in Ofgem's revamped price control framework[5]. However, there remain a number of broader policy and regulatory uncertainties:

- **Review of the Electricity Market Arrangements (REMA)** - In August 2022, BEIS launched the REMA[6], introducing market design options that have the power to change the wider policy and market environment for flexibility solutions. Some of the suggested solutions include **introducing a locational pricing**, with the expectation that zonal and nodal pricing would eliminate complexity and electricity prices would reflect the relative network capacities, and creating **local distribution network led markets**, on the prediction that transmission network constrains would be significantly fewer if suppliers were encouraged to source energy generation locally[7] - also identified as a viable solution by ESC. However, the implementation of location pricing without accommodating mitigation policy measures could increase investment risk – particularly for renewable and nuclear energy. As such, this could potentially lead to a reduction in new generation capacity, which would ultimately delay progress towards a net-zero electricity system[8]. Pending a resolution to REMA, the revenue streams of any business models remain uncertain. This uncertainty stems from the fact that potential market reforms could alter the distribution of value across the system.

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[3] Department for Energy Security and Net Zero (2022) Net zero strategy: Build back greener, GOV.UK. GOV.UK. Available at: https://www.gov.uk/government/publications/net-zero-strategy

[4] Department for Energy Security and Net Zero (2020) Energy white paper: Powering our net zero future, GOV.UK. GOV.UK. Available at: https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[5] Green, K. (2022) Rema: Electricity Market Design choices, Cornwall Insight. Available at: https://www.cornwall-insight.com/rema-electricity-market-design-choices/

[6] Green, K. (2022) Rema: Electricity Market Design choices, Cornwall Insight. Available at: https://www.cornwall-insight.com/rema-electricity-market-design-choices/

[7] Green, K. (2022) Rema: Electricity Market Design choices, Cornwall Insight. Available at: https://www.cornwall-insight.com/rema-electricity-market-design-choices/

[8] Wild texas wind: Regen Insight Paper on locational marginal pricing (2022) Regen. Available at: https://www.regen.co.uk/publications/regen-insight-paper-on-locational-marginal-pricing/

- **Digitalisation of the energy sector**: This is a necessary enabler for reforming existing markets, allowing for new regulatory systems to be implemented, and facilitating a large number of smaller assets. At the start of PFER, there was limited visibility of data flows across the system and a lack of standards to establish data sharing and management. While data sharing and access remains a key barrier, several key developments have started to address these issues, including the Energy Data Taskforce (EDT)[9] and Energy Digitalisation Taskforce (EDiT)[10], both set up as a result of PFER collaboration with BEIS and Ofgem. BEIS, Ofgem and Innovate UK co-authored and published the UK's first Energy Digitalisation Strategy[11] based on the work of the EDT in June 2021.

- **Changes to the charging regime**: To recover fixed costs more efficiently, stakeholders like the Energy Systems Catapult have suggested it's necessary to rebalance fixed and volumetric charges into standing and unit prices. This would potentially help in enabling cost-reflective pricing that could support the adoption of low carbon technologies used in SLES, however any solution would need to recognise the role of flexibility providers in creating value. Further changes are needed to the charging regime to accurately reflect the value that avoiding peak demand creates for networks, allowing suppliers to generate revenue from time of use tariffs.

  Most pressing is the need for decisions on the Targeted Charging Review (TCR) and Access and Forward Charging Reform, and how these will be implemented. Both review the way in which the costs of maintaining the electricity grid are passed down to domestic and non-domestic customers, and the extent to which these costs can be priced flexibly. Changes to the TCR during the first year of PFER substantially changed the incentives for some business models, particularly project LEO. Further regulatory change is expected for the heat and transport sectors that are comparatively further behind the electricity sector, including creating new consumer offers that are desirable and accelerate the net-zero pathway.

2.2.2 Retail energy market challenges

It is estimated that by January 2023 15 million UK homes were experiencing fuel poverty[12], whilst the annual household bills rose to an average of £3,500 per year across UK households. The UK is particularly affected due to the country's dependency on imported gas, (85% of houses use gas boilers for heating), and due to the post-COVID-19 increased demand for energy, coinciding with the Ukraine war, which restricted supplies into Europe. All these factors combined have driven up the price of gas and electricity paid by providers, which has been subsequently passed on to household energy bills[13]. The steep rise in energy bills will likely aide the uptake of the SLES, as consumers are becoming more aware of their energy usage.

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[9] Energy Data Taskforce (2021), A Strategy for a Modern Digitalised Energy System. Available at: https://es.catapult.org.uk/reports/energy-data-taskforce-report/

[10] Energy Digitalisation Taskforce launches (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/news/energy-digitalisation-taskforce-launches/

[11] BEIS (2021), Digitalising our energy system for net zero: Strategy and Action Plan 2021. Available at: https://www.gov.uk/government/publications/digitalising-our-energy-system-for-net-zero-strategy-and-action-plan

[12] Fuel poverty: Updated estimates for the UK (2022) CPAG. Available at: https://cpag.org.uk/news-blogs/news-listings/fuel-poverty-updated-estimates-uk

[13] Valero, D.A. (2022) Why have energy bills in the UK been rising?, British Politics and Policy at LSE. Available at: https://blogs.lse.ac.uk/politicsandpolicy/why-have-energy-bills-in-the-uk-been-rising-net-zero/

Moreover, a lack of retail energy market reform has restricted new models of supply. The prevailing supplier hub model in the UK energy market affords suppliers the licence to dominate their engagement with consumers, thereby restricting each bill-payer to have only one licenced supplier for both gas and electricity. This structure inadvertently raises the entry barrier for innovative suppliers and complicates the integration of new systems, such as local supply frameworks, into national supplier systems. Consequently, the existing competition among suppliers is largely focused on provision of identical services at slightly varied costs, rather than differentiation in service delivery tailored to distinct consumer needs. Suboptimal capital allocation among suppliers has resulted in many exiting the market. The current model inhibits competition based on specialised services (like offering multiple suppliers for different parts of the consumers' system or incorporating efficiency measures into supply contracts), hence favouring larger suppliers disproportionately. The need for alterations in the model to accommodate more flexible, and consumer-centric competition is evident.

2.2.3 COVID-19 pandemic

COVID-19 has influenced the wider context within which PFER has been delivered, in several ways:

- Despite COVID-19 having an initially positive environmental impact due to reduced CO2 emissions, restricted mobility and reduced industrial activity **impacted ongoing energy installations, and slowed down new renewable generation**, including SLES-enabling infrastructure. Though this was largely the result of national and/or local restrictions, parts of the supply chain that depended on international trade suffered a great deal as well, causing varied implications on importing products, technology, and appliances, and so subsequently, to the progression of the energy industry overall[14].

- **Digitalising energy systems**[15]: COVID-19 had an overarchingly positive impact on promoting broader SLES diffusion. Radtke (2022) suggested that this was due to protective measures enforcing the new 'work-from-home' policy, which elicited a new awareness of digital tools and workflows as work transitioned to virtual platforms and digital technologies. During the pandemic, new smart tools appear to have proliferated mostly in the context of smart homes and smart mobility. Based on these observations, Radtke (2022)[16] argued that such newly learnt attitudes could ease the way to a broader diffusion of smart energy systems.

2.2.4 Progress on SLES-enabling infrastructure and technologies

Key developments since the start of PFER include:

- **Smart Meters**: At the start of the programme, there was a broad base of penetration with roughly 13.8m smart meters operating across Great Britain. As at the end Q2 2022, the number of operational smart meters in domestic and non-domestic settings has increased to 29.5m across Great Britain17. Smart meter rollout is an important aspect in optimising flexibility business

[14] Kuzemko, C. et al. (2020) Covid-19 and the politics of Sustainable Energy Transitions, Energy Research & Social Science, 68, p. 101685. Available at: https://www.sciencedirect.com/science/article/pii/S2214629620302607

[15] Radtke, J. (2022) Smart Energy Systems beyond the age of covid-19: Towards a new order of monitoring, disciplining and sanctioning energy behavior?, Energy Research & Social Science, 84, p. 102355. Available at: https://www.sciencedirect.com/science/article/pii/S2214629621004461

[16] Radtke, J. (2022) "mart Energy Systems beyond the age of covid-19: Towards a new order of monitoring, disciplining and sanctioning energy behavior?, Energy Research & Social Science, 84, p. 102355. Available at: https://www.sciencedirect.com/science/article/pii/S2214629621004461

[17] BEIS (2021) Smart meters in Great Britain, Quarterly Update March 2021, GOV.UK. GOV.UK. Available at: https://www.gov.uk/government/statistics/smart-meters-in-great-britain-quarterly-update-march-2021

models, such as DSR or peer-to-peer trading networks. BEIS has recently launched the smart meter data repository projects, looking at improving data access. In response to this, the Energy Digitalisation Taskforce (EDiT) made several recommendations for consumers to gain greater control over their data, including developing a consent dashboard where consumers can see who has access to their data, mandating carbon data monitoring to improve understanding of carbon impacts, and mandating smart energy assets to ensure that consumer devices function adequately18.

- **Household-scale generation**: Take-up on household-scale generation technology assets was captured through records of Feed-in Tariff [19] (FiT) commissioned installations. Records show that FiT-scale installations had risen to just under 820,000 by the start of the programme. Growth in FiT-scale installations since the start of the PFER Challenge has slowed due to the schemes closure in April 2019 – largely due to its success in reducing capital costs of installations, particularly in solar PV deployment –reaching just under 870,000 as of December 2020, and approx. 871,000 in March 2022. Growth in Feed-in-Tariff (FiT) scale installations since the start of PFER has slowed due to closure of the FiT support scheme in April 2019, which was replaced by the Smart Export Guarantee (SEG) scheme in January 2020. The switch to SEG is expected to encourage energy suppliers to develop tariffs that provide more innovative solutions, such as tariffs that works for users with EVs or battery storage, as is the case under several of the PFER funded Key Technology Component projects. The SEG scheme is only possible if the generator has a smart meter installed, requiring continued rollout of the smart meter programme if more prosumers are to be seen across the GB energy system.

- **Electric vehicles**: At the start of ISCF PFER, there were almost 20,000 Ultra Low Emission Vehicles (ULEVs)[20] licensed across the UK. There had been a marked increase in the number of ULEVs by 2022, reaching 351,000[21].A further increase is anticipated in the next decade, as new national policy banning new petrol and diesel cars will come into effect in 2030[22].

- **Distributed energy generation**: Renewables' share of electricity generation (excluding offshore wind) rose to around 22 percent at the time the programme was launched. This share has significantly increased in recent years, reaching 28.6% in Q1 2023[23].

- **Electrification of heat**: While c43,000 heat pumps were installed in the UK in 2021, the rate of instalment remains low for reaching net zero by 2050[24] and enabling wider SLES take up. In an

[18] Energy Digitalisation Taskforce publishes recommendations for a digitalised net zero energy system (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/news/energy-digitalisation-taskforce-publishes-recommendations-for-a-digitalised-net-zero-energy-system/

[19] The FIT scheme was a government programme run between 1st April 2010 to 1st April 2019, designed to promote the uptake of renewable and low-carbon electricity generation technologies. It is available for anyone who has installed, or was looking to install either solar PV, Wind, Micro CHP, Hydro or Anaerobic Digestion technologies up to a capacity of 5MW, or 2kW for CHP.

[20] ULEVs are vehicles that are reported to emit less than 75g of carbon dioxide (CO2) from the tailpipe for every kilometre travelled. In practice, the term typically refers to battery electric, plug-in hybrid electric and fuel cell electric vehicles.

[21] Vehicle licensing statistics data tables (no date) GOV.UK. Available at: https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01#ultra-low-emissions-vehicles-ulevs

[22] Gallagher, S. (2022) UK ban of petrol engined cars from 2030. Available at: https://www.evo.co.uk/electric-cars/19743/uk-ban-of-petrol-engined-cars-from-2030-oems-react#:~:text=The%20UK%20government%20has%20reaffirmed,to%20be%20sold%20until%202035

[23] 2017 -2021 data from BEIS Energy Trends https://www.gov.uk/government/statistics/energy-trends-section-6-renewables

[24] Woodward, K. (2022) The future of heating in the UK: Heat pumps or hydrogen?, Energy Saving Trust. Available at: https://energysavingtrust.org.uk/the-future-of-heating-in-the-uk-heat-pumps-or-hydrogen/

effort to scale up heat electrification, BEIS introduced the Boiler Upgrade Scheme (BUS) in 2022, aimed at supporting the decarbonization of heat in the built environment[25].

- **Artificial Intelligence**: Applications of AI can increase energy efficiency, optimization, and automation. This can potentially have significant implications for renewable energy and smart grid technologies, including more precise forecasting, more sophisticated outage alerts and improved data security[26].

- **Interoperable Energy Smart Appliances**: The British Standards Institution worked with BEIS to develop standards that require energy smart appliances to be compatible with Demand-Side-Response (DSR) activities. New standards, such as PAS 1878, should facilitate consumer choice to purchase products that can be integrated with other DSR technologies within their home. This will be a strong enabler for local flexibility markets.

2.2.5 Parallel initiatives

Several parallel initiatives have been launched since PFER started, indicating growing interest in SLES, amounting to a total of £529m in Government support for SLES – these include:

- **Ofgem's Strategic Innovation Fund (SIF)[27]**: The Strategic Innovation Fund is a £450m funding mechanism, primarily supporting energy network innovation, and was led by the SIF founding team (largely comprised by PFER team members) and delivered jointly by Ofgem and Innovate UK. The SIF funding mechanism is an evolved approach of the old NIC specifically designed for Electricity System Operators, Electricity Transmission, Gas Transmission and Gas Distribution sectors. The overarching objective underpinning the development of the SIF is to contribute towards decarbonising energy networks and subsequently creating a net zero power system by 2035 and fund innovative projects led testing novel business models on the energy networks.

- **BEIS' Flexibility Innovation Programme (FIP)** [28]: The Flexibility Innovation Programme is a £65million programme seeking to enable large-scale widespread electricity system flexibility through smart, flexible, secure, and accessible technologies and markets. Key objectives of the programme are to assess interoperable DSR, Alternative Energy Markets, and long duration storage, and to define the problems that it can solve, as well as to identify relevant constrains and dependencies, and provide evidence for future policy. FIP funds 6 sub-programmes, each of which allocates funding to its respective demonstrators, and distribution flexibility markets have evolved significantly since 2018.

2.3 Evolution of PFER

All major Challenge strands have progressed towards their completion. The programme has also been augmented throughout its lifetime, adjusting to novel insights and market requirements:

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[25] Boiler upgrade scheme (bus) (no date) Ofgem. Available at: https://www.ofgem.gov.uk/environmental-and-social-schemes/boiler-upgrade-scheme-bus
[26] The smart grid: How ai is powering Today's energy technologies: SAP insights (no date) SAP. Available at: https://www.sap.com/insights/smart-grid-ai-in-energy-technologies.html
[27] Strategic Innovation Fund (SIF) (no date) Ofgem. Available at: https://www.ofgem.gov.uk/strategic-innovation-fund-sif
[28] Flexibility innovation programme (no date) GOV.UK. Available at: https://www.gov.uk/government/publications/flexibility-innovation

- The critical role of digitalisation and data access has been recognised through a new programme strand to MEDA and develop applications utilising shared energy data. This builds on work of the (BEIS-, Ofgem- and Innovate UK-sponsored) Energy Data Taskforce led out of the Energy Systems Catapult.

- The role of ERIS has pivoted from a focus on support for PFER funded projects to offering services to a more diverse set of stakeholders, including local authorities. A central component of the new ERIS brief is the development of the Net Zero Go toolkit to support local areas and their partners in defining, designing, and deploying Smart Local Energy Systems (SLES).

Table 2.1: Overview of Challenge strands, March 2023

Challenge strand	Start date	End date	No. of projects funded	PFER funding
Place-based SLES projects				
Demonstrators	April 2019	March 2023	4	£51.3m
Concept and future designs	December 2018	July 2019	11	£1.5m
Detailed Designs	January 2020	March 2023	10	£20.5m
Technology development				
Innovation Accelerator – Fast Starts	July 2018	April 2019	17	£3.1m
Innovation Accelerator – Key Technology Components	April 2020	March 2022	16	£4.5m
Modernising Energy Data Access (all phases)	June 2020	August 2021	1 (in Phase 3)	£1.8m
Modernising Energy Data Applications	October 2020	June 2021	9 (in Phase 1) 5 (in Phase 2)	£3.54m
Open Digital Solutions competition	July 2022	March 2023	6	£1.7m
Research and Capability Development				
ERIS	September 2018	March 2023	1	£8.87m
EnergyREV	September 2018	March 2023	1	£11.7m[29]

[29] £9m core grant with £0.8m of additional, optional work packages.

3 Summary of Key Evaluation Metrics

This section provides a summary of key evaluation metrics at the final stage (December 2022), drawing on the baseline metrics set out at the baseline (Table 3.1 and 3.2 in the evaluation baseline report) . Separately, the PFER Programme Team have collected programme-level KPIs which have been submitted to the Programme Board for finalisation and will be available for review in the Programme Benefits documentation.

Table 3.1: PFER – updated evaluation metrics

Outcome Area (as referenced in the Theory of Change)	Indicator	Baseline	Source	Position at Final Stage
Smart local energy technology development and intellectual property	Technology Readiness Level (TRL) levels associated with core assets of Demonstrator projects	6-7	Demonstrator case studies	7-9
Business models validated for local energy systems	Commercial Readiness Level (CRL) levels associated with business models underlying Demonstrator	3-6	Demonstrator case studies	7.3
Business models validated for local energy systems	CRL levels associated with Detailed Design projects	3.9 (range from 2-5)	Demonstrator case studies	4.6 (range from 1-5)
Business models validated for local energy systems	No. of non-domestic users (e.g. businesses, public organisations, EV charging point operators) signed up to Demonstrators	0	Demonstrator case studies	5 – Project ESO 30 – ReFLEX 24 – Project LEO
Business models validated for local energy systems	No of households signed up to Demonstrators	0	Demonstrator case studies	57 – Project ESO 273 – ReFLEX 308 – Project LEO
Business models validated for local energy systems / consumer effects	Project network cost savings (£)	n/a	ERIS technical evaluation[30]	0 – 57.1% network cost savings in 2032

[30] Based on ERIS technical modelling. Projects established a basis of Factual and Counterfactual data, which was used to calculate 2032 end-user bills and network costs.

Business models validated for local energy systems (Environmental benefits)	Total local greenhouse gas emissions (tCO_2e)[31]	n/a	ERIS technical evaluation[32]	1.9 – 108.1% emissions savings in 2032
Business models validated for local energy systems	Local energy system upgrades/investment	n/a	ERIS technical evaluation[33]	Project ESO - £27.5m ReFLEX - £5.3m
Business models validated for local energy systems	User acceptance (% increase since baseline) of products/services developed by Demonstrators/Detailed designs	n/a	ERIS technical evaluation[34]	8% increase for ESO & 13% for ReFLEX Rest of projects had an insufficient number of users for large-scale user acceptance[35]
Roll-out /scale-up of integrated energy systems	Replication sites identified by Demonstrators	45	Demonstrator proposals, Demonstrator case studies	45
Follow-on funding	Number and % of concept and future design projects securing funding for detailed designs	n/a	Detailed Designs funders panel	5/11
PFER Challenge participants' company performance & high GVA jobs	R&D spend of participating firms in £	£1.2m (average)	Applicant survey	£419.6k (average)[36]

[31] NOx/Sox where relevant – for instance electrification of fleets in ESO demonstrator.
[32] Based on ERIS technical modelling. Project information and outcomes established a basis of Factual and Counterfactual data, which was used to model CO2 reductions by 2032.
[33] Based on ERIS technical modelling.
[34] Based on ERIS technical evaluation measuring the impact of the PFER projects on awareness and acceptance of SLES amongst residents in project areas. Respondents gave feedback on a high-level description of a SLES and five propositions outlining technologies and services that could be included in these systems.
[35] For LEO specifically, only three of the Oxfordshire respondents (n=99) that took part in the User Acceptance survey reported having any degree of knowledge of the LEO project, and only one claimed to have participated. Hence sample sizes were too small to report figures here.
[36] Endline figures should be treated with caution due to low sample sizes.

PFER Challenge participants' company performance & high GVA jobs	Turnover in £, out of which turnover £ linked to rollout or maintenance of integrated energy systems	n/a		£68m of additional turnover generated by PFER grants
Increased investment in smart local energy systems	£ of match funding committed	£n/a	UKRI monitoring information	£60.9m[37]
Increased investment in smart local energy systems	Realised co-investment	£n/a	UKRI monitoring information	£856.25m[38]

Table 3.2: Key Contextual Metrics

Contextual theme	Metric	Baseline Measure	Position at Final Stage	Source
Environmental impacts	Energy storage installed in demonstrator area (MW, additional capacity, annual (all types))	n/a	10MW – project ReFLEX 50MW – project ESO NA – Project LEO	ERIS technical evaluation
Business models validated for local energy systems	% of private EV registrations in Demonstrator area[39]	n/a	85% – ReFLEX 49.8% - project ESO and project LEO	ERIS technical evaluation
Wider investment in integrated energy systems	Equity finance (£) in energy systems and component technologies	£8,866m	~£16bn	Pitchbook
Increased investment in smart local energy systems	Private sector finance (£) in applicant firms prior to PFER funding	£151.4m (see section 5.3.2 of baseline report)	£1,26bn	Pitchbook

[37] This decrease of match funding is due to the discontinuation of the SmartHubs Demonstrator project.

[38] Includes up-front, committed co-investment, additional committed co-investment, induced or aligned co-investment and follow-on co-investment.

[39] Indication of the take up of enabling and/or participating technology

Structural changes to energy market	Changes to energy regulation	See section 4.2.5: of baseline report**Error! Reference source not found.**	See section 4.6 of final evaluation report	Literature review, desk research, interviews with wider stakeholders
Enhanced knowledge and learning of SLES	Field Weighted Citation Impact (FWCI) and Altmetrics (policy citations) for EnergyREV research outputs[40]	n/a	median of 9.26	Bibliometrics
Environmental benefits in UK	UK % of renewable electricity generation	29.2%	36.3%	BEIS[41]
Environmental benefits in UK	UK carbon emissions (MtCO2e, as established by CCC[42])	488	447	CCC[43]
Environmental benefits in UK	UK EV registrations (total/new registrations), including hybrid electric vehicles	1.5% / 4.7%	13% / 53%	DfT and Driver and Vehicle Licensing Agency[44]

[40] In order to track the progress of PFER in promoting applied research, the study team have sourced number of citations and field-citation ratio scores for EnergyREV publications. Further expanded in Chapter 7.

[41] BEIS (2021), Energy Trends Statistical Release 30 September 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1022019/Energy_Trends_September_2021.pdf updated link for final stage stat: https://www.gov.uk/government/statistics/energy-trends-section-6-renewables

[42] Committee on Climate Change (2018), Reducing UK Emissions: 2018 Progress Report to Parliament. Available at: https://www.theccc.org.uk/publication/reducing-uk-emissions-2018-progress-report-to-parliament/

[43] Committee on Climate Change (2021), Progress in reducing emissions: 2021 Report to Parliament. Available at: https://www.theccc.org.uk/wp-content/uploads/2021/06/Progress-in-reducing-emissions-2021-Report-to-Parliament.pdf updated stat at final stage: file:///C:/Users/Ioanna.fotiadis/Downloads/Progress-in-reducing-emissions-2022-Report-to-Parliament%20(1).pdf

[44] BEIS (2022), Vehicle Licensing Statistics: Annual 2022 Statistical Release. Available at: https://www.gov.uk/government/statistics/vehicle-licensing-statistics-april-to-june-2022/vehicle-licensing-statistics-april-to-june-2022

4 Build UK leadership in integrated energy provision

Through work undertaken by ERIS, EnergyREV and PFER's policy and regulatory working group, a core objective of PFER was to provide policy and regulatory leadership to position the UK further strategically as a leader in this space, providing evidence to support new business models and improve the U.K'ss international offering in integrated systems design and delivery. PFER synthesised knowledge from funded projects into relevant policy and regulatory discussions that could alleviate issues for future SLES innovators.

This section discusses how PFER was able to support the wider SLES ecosystem grow through ***stakeholder engagement*** with UK consumers, policymakers, regulators, and investors (see programme Output 4 in the ToC outlined in Figure 2.1). Furthermore, this section discusses how the Challenge, through its network of academics and technical energy market specialists (funded through the ERIS and EnergyREV strands), created a legacy of ***enhanced knowledge and learning*** (see programme Output 3 in the ToC outlined in Figure 2.1), significant ***research impact*** (see programme Outcome 10 in the ToC outlined in Figure 2.1), and provide ***learning for investors, government and regulators*** (see programme Outcome 11 in the ToC outlined in Figure 2.1).

4.1 Key findings

- PFER has been highly effective in growing the understanding of place-based delivery of net-zero projects and programmes and has generated a significant evidence base around both the implementation and the benefits of smart local energy systems. Research conducted by PwC[45] showed that locally tailored approaches could achieve dramatically improved outcomes, saving in the region of £137bn in investment cost while generating an additional £431bn in energy savings and wider social benefits. EnergyREV research[46] further highlighted the system savings potential of SLES scale out in the region of £1.2bn to £2.8bn relative to no SLES rollout. Moreover, findings from ERIS' technical evaluation showed that SLES have the potential to reduce greenhouse gas emissions by 2 to 108 percent and user bill savings by up to 57 percent.

- Insights from across the PFER portfolio have influenced various central Government policies and regulation, particularly addressing pertinent challenges facing projects at the outset related to energy data sharing and access. PFER has specifically addressed these challenges through formation of the Energy Data Taskforce which provided critical inputs into several policy and regulatory initiatives that have put the UK energy industry on a pathway to more collaborative data access and sharing.

- PFER's impact on policy and regulatory changes through engagement with key stakeholders has been a key success for the programme and has gone beyond the original expectations of the programme in terms of impact. Engagement with Ofgem has led to a number of critical impacts

[45] PwC, Accelerating Net Zero Delivery, *Unlocking benefits of climate action in UK city-regions*. March 2022. Available at: https://www.ukri.org/wp-content/uploads/2022/03/IUK-090322-AcceleratingNetZeroDelivery-UnlockingBenefitsClimateActionUKCityRegions.pdf
[46] M. Aunedi & T. Green., *Early insights into system impacts of Smart Local Energy Systems*. May 2020. Available at: https://www.energyrev.org.uk/media/1420/energyrev-newwave_earlyinsightsreport_final_202006.pdf

for SLES scale-up, including increasing funds for innovators looking to exploit opportunities in SLES through the Strategic Innovation Fund, as well as influencing key regulatory barriers that have impacted demonstrators' ability to prove commercial viability of their business models, including a recent minded-to decision communicated by Ofgem on a four-band option for Transmission Demand Residuals (advocated by the PFER team). Most notable, engagement with Ofgem has led to a full review into local energy system operation that sought to understand how to facilitate the transition to net-zero at a sub-national level and whether the institutional and governance arrangements are in place to deliver against this transition. Innovate UK's engagement with the wider energy community also led to sharing PFER insights that contributed to Chris Skidmore's Independent Review of Net Zero which advocated for local Net Zero delivery.

- PFER interdisciplinary research and capacity building teams (EnergyREV and ERIS) have delivered key research outputs that help identify some of the key barriers facing SLES actors, as well as develop tools for industry and local authorities in their local energy delivery planning. The contributions of EnergyREV have been differing in nature to that originally intended, however. There was more limited engagement with projects than anticipated due to the different nature and timescale of research (novel academic research takes significant time to deliver and publish outputs compared to industry outputs). Significant effort was made to ensure agility and rapid outputs from EnergyREV workstreams. Future programmes that establish an academic network should recognise the timescales associated with this work and encourage rapid implementation of research projects to mitigate this. ERIS activities, re-directed mid-programme, have had a substantial impact on building capacity and capability in the sector, in supporting local authorities in their energy planning and Net Zero transformation initiatives. This indicates PFER has addressed a key barrier to delivering new SLES markets and should support quicker mobilisation of local energy initiatives in the future.

4.2 Policy outcomes

Enhanced knowledge and learning across the Challenge were expected to raise awareness among stakeholders in the energy/utility sector, industry/manufacturing sectors, policymakers, regulators and the financial community. This in turn, was expected to lead to better understanding of the business and financial opportunities associated with the different business models, and potential for improved policymaking where necessary. **The Challenge made considerable in-roads in feeding learnings into Government, with a number of policy outcomes reported by the end of the PFER Challenge**.

A recent NAO report[47] recognising "serious weaknesses in central government's approach to working with local authorities on decarbonisation, stemming from a lack of clarity over local authorities' overall roles, piecemeal funding, and diffuse accountabilities." The report found that there are 45 policies and 25 funding streams from national government to support local government in achieving Net Zero, which lack coordination and are not joined up. Similarly, the Climate Change Committee has highlighted the need for local-level policies in its latest report[48] outlining policies for the Sixth Carbon Budget and Net Zero, whereas previously efforts had been at a sectoral or national level.

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[47] National Audit Office, Local government and net zero in England. Available at: https://www.nao.org.uk/wp-content/uploads/2021/07/Local-government-and-net-zero-in-England.pdf
[48] Climate Change Committee (no date). Available at: https://www.theccc.org.uk/wp-content/uploads/2020/12/Policies-for-the-Sixth-Carbon-Budget-and-Net-Zero.pdf

The PFER Challenge has undertaken work in a context of increased urgency to achieve Net Zero targets, which has helped raise the profile of the Challenge. **Work undertaken via the PFER Challenge has led to greater understanding of place-based delivery of net-zero project and programmes**, which is becoming increasingly recognised as the most cost-effective routes to decarbonisation[49]. Several specific **examples of how work funded by the PFER Challenges has influenced central Government policy were identified**:

- Work resulting from the **Energy Data Taskforce coordinated by ESC and Innovate UK[50] and launched as part of the PFER Challenge has been endorsed by BEIS and Ofgem, and the final Taskforce report has been cited by several stakeholders interviewed as a critical input into a number of policy and regulatory initiatives** (see below). BEIS and Ofgem have committed to implementing the five recommendations resulting from this work[51]. In June 2021, BEIS published the UK's first Energy Digitalisation Strategy[52] based on this work.

- **Following on from the Energy Data Taskforce, BEIS, Innovate UK and Ofgem launched a new Energy Digitalisation Taskforce (EdiT)[53]** to accelerate digitalisation of energy systems, identify gaps, and mitigate governance risks for net-zero compatible business models. **The Taskforce provided several recommendations to policymakers and regulators, which have been implemented by the likes of BEIS, Innovate UK and Ofgem**.

- Work undertaken via **the MEDA competition, in particular the data architecture established for search and exchange of energy data, has led to significant momentum across the energy sector and Government**. While take-up to the initiative has so far been restricted to a few major players in across the energy supply chain, there is growing recognition among network operators for the need to standardise data and ways of triaging their data. Whilst no formal policy documents have referenced this work yet, the open architecture established under this strand of the PFER Challenge was recognised throughout by stakeholders interviewed.

  Strategy changes within BEIS driven by personnel change meant that BEIS launched a digital spine competition[54] that sought further evidence in applying outputs of the MEDA programme across the energy system.

- More recently, the UK Government's National Digital Twin programme was launched, resulting in the creation of a Digital Twin Hub that is being delivered from the Connected Places Catapult. The Hub offers new opportunities for place-based organisations and supporting companies to launch projects focused on digital twins. Though this is not a direct impact of the PFER Challenge, **stakeholders interviewed highlighted that the learnings from the detailed**

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[49] PwC, Strategic and Economic Analysis for Net Zero – Strategic Report (DRAFT), July 2021.
[50] Energy Data Taskforce (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/impact/specialisms/energy-data-taskforce/
[51] Energy Data Taskforce: A strategy for a modern digitalised energy system (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/reports/energy-data-taskforce-report/
[52] Department for Energy Security and Net Zero (2022) Digitalising our energy system for NET zero: Strategy and action plan, GOV.UK. GOV.UK. Available at: https://www.gov.uk/government/publications/digitalising-our-energy-system-for-net-zero-strategy-and-action-plan
[53] Energy Digitalisation Taskforce launches (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/news/energy-digitalisation-taskforce-launches/
[54] As recommended within the Delivering a Digitalised Energy System report published by EDiT in 2021

designs competition were a contributing factor in establishing the need for a more concerted effort to grow capabilities in developing digital twins.

- Efforts to raise awareness of the barriers for local net zero projects in accessing finance and investment, including its **Mobilising Local Net Zero Investment report** published in partnership with the Green Finance Institute and work led by the programme's SLES Investor Panel, have **had a crucial role in informing the government's second iteration of its Green Finance Strategy** due to be published in March 2023. Regular engagement with the then BEIS Green Finance Team and a series of stakeholder workshops have enabled PFER to share key insights from projects in this area. Similar **engagement with the UK Infrastructure Bank is focussed on understanding how the bank could play a role earlier in the project development journey in actively de-risking portfolios of locally-integrated net zero projects like SLES**.

PFER is understood to have contributed to building momentum around 'local' energy and local planning for delivering Net-Zero. Examples of this include:

- **An expanding portfolio of place-based approaches to achieving Net-Zero funded through PFER**. PFER has enabled the formation of multi-disciplinary consortiums with shared objectives to deliver ambitious SLES plans. PFER led to six follow-on projects raising a total of c. £425,000 of additional government funding via the first stages of the Net Zero Living grant programme. This reflects the **growing size and scale of place-based approaches which did not exist prior to the start of ISCF PFER**.

- The updated **Smart Systems and Flexibility Plan**, published in June 2021, underlines the importance of integrating local solutions for low carbon power, heat and transport, and Government **stakeholders highlighted how influential work undertaken by the PFER Challenge has been in drafting this strategy**.

- The Climate Change Committee's '**Progress in reducing emissions' report**[55] to Parliament and the Department for BEIS' **Net Zero Strategy**[56] both recognise the **potential for local energy planning and whole-systems approaches in achieving emissions targets**.

- **Innovate UK stakeholders highlighted the importance of PFER insights in feeding into Chris Skidmore's Independent Review of Net Zero**[57] which highlights role of local delivery for the energy transition and governance framework, following meetings with PFER demonstrators and team in Oxford. The review's findings into local area energy planning have fed back into the PFER Challenge with ERIS and PFER team reviewing LAEP activity and ways of planning for decarbonisation as a continuing function.

PFER has also significantly contributed to expanding the evidence base around both the implementation and the benefits of smart local energy systems. Key insight reports have provided

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[55] Climate Change Committee, *Progress in reducing emissions: 2023 Report to Parliament*. June 2023. Available at: https://www.theccc.org.uk/wp-content/uploads/2023/06/Progress-in-reducing-UK-emissions-2023-Report-to-Parliament.pdf
[56] BEIS, *Net Zero Strategy*. October 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf
[57] Chris Skidmore, Independent Review of Net Zero. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1128689/mission-zero-independent-review.pdf

important evidence to support the argument for local net zero energy planning and have directly fed into Ofgem's latest consultation on regional system planning[58] and other key outputs including the Skidmore Independent Review of Net Zero. Examples include:

- Reports produced by Regen[59] provided important thematic insights related to skills and capabilities, data and digitalisation, policy and regulation and finance and investment in smart local energy systems. The research identifies successes in each of these thematic areas while also highlighting barriers that remain and recommendations to unlock the full potential of place-based energy approaches.

- Research commissioned by the programme from PwC[60] highlighted the social costs and benefits from place-based approaches to meeting the Climate Change Committee's Sixth Carbon Budget. The research modelled for the very first time the direct and spillover benefits of tailoring decarbonisation actions for place to HMT green book standards. This showed that locally tailored approaches could achieve dramatically improved outcomes, saving in the region of £137bn in investment cost while generating an additional £431bn in energy savings and wider social benefits.

- Other specific PFER Challenge results were cited by Government stakeholders as being influential in driving forward thinking around how to achieve Net Zero – including ERIS' paper on investment in SLES[61] and outputs produced by EnergyREV. EnergyREV have also strengthened the case for place-based approaches through outputs produced that highlight the system cost savings of flexibility provided by SLES is in the region of £1.1bn and £2.5bn (should SLES be rolled out and scaled)[62].

Enhanced knowledge and learning generated across the programme is expected to raise awareness among the stakeholders and investors in the energy/utility sector (including those associated with the Demonstrators, and Detailed Design projects themselves), industry/manufacturing sectors, policymakers, regulators, and the financial community. In turn, this should lead to better understanding of the business and financial opportunities associated with these models, and potential for improved regulation and policymaking where necessary.

4.3 Working with regulators

The increased knowledge and understanding of the market dynamics of local energy systems and their interplay with regulation was expected to lead to better decisions in the energy market made by industry, government, regulator(s), local and regional bodies, communities and individuals. This in turn, was expected to lead to changes in both regulation and market structures to support and enable local energy

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[58] Ofgem, Future of Local Energy Institutions and governance. March 2023. Available at: https://www.ofgem.gov.uk/sites/default/files/2023-02/Future%20of%20local%20energy%20institutions%20and%20governance.pdf
[59] Regen, Smart Local Energy Systems: Insights from the UKRI-funded innovation projects. February 2023. Available at: https://regensw.wpenginepowered.com/wp-content/uploads/InnovateUK-smart-local-energy-systems-insights-summary.pdf
[60] PwC, Accelerating Net Zero Delivery, *Unlocking benefits of climate action in UK city-regions*. March 2022. Available at: https://www.ukri.org/wp-content/uploads/2022/03/IUK-090322-AcceleratingNetZeroDelivery-UnlockingBenefitsClimateActionUKCityRegions.pdf
[61] Insights and comment (2022) Energy Systems Catapult. Available at: https://es.catapult.org.uk/comment/
[62] EnergyREV, Benefits of flexibility of Smart Local Energy systems in supporting national decarbonisation. May 2022. Available at: https://www.energyrev.org.uk/media/1965/energyrev_flexiblesystemimpacts_202205_final.pdf

systems to flourish in the UK. **The PFER Challenge has already made several contributions to the wider regulatory regime**.

Following intensive efforts by the PFER Challenge, in particular the Policy and Regulation Working Group and the ERIS team, **the Challenge is now in regular exchange with key stakeholders at Ofgem. This engagement with Ofgem has already led to a number of critical outcomes**:

- Engagement with Ofgem on their RIIO-2 network price control has led to **Ofgem and UKRI partnering on the Strategic Innovation Fund**[63], a £450 million envelope to invest into energy network innovation from 2021-2026, which is now run by Innovate UK's energy innovation team.
- Based on the **work undertaken by the Energy Data Taskforce, Ofgem are now obliging networks to abide by best practice guidance developed by the Taskforce**[64].
- The **work undertaken by the Energy Data Taskforce has also led to Ofgem requesting and publishing digitalisation strategies of DNOs and other network actors**, to facilitate development of novel services and business models using energy data[65].
- **A recent minded-to decision communicated a four-band option for Transmission Demand Residuals (TDR), a solution that had been advocated by the PFER Challenge**.[66] This has enabled multiple SLES projects' business models, including that of the Energy Superhub Oxford Demonstrator. Where originally a flat fee connection was the incumbent model (costing smaller energy asset owners the same as large power stations), the four-band option supports business models with smaller energy assets. Despite this, the Ofgem's TCR does not address issues related to peak and off-peak energy charges (see section 4.6.)

Engagement with Ofgem has also given impetus for a full review into local energy system operation. In 2022, Ofgem was seeking views from industry and local authorities to better understand how the energy system is planned and operated locally, recognising that local power grids are expected to play a greater role in meeting net-zero and delivering benefits to consumers. The Call for input sought to understand how to facilitate the transition to net-zero at a sub-national level, whether the institutional and governance arrangements are in place to deliver against this transition and explore alternative options. Several organisations involved in the delivery of PFER-funded projects have so far provided inputs to the review, including organisations such as EMEC and SSEN that lead the ReFLEX and project LEO demonstration projects, respectively. The full consultation was run in 2023 alongside a call for input on the role of distributed flexibility. In this call for input, a common vision for distributed flexibility is proposed that hinges on a common digital energy infrastructure. Feedback on three potential models is sought, alongside consideration of delivery means, financing methods, market issues, and wider energy system capabilities necessary to unlock distributed flexibility.

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[63] Strategic Innovation Fund (SIF) (no date) Ofgem. Available at: https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/network-price-controls-2021-2028-riio-2/riio-2-network-innovation-funding/strategic-innovation-fund-sif

[64] 64 Data Best Practice guidance - ofgem.gov.uk (no date). Available at: https://www.ofgem.gov.uk/sites/default/files/docs/2021/05/data_best_practice_guidance_v0.3_0.pdf

[65] Digitalisation strategies for Modernising Energy Data (no date) Ofgem. Available at: https://www.ofgem.gov.uk/publications/digitalisation-strategies-modernising-energy-data

[66] This decision was under public consultation until July 2021, with implementation of the new TCR regime delayed to April 2023: https://www.ofgem.gov.uk/publications/cmp343-consultation-minded-decision-and-impact-assessment

Furthermore, **Ofgem's consultation on the future of local energy institutions and governance** commenced in April 2022, highlighting the need to modify sub-national governance arrangements to achieve net zero cost-effectively. The current consultation forms part of this review, seeking stakeholder views on proposed arrangements, design decisions, and inviting data contributions for an impact assessment of these reforms.

4.4 Collaborative Research in Integrated Energy Provision

EnergyREV focussed efforts on enhancing applied research and research partnerships within academia that took a whole-systems focused approach to research that considered the interdisciplinary aspect of SLES. To achieve these objectives, EnergyREV built a network of academics who collaboratively produced insights about SLES. The diversity of academic backgrounds combined with the adaptation of their research into various formats beside the typical academic publication enabled them to disseminate knowledge to a broad audience of wider stakeholders outside of the Challenge.

EnergyREV has created thematic/topic led consultations with PFER projects using a variety of engagement mechanisms. These have been both collaborative work (e.g. with Demonstrators during lifetime of their project to date) and shorter targeted forms (e.g. request to all PFER projects to complete a survey).

Feedback across PFER strands suggested that there was limited immediate value for PFER projects in engaging with EnergyREV, potentially a result of engagement activities with projects not always being project-oriented or designed to provide support to the specific project delivery. There was also evidence of EnergyREV not communicating their insights and outputs effectively to projects. This is likely explained as EnergyREV outputs have been delivered after project delivery as their novel academic research has taken time to deliver (conducted simultaneously with PFER projects).

EnergyREV produced a large body of publication, following some delays in establishing the EnergyREV partnership across all academic groups involved.

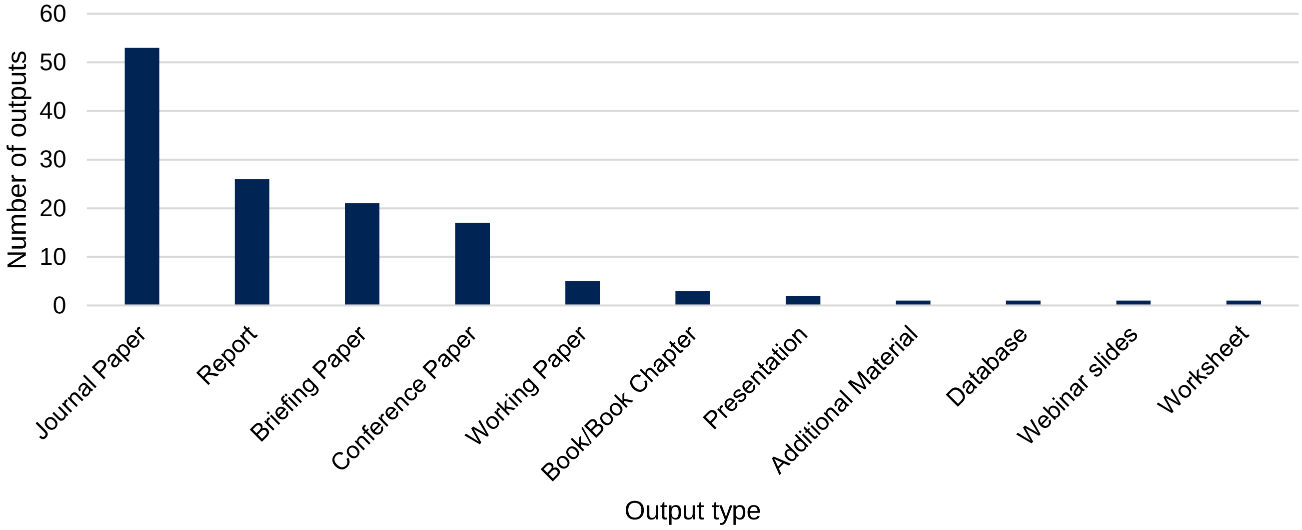
Despite this, **bibliometric analysis suggests that EnergyREV publications already achieved a higher-than-average citation score, compared to similar publications not funded by PFER** (note that citation impact is cumulative, and hence this is expected to increase further over time). **There were also early signs of policy impact, with the World Bank, OECD and other international organisations citing EnergyREV publications**.

Furthermore, two follow-on academic programmes have since been launched off the back of the work undertaken by the wider EnergyREV team, as well as having informed EPSRC thinking about how research programmes such as EnergyREV can and should function.

4.4.1 Nature of EnergyREV publications

Since 2019, the consortium has produced 131 outputs in various formats (See Figure 4.1). Existing outputs provide evidence against PFER's business models, opportunities linked to scaling up SLES, and successful models (or unsuccessful models) for scaling up SLES. A core strand of EnergyREV work and outputs has been dedicated to developing a definition of SLES, how to scale SLES, and how this can measured.

Figure 4.1: EnergyREV outputs published by November 2022



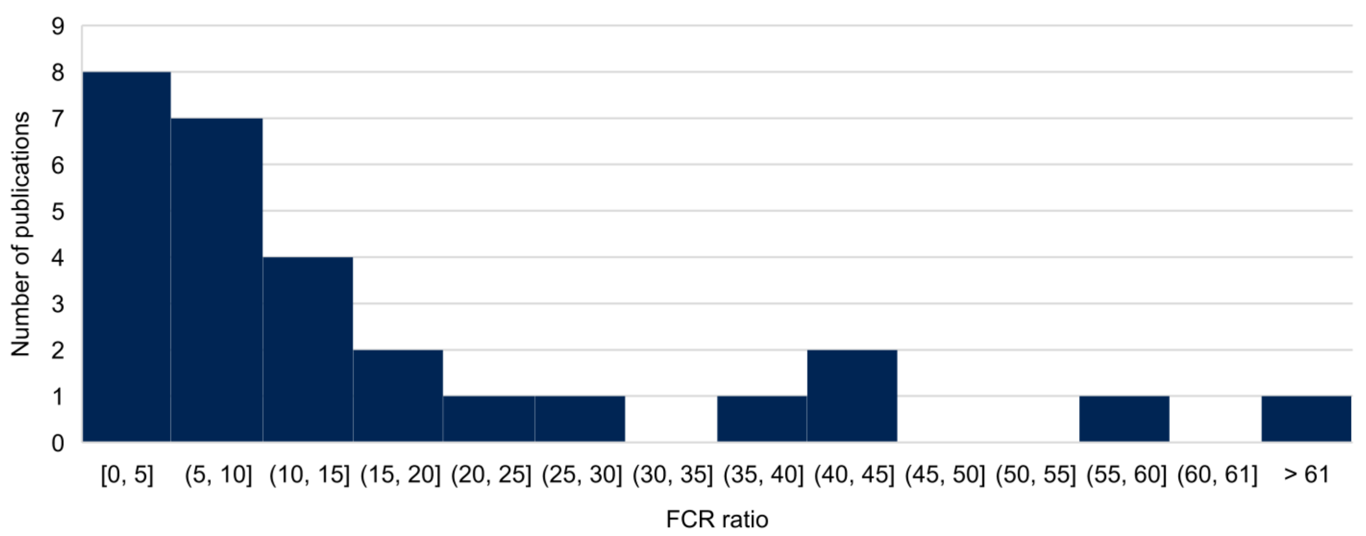
Source: EnergyREV

4.4.2 Number of citations and Field-Citation-Ratio (FCR)

In order to track the progress of PFER in promoting applied research, the study team have sourced number of citations and field-citation ratio scores for EnergyREV publications. It should be noted that here the limited number of publications and relatively short timeframe that they have been in circulation. The majority of EnergyREV outputs have had limited citations per output to date, reflecting the short timeframe they have been in circulation.

Of the 28 EnergyREV publications that have a field-citation-ratio (FCR) (scores are only made available once a publication has been in circulation for at least two years), only two have a ratio less than one. All other outputs have a ratio higher than one, meaning the majority of publications have a higher-than average number of citations for their field. In fact, most outputs are outperforming their field average quite significantly (see figure 4.2) with a median FCR of 9.62.

Figure 4.2: EnergyREV publication FCRs



Source: Dimensions data

There is growing recognition of EnergyREV outputs in policy making, through citations by international organisations such as the World Bank, the Organisation for Economic Co-Operation and Development, the International Institute for Sustainable Development and the Stockholm Environment Institute. EnergyREV's Hepburn et al (2020) review of COVID-19 fiscal recovery packages on climate change progress has been widely cited, reflecting on national climate change strategies that can be implemented to recover from the effects of the COVID-19.

4.5 Uptake of systems approach and local area energy planning

By using robust data analysis to create integrated local energy plans, decarbonisation can be driven through coordinated investment in energy infrastructure from a whole systems perspective, avoiding isolated action. **The ESC, through the ERIS programme funded by PFER, has contributed directly to the wider uptake and understanding of such a systems approach**.

Since 2018, the activities of ERIS pivoted from supporting PFER projects to disseminating knowledge generated by PFER to a broader audience. The PFER team played a key role in repositioning ERIS activities, showing awareness of changes in the wider programme context and recognising significant capacity gaps at the local authority level which presented critical barriers for wider replication and scale-up of any SLES technologies or business models across the UK.

More recent ERIS activities focussed on supporting local authorities to help implement systems-based approaches to local area energy planning and SLES projects (in response to key reports from the Climate Change Committee and Public Accounts Committee) suggesting a focus on building capacity and capabilities of local authorities to deliver local action against the national Net Zero targets.[67][68]

ERIS activities have had a substantial impact on building capacity and capability in the sector:

- **The Net Zero Go[69] knowledge sharing and advice platform** is currently being used by over 100 local authorities across England, and has received follow on funding through BEIS' to continue operations.

- **Capacity building and support offer for local authorities** – working with Oxford County Council to apply the SLES toolkit and Local Energy Asset Representation model for local area energy planning – this will help Oxford Country Council to identify potential SLES projects to implement, taking account of the building stock, existing energy networks, heating technologies available, electrification of transport, and local spatial constraints. Further engagement with the capacity building offer was evidenced through workshops and events, including Oxford City, Peterborough, Orkney, Greater London Authority and Greater Manchester Combined Authority.

- **Engaging a group of institutional investors in the development of a due diligence framework** for system level investment propositions and supporting local authorities in using this framework to develop proposals. This framework is now being used to structure investment

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[67] Climate Change Committee (2020), Local authorities and the Sixth Carbon Budget. https://www.theccc.org.uk/publication/local-authorities-and-the-sixth-carbon-budget/
[68] Public Accounts Committee (2021), Achieving Net Zero. https://publications.parliament.uk/pa/cm5801/cmselect/cmpubacc/935/93502.htm
[69] Net zero go (2023) Energy Systems Catapult. Available at: https://es.catapult.org.uk/tools-and-labs/our-place-based-net-zero-toolkit/net-zero-go/

propositions using a common approach, facilitating engagement with potential investors for SLES projects.

- **Continued engagement with projects** –the Local Energy Asset Representation (LEAR) modelling tool was used to help Demonstrator and Detailed Designs projects to plan demonstration activities and identify potential areas for scaling up roll-out of the integration and flexibility solutions developed.

4.6 Recommendations

<table>
<tr><th>Evaluation finding</th><th>Recommended action</th><th>Responsible parties</th></tr>
<tr><td>Full commercialisation of the programme’s business models continued to be led by the wider regulatory and market environment</td><td>Innovate UK, DESNZ and Treasury should consider the recommended actions provided through research produced by organisations such as EnergyREV, ERIS, Regen, PwC and Chris Skidmore’s Independent Review of Net Zero to address the policy and regulatory barriers still persistent in place-based approaches to Net Zero.</td><td>IUK, DESNZ, Treasury</td></tr>
<tr><td>PFER's working groups have been effective in identifying policy and regulatory barriers related to smart local energy systems and bringing them to the attention of relevant stakeholders, resulting in improvements in the policy and regulatory landscape.</td><td rowspan="2">IUK should continue to use working groups or similar mechanisms to engage with the relevant policy and regulatory stakeholders and identify barriers to innovation in emerging areas in the smart local energy systems space.

Future UKRI programmes with high dependency on the regulatory environment might benefit from setting out a structured engagement plan with regulators at the outset.</td><td rowspan="2">IUK</td></tr>
<tr><td>Establishing a direct line of communication between a government programme's projects and policy and regulatory stakeholders can facilitate efficient and timely addressing of issues that arise.</td></tr>
<tr><td>Feedback across PFER strands suggested that there was limited immediate value for PFER projects in engaging with EnergyREV, potentially a result of engagement activities with projects not always being project-oriented or designed to provide support to the specific project delivery. This was due to the timing of research activities misaligning with project delivery of funded PFER projects.</td><td>IUK should ensure that future programmes that incorporate inter-disciplinary research services with technology development and/or large-scale demonstration projects are more project oriented. This could involve providing feedback on research proposals, setting priorities for research activities, and facilitating connections between the consortium and relevant experts. More strategic planning/staging of research activities and project delivery would enable better engagement across the network.</td><td>IUK</td></tr>
</table>

5 Unlock investment and economic opportunities in local integrated energy systems

The outputs of ISCF PFER were intended to deliver several programme-level outcomes. Most of these outcomes were expected to materialise several years beyond the end of PFER. This evaluation has explored the presence of several outcomes that were expected to be achieved towards the end of ISCF PFER, including increased R&D, turnover, and employment among programme participants. In addition, leveraging additional follow-on investment was a core outcome for projects participating in the programme.

To the degree that firms funded through the PFER Challenge could improve the efficiency of their processes and reduce prices, or offer other advantages to customers, they will acquire a competitive advantage over other producers. This would be expected to lead to growth in turnover and outputs of the firms. These businesses are well-positioned to take advantage of the further demand arising from increased investment in local energy systems, generating business growth and high-value jobs. Additionally, the firms concerned may need to recruit additional workers to satisfy any expansion in demand.

Firms were expected to leverage additional follow-on investment as a result de-risked commercial propositions and sufficient technology development.

This section provides a final assessment of the ***direct economic effects of the programme among participants*** (see programme Outcome 9 in the programme level Theory of Change summarised in Figure 2.1) and ***investment in integrated energy systems*** (see programme outcome 5 in the programme level Theory of Change summarised in Figure 2.1).

5.1 Key findings

- PFER funding has been critical in scaling up SLES demonstrations that would not have otherwise taken place, indicating additionality of the programme. Notably, the programme has supported projects in overcoming barriers in the wider policy and regulatory environment and engaging with relevant policy and regulatory stakeholders to demonstrate the impact of existing market structures on SLES viability.

- PFER funding has demonstrated its usefulness as a supportive means for funded firms to establish new partnerships that would not typically collaborate under existing market structures and business models. The impacts of this have been new opportunities and access to markets that organisations can now participate in which would not have occurred otherwise. There have been several instances where PFER funding has served as a catalyst for the further development of PFER-funded ideas, as well creating new opportunities beyond PFER.

- PFER funding has been an important instrument in supporting firms leverage additional investment to develop and commercialise their products and services. Firms awarded PFER funding raised £1.26bn in external funding between 2019 and 2021, of which £94m to £225m was estimated to be directly attributable to the programme, indicating that every £1 of public spending has helped funded firms leverage an additional £1.07 to £2.56 of equity investment. This indicates there is strong interest from the investment community to provide private funding in SLES-related products.

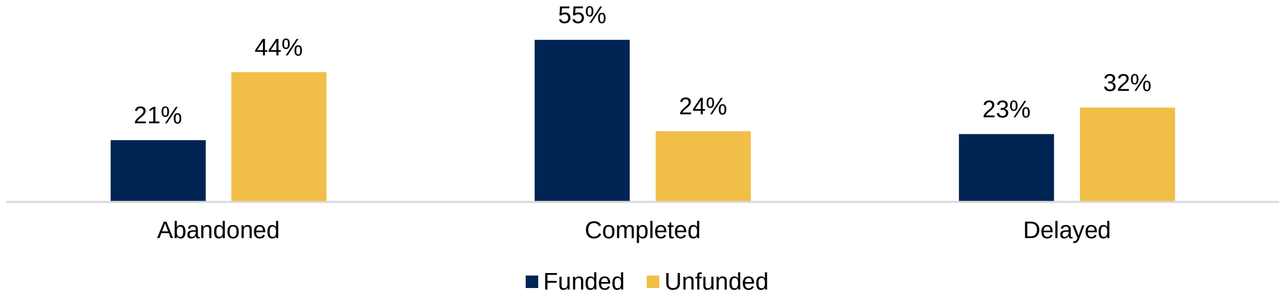
- PFER has proven to be particularly effective in supporting firms to acquire a competitive advantage over other producers through the development of products and services. PFER funding has been shown to support firms to increase their turnover, generating an additional £68m in income estimated to be directly attributable to the programme. Significant effects of grant funding on employment and productivity were not detected, potentially due to the nature of firms supported and the short amount of time elapsed for such effects to materialise. It was also shown that funded firms were able to lever additional R&D spend to develop new SLES products and services compared to unfunded firms. This presents a strong rationale for future support from Innovate UK or Central Government to provide CR&D grant funding as a way of generating additional R&D investment that can support the Government's wider Clean Growth strategy.

5.2 Additionality

Qualitative case study evidence from funded project partners of all sizes suggested that public funding was essential to deliver their projects and identified that public funding allowed them to collaborate with project partners in ways that were typically outside of BAU. Larger, more complex projects required public funding to fill the funding gap for coordination whilst smaller simpler projects required seed funding to deliver at greater scale (Figure 5.1).

Funded projects were more likely to have completed their proposed delivery tasks while unfunded projects were more likely to face delays or even abandon their project delivery.

Figure 5.1: Project status



Source: data extracted from the final stage questionnaire. Based on the sample N = 72, 36% of the projects were 'concept designs', 3% were fast tracks, 22% were detailed designs, 20% were KTCs, 8% were MEDA, and 11% were MEDApps.

The highest number of completed projects were those that were successful in receiving PFER funding (55%), whilst the highest number of abandoned projects (44%) were also those that failed to secure funding. Of the 21% of funded projects that had reported abandoning their project, seven of the eight respondents were Concept and Future Design projects, all of which reported difficulties securing follow-on finance to continue delivery of work funded under PFER. Likewise, a higher percentage of unfunded projects are currently 'delayed' (32%).

The most prevalent reason behind project abandonment for both funded and unfunded projects was down to financial barriers (70% and 73% respectively). Only two of the successful projects noted that there were additional barriers to the financial ones. These included policy and regulatory barriers, failure to meet milestones and lower user take-up than expected.

There were other elements of added value, as highlighted in interviews and case study work:

- **Scaling up demonstration activities that would have otherwise not been possible**: Challenge funding was integral in supporting projects undertake large-scale demonstrations. **Challenge funding provided the impetus for project partners to combine existing technologies in novel ways that could enable the opening of SLES markets** (for example, ESO's hybrid battery was capable of providing flexibility into the transmission market previously but had not been tested in ways that also used transportation assets to yield additional flexibility). Moreover, the high-risk nature and capital investment costs associated with delivering demonstrations such as those funded under PFER were likely to have deterred some project partners from taking part.

- **Skills, capabilities, partnerships and follow-on opportunities**: Challenge funding has allowed projects to establish close partnerships with new organisations, which in turn has supported knowledge sharing and opened up new opportunities and markets for participating organisation. **There are several cases of PFER funding having catalysed onward progression of existing ideas and development of new opportunities**. For example, project partners participating in the GreenSCIES Detailed Design project have begun the creation of a Centre for Excellence to support the development of smart local energy systems across the UK through consultancy and training. Other examples include Greater Manchester Combined Authority's partnership with Japanese firm Daikin to supply Manchester with heat pumps up to 2025, and a new international collaboration between ev.energy and Smartenit to launch a low-cost, smart EV charging cable.

- **Integration of component technologies**: Challenge funding was an important factor in developing novel integration solutions that could enable the scale up of SLES. A lack of funding and policy direction would likely have reduced the overall efforts of the industry to develop and test such solutions. **Grant funding has helped create a suite of potentially useful integration solutions that could be used in future SLES scale up**.

- **Establishment of industry-leading data platform (MEDA's Ice Breaker One platform):** The final solution developed by **Ice Breaker One provided the building blocks for a comprehensive governance framework** that enables actors across industry and wider to provide and share data. This was viewed as an essential component of future local energy area planning in regards to setting up a SLES.

5.3 R&D outcomes

Project partners funded under the Fast Start, Key Technology Components, MEDA, MEDApps, Open Digital Solutions and Demonstrators were expected to lever additional R&D into technologies needed to enable SLES and increase their technical maturity. **There are some indications that funded projects were able to lever additional R&D spend to develop new SLES products and services, however due to low sample sizes, only descriptive statistics are presented here**. Below we present descriptive findings from data gathered from baseline and endline surveys:

- **Demonstrators**: **R&D spend for Demonstrator firms increased by 14% from the baseline to an average of £1.91m**. Of this, total R&D spend, 65% was allocated to projects with a specific smart local energy system focus, compared to 25% at the baseline. Demonstrator projects saw a 32% decrease in the number of distinct R&D projects from the baseline. **The proportion of distinct projects that were SLES-focused increased from 24% to 33% suggesting SLES projects have come to the fore for these organisations**. There was no change in the number of R&D staff employed between baseline and endline, however, **the proportion of R&D staff that were working on SLES-specific projects increased by 52%.**

- **Fast Starts:** R&D spend for Fast Start applicants have increased their R&D spending by 44% from the baseline to an average of £270,000. Of this total R&D spend, 85% was used to develop component technologies and 15% was invested in user testing and trialling new products or services. **Although Fast Start applicants have increased their overall R&D spend, this has mostly not been directed towards specific SLES projects**: by the 2021/22 financial year, only one project had R&D programmes ongoing relating to SLES employing 3 full time equivalent staff.[70] **This may be due to the tangential nature of the focus of the Fast-Start projects to SLES**.

- **Concept and Future Designs: Successful applicants to Concept and Future designs have increased average R&D spending more than fourfold since the baseline**, to £249,000. Projects have invested most R&D spend (25%) into developing new business models and energy service models, with further spending shared fairly evenly across user testing and trialling new products/services, development of system integration and development of component technologies. On average, successful applicants were involved in more R&D projects related to SLES compared to unsuccessful applicants. On average, each applicant is working on 2 programmes of R&D relating to SLES as of the 2021/22 financial year, employing an average of 5.5 full time employees. Unsuccessful applicants have also increased the R&D spending since the baseline, although one project has a significantly higher R&D than the rest. Excluding this outlier, **R&D spend for unsuccessful applicants has risen by 61%**, with projects working on an average 1 programme of R&D related to SLES by the 2021/22 financial year.

- **Detailed Designs**: Successful Detailed Designs applicants are spending an average of £373,000 on R&D, **a tenfold increase from the baseline. Unsuccessful applicants have modestly increased their average R&D spend by 22%** to £60,000, a smaller increase compared to those funded by PFER. Successful projects primarily allocate R&D spend to developing new business models and energy service models, and developing system integration. They were working on an average of 2 programmes of R&D relating to SLES in the 2021/22 financial year, using an average of 6.7 full time equivalent members of staff. In contrast, unsuccessful applicants have no ongoing R&D programmes relating to SLES.

- **Key Technology Components: R&D spend for projects that successfully applied for PFER funding has remained relatively unchanged**, **decreasing by about 7%** to £100,000 on average. **Average R&D spend of unsuccessful projects has declined more strongly, by 22%,** to £62,600. Successful projects invested most R&D spend into developing new business models and energy service models, while unsuccessful projects have spent most on user testing and trialling new products. Successful projects were working on slightly fewer SLES programmes of research in 2021/22 compared to unsuccessful applicants, but both were working on roughly 1 programme of research.

- **MEDApps: Average R&D spend on successful MEDApps projects was £430,000, much higher than the average of £75,000 invested into R&D by unsuccessful MEDApps projects**.

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[70] This could be a result of respondents' understanding of SLES-specific projects.

Successful projects were managing slightly fewer SLES related programmes of R&D in the 2021/22 financial year but were using almost double the FTE members of staff than unsuccessful projects. **It was not possible to compare these endline results with baseline results, as the MEDApps projects had not been awarded at the time the baseline survey was undertaken**.

5.4 Economic outcomes

This section provides an overview of the findings from the econometric analysis of firm-level impacts on PFER funded firms, when compared with unsuccessful applicants. Details of the data and methodology are provided in Annex B. Results of the analysis of the econometric analysis are presented in the annex in table 8.2. These outcomes included employment, turnover, and productivity.

5.4.1 Turnover outcomes

There is a high level of confidence (at the 1% statistical significance level) that the PFER Challenge has increased firm-level turnover among grant recipient firms. The findings implied that turnover increased by around £730 for every £1000 of grant funding. Aggregating these results over the entire PFER Challenge, this equates to **£68m of additional turnover generated by the PFER grants** for recipient firms.

5.4.2 Employment outcomes

The findings showed a small but statistically significant effect of PFER funding on net employment. **The findings suggest that PFER funding did not result in significant changes in employee counts for recipient firms**, consistent with previous research undertaken by Ipsos on similar Innovate UK programmes – **any employment outcomes are likely to be observed with substantial lag after the end of the PFER Challenge** and more substantial outcomes on employment are therefore likely to be observed beyond this current evaluation.

5.4.3 Productivity outcomes

No significant productivity outcomes were found in the analysis. Again, this is consistent with past research – firms that typically apply for Innovate UK funding are small and in early-growth stages. These firms tend to have lower productivity than larger firms and **we would expect productivity outcomes to only be observable at a later stage, well beyond the lifetime of the PFER Challenge.**

5.5 Equity investment in SLES

Increased awareness of the potential of SLES and the de-risking of commercial propositions was expected to increase investors' willingness to invest in both the scale-up, replication and commercialisation SLES business models, as well as firms that provide technical solutions to SLES markets. The proceeding section discusses the extent to which the programme's medium-term outcomes (see Figure 2.1) related to wider investment in integrated energy systems across the UK has been achieved.

5.5.1 International trends in equity investment in SLES relevant companies

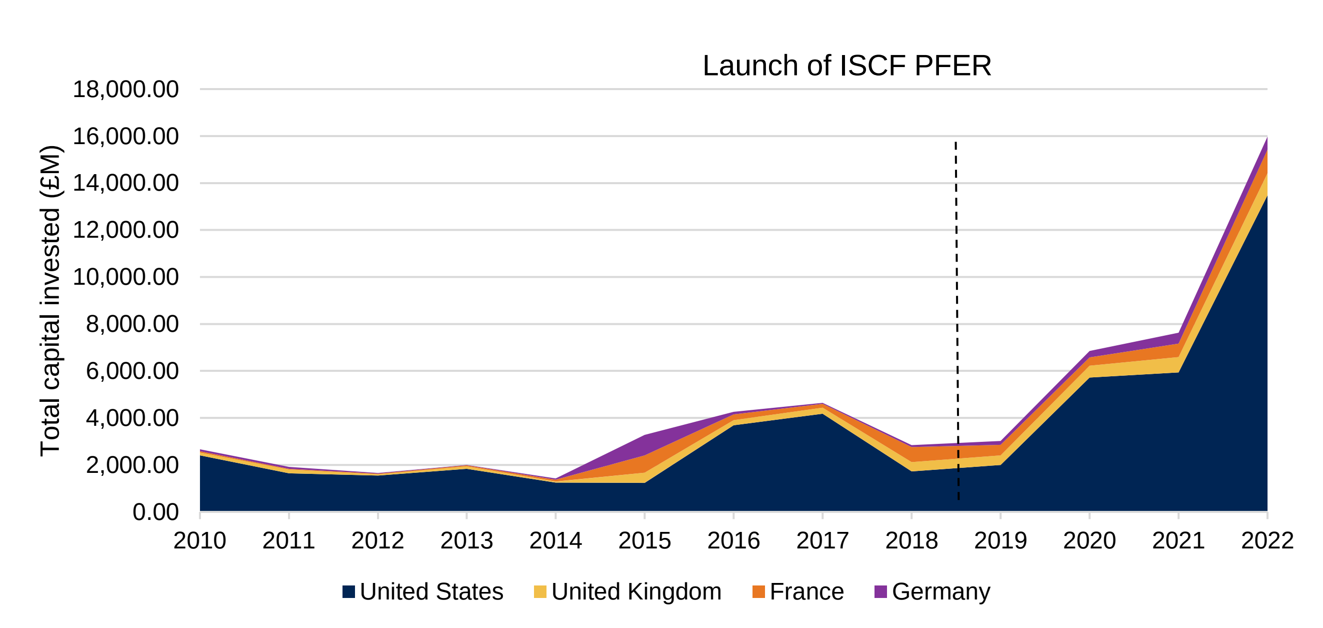
Figure 5.2 illustrates the trends in equity investment (spanning venture capital, growth capital from private equity funds, and fundraising from capital markets) in energy systems and smart energy companies from the UK, US, France, and Germany between 2010 and 2022. **Equity investment in**

SLES companies across these countries has risen substantially since the launch of PFER in 2018, to nearly £16bn, primarily driven by an expansion in PIPE[71] and 2PO[72] investment.

The US maintains a leading position and accounted for 80% of the capital raised since 2010. The rise in US equity investment over the period is mainly driven by significant funding raised by individual companies, including:

- **Tesla:** Tesla – a vertically integrated sustainable energy company which also aims to transition the world to electric mobility by making electric vehicles – raised £3.8bn and £1.6bn in two 2Pos.
- **NextEra Energy:** NextEra Energy – a power distributor to roughly 5m customers in Florida and a leader of innovative energy storage solutions in the US – attracted £1.5bn and £1.9bn in two separate PIPE investments.

Figure 5.2: Total equity investment (venture capital, growth capital via private equity and public fundraisings), UK, US, France, and Germany, 2010 to 2022



Source: PitchBook, Ipsos MORI user defined queries. Search criteria used: see Annex X. Only companies headquartered in respective countries.

There are indications that UK competitiveness in attracting investment in smart energy systems has risen relative to European competitors. Prior to 2018, the UK attracted a smaller share of investment (7.4%) compared to France (8.2%), but greater than Germany (5.3% in SLES relevant companies. However, since the programme was launched in 2018, the UK share has risen to 7.5% (inclusive of all investment between 2010-2022), surpassing both France (7.1%) and Germany (4.4%).

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[71] Private Investment in Public Equity (PIPE) is the purchase of stock in a public company by a private investor, usually for less than the current market price.

[72] A Second Public Offering (2PO) refers to the sale of shares owned by an investor to the public on the secondary market. These are shares that have already been sold by the company in an Initial Public Offering (IPO).

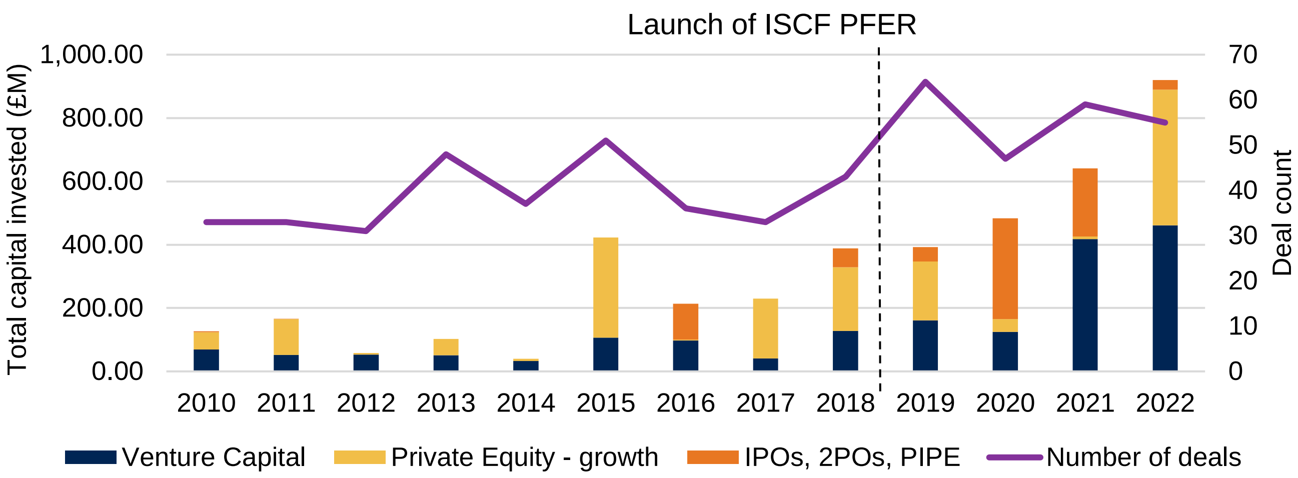
5.5.2 Investments in UK headquartered companies

Equity investment in UK headquartered companies relevant to SLES increased markedly following the launch of PFER, driven by substantial growth in venture capital and PIPE funding, particularly in 2021 (see Figure 5.3). This rise was predominantly driven by significant fundraisings of single companies, including:

- **Octopus Energy:** a producer and supplier of renewable solar energy intended to enable customers to switch to green energy online – raised £475.6m in 2021 through PE growth/expansion funding.
- **Ceres Power:** a technology solutions provider and one of the foremost developers of fuel cell technology, enabling the production of clean and low-cost energy – attracted £181m of PIPE investment in 2021.
- **Onto:** an electric car subscription platform intended to offer ownership of electric vehicles without having to purchase them – raised £175m of early-stage venture capital (Series B)[73] in 2021.

The main change between 2021 and 22 was an increase in total investment, driven by a distinct return to growth capital investments that were more common in the years prior to Covid-19.

Figure 5.3: Trends in in venture capital and growth capital via Private Equity investments and public fundraisings in UK-headquartered firms, 2010 to 2022



Source: PitchBook, Ipsos MORI user defined queries. Search criteria used: see Annex X. Only companies headquartered in the UK..

5.5.3 Investment in companies funded through PFER

This section presents the final impact analysis of how far Innovate UK's funding, via PFER, has supported participants' ability to leverage further funding through the commercialisation of their innovations. The projects were funded through the: Demonstrator, Concept and Future Design, Detailed

[73] Follows seed and Series A funding rounds where private investors fund businesses past their development stage to expand market reach and meet higher levels of demand.

Designs, Innovation Accelerator Fast-Start, Key Technology Component (KTC) and Modernising Energy Data Access (MEDA) and Modernising Energy Data Access Applications (MEDApps) competitions.

Findings from a series of econometric analyses that sought to estimate the net impact of PFER in leveraging additional investment are also presented. A summary of the econometric methodology is presented in Annex B.

Private equity and Initial Public Offerings (IPO)

As of December 2022, **there were five firms that had attracted private equity investment at some point after being awarded a grant through PFER. These companies raised a total of £747.2m over nine funding rounds** and were a mixture of firms from the Demonstrator, Innovation Accelerator Fast Start and Detailed Design competitions (see Table 6.1).

More than **one third (38 percent) of the funds raised appear to be directly linked to the commercialisation of technologies being developed by PFER**. These investments were also linked to three of the four Demonstrator projects, signalling that these projects may have been successful in leveraging growth capital into flexibility systems.

All growth capital raised appears to have been invested in firms specialising in energy infrastructure provision and hardware that underpin SLES. Table 6.1 outlines the firms receiving private equity investment and their respective innovation receiving funding through PFER.

Table 5.1: PFER beneficiaries with most significant private equity investment

Company	Amount raised since grant award	Innovate UK project(s)	Investment deal purpose and attribution of PFER participation in securing funds
ITM Power – is a design and manufacturing firm specialising in integrated hydrogen systems for energy storage and clean fuel production.	£217.8m	**Smarthubs SLES** – ITM Power were involved in the fourth demonstrator funded under PFER. **Frankenstack** – ITM Power were the lead organisation delivering a Collaborative Research and Development Fast Start project. The roll out of Hydrogen Refuelling Stations and Power to Gas systems globally is expected to grow the market for hydrogen production. However, current costs of producing and maintaining an electrolyser limit the commercial viability of widespread uptake of the technology. Frankenstack sought to assess the feasibility of re-using electrolyser stack components through in-field trials.	ITM Power has been able to attract £217.8m in private equity investment since receiving funding through PFER. These funds were primarily used to enhance the company's manufacturing capabilities, particularly for the development and production of large scale 5MW electrolysers. The funding attracted does appear to be linked to scale-up of the technologies involved in ITM Power's IUK project.
Nuvve Corporation – is a developer of proprietary vehicle-to-grid (V2G) technology, allowing bidirectional charging solutions that will support the next generation of electric vehicle (EV) fleets.	£44.5m	**Project LEO** – Nuvve Corporation are one of the partner firms delivering the project LEO Demonstrator project. Their role is to provide V2G capability and smart EV chargers to the network within Oxfordshire as part of the demonstrators' testing of new products and services that create commercial opportunities for communities.	Nuvve received £44.5m in equity investment which are expected to be used by Nuvve to further develop its offerings by combining its turnkey V2G solutions with finance packages to customers, including equipment financing, V2G services, infrastructure and maintenance operations. The funding attracted appears to be linked to the scale-up and commercialisation of the firm's technology being used in Project LEO.
Invinity Energy Systems – is a producer of the vanadium flow battery that acts as a heavy-duty,	£20.5m	**The Energy Superhub Oxford (ESO)** – Invinity is delivering a 2MW / 5MWh battery, based on company's VS3 module. Their vanadium redox flow battery technology will	Invinity received £20.5m in equity investment that will be used to scale up production capabilities of its vanadium flow battery to meet commercial demand, execute on sales pipeline and assist in driving down unit costs. There appears to be a direct

stationary energy storage solution.		sit within the total 50MW 'hybrid' Lithium/vanadium flow battery system and will enable load shifting for overnight charging of fleet vehicles and the opportunity to provide services to National Grid and to trade on energy markets.	link between funds received and the scale up of operations surrounding the firm's innovation in the ESO project.
Ceres Power – is a developer of fuel cell technologies which enable the production of clean and low-cost energy. Its core technology is the SteelCell technology which uses perforated steel sheets coupled with ceramic layers to convert fuel directly into electrical power.	£289.3m	**Low-Cost Energy Vectors for a Microwave Induced Plasma Gasification System** – Ceres Power formed part of a Fast Start project aimed at trialling a microwave plasma technology that would improve the efficiency of Advanced Thermal Treatments (ATTs) and make them a more viable proposition to generate heat and power from increasing waste arisings. This project built on previously funded research with the aim of removing significant barriers to technology uptake for low carbon energy from waste using ATTs and High Temperature Fuel Cells	Ceres Power has been able to attract £289.3m in equity investment over three funding rounds, with the latest round its most substantial (£181m). Its earliest fund raising was sought to enable the firm to continue to grow its core SteelCell technology. The latest investment was a growth capital injection, aimed at growing its power system business and entering new markets, including marine applications that can decarbonise shipping. It will also enable it to cement its market position in development of technologies related to green hydrogen production. Given the outcome of the PFER funded project was that more results were required to validate the technology in its then current use-cases, there does not appear to be a direct link between the focus of the PFER-funded project and the SteelCell technology that attracted the private equity funds.
Smart Metering Systems (SMS) – is an integrated energy infrastructure company that installs and manages smart meters, energy data, grid-scale battery storage and other carbon reduction assets.	£175.1m	**Project REMEDY –** SMS are one of the competition partner firms delivering the project REMEDY detailed design project. Their role is to co-develop the system technical design, contributing to the development and validation of the project's business and financial model.	SMS raised £175.1m in development capital during a single funding round in 2021. The investment will be used to fund its contracted smart meter order pipeline and its planned grid-scale battery projects, as the company progresses its strategic goal of enabling the UK's transition to a low carbon energy economy. This does not appear to be linked to the funds received through PFER.

Mergers and Acquisitions

There have been 19 M&A deals completed on PFER funded firms since their award date. Deal values of eight transactions were not available, but some key trends can be identified:

- **Acquisitions of innovative intellectual property:** More than half (11) of the M&A deals identified were reported in this category. The acquisitions were focussed on acquisitions of companies that held mature: software solutions providing services such as energy aggregation and in-home energy analytics; and physical technology assets in areas such as battery storage, Electric Vehicle (EV) charging infrastructure and CO2 storage. Deals in this category are further explored in Table 6.2.

Table 5.2: Examples of ISCF PFER beneficiaries being acquired since 2018

Company	Acquisition value	Innovate UK project(s)
Solo Energy – was a developer of a virtual power plant offering energy storage, blockchain and peer to peer functionalities. It was acquired by SMS in 2019. SMS are a smart meter installation company and are looking to strengthen their position in the market for installing carbon reduction assets.[74]	£1m	**Project ReFLEX** – Solo Energy is a partner in the ReFLEX demonstrator project. Solo Energy is provided the battery and control software (FlexiGRID) to enable integration of the various energy assets being installed by the project (EV charging, domestic batteries, heating).
Opus One Solutions is a software engineering and solutions company that helps utilities optimise energy planning, operations and market management using its proprietary analytics software. The company was acquired by General Electric (GE) for £52.71m ($70m) in December 2021 to reinforce GE Digital's commitment to helping customers move to a sustainable grid.	£52.71m	**Zero Carbon Rugeley** – Opus One Solutions is a partner in the Zero Carbon Rugeley detailed design project and is providing a real-time energy market platform service. The service will enable real-time trading of energy that links individual local energy assets from different vectors with wholesale markets.
Pivot Power develops and operates grid-scale batteries and provide power infrastructure required for EV charging throughout the UK. Pivot Power was acquired by EDF Renewables Energy UK for an undisclosed amount and is	Undisclosed	**Energy Superhub Oxford** – Pivot Power LLP is the lead participant in The Energy Superhub Oxford (ESO) project which will demonstrate practical solutions to battery storage, EV charging and heat, by applying innovative machine learning approaches and direct connection to a transmission substation to

[74] Webmaster (2022) SMS enters 'virtual power plant' market after Solo Energy Acquisition, SMS. Available at: https://www.sms-plc.com/insights/blogs-news/sms-enters-virtual-power-plant-market-after-solo-energy-acquisition/ .

now a wholly owned subsidiary of EDF Renewables UK.		alleviate or bypass distribution network constraints.
EB charging is a provider of Evcharging and sustainable energy solutions and technologies. It was acquired by Blink charging in April 2022 for £17.88m ($23.4m)	£17.88m	**Rail-charge** – EB charging is a partner in the Rail-charge key technology component project. EB charging is providing the practical experience in installing and operating electric vehicle charging points for fleets of electric taxis and private users. They are also providing the smart load management system and supply the chargers for the project.
Moixa is a British cleantech company that develops software and hardware for better use of renewable energy. It was acquired by Lunar Energy in 2022 for an undisclosed amount to utilise Moixa's GridShare software for smart charging, fleet management and optimisation.	Undisclosed	**Smarthubs SLES** – Moixa were involved in the fourth demonstrator funded under PFER.
Flexitricity is the UK's first demand response aggregator. It was acquired by Quinbrook Infrastructure Partners in 2020 for £15m.	£15m	**Smarthubs SLES (West Sussex)** – Flexitricity was a partner in the Smarthubs SLES demonstrator project providing asset monetisation services for the project's Virtual Power Plant (VPP).
GenGame is an app. Developer creating solutions that use smart meter data to deliver insights in the domestic sector on how best to consume energy in the home. It was acquired by Chameleon Technology for an undisclosed amount to integrate their GenGame Energy Saver app into a new platform for intelligent and optimised control of energy in homes using real-time energy data insights.	Undisclosed	**M-GSEV** – GenGame has partnered with ev.energy in the M-GSEV key technology component project to integrate their in-house gamification features to the ev.energy solution, alongside newly-developed grid services to maximise grid services through technology-based and behaviour-change-based actions.

- **Attempts at creating/increasing economies of scale, or absorbing competitors to increase market shares:** Seven large deals worth a total of £9.1bn, with deal sizes between £14m and £7.6bn, focussed on consolidating the Distribution Network Operator or energy supplier market were reported. This included Western Power Networks being acquired by National Grid for £7.56bn ($10.7bn), the acquisition of Bristol Energy by Together Energy, and the acquisition of SSE Energy Services by Ovo Energy for £500m. Additionally, there was a merger between battery manufacturers Avalon and redT in April 2020. The merger between Avalon and redT created Invinity Energy Systems. PFER initially supported redT as part of the ESO demonstrator, and merging with Avalon will provide the necessary scale to expand on the battery systems installed in Oxford as part of the ESO project. The magnitude of the ESO project likely incited RedT to consider Avalon's manufacturing expertise, recognising it as a valuable opportunity for constructing scaled-up units. Correspondingly, Avalon likely perceived this large-scale venture as a chance to be involved in a business capable of demonstrating proof-of-concept at a substantial scale which likely influenced Avalon's decision to merge with RedT.

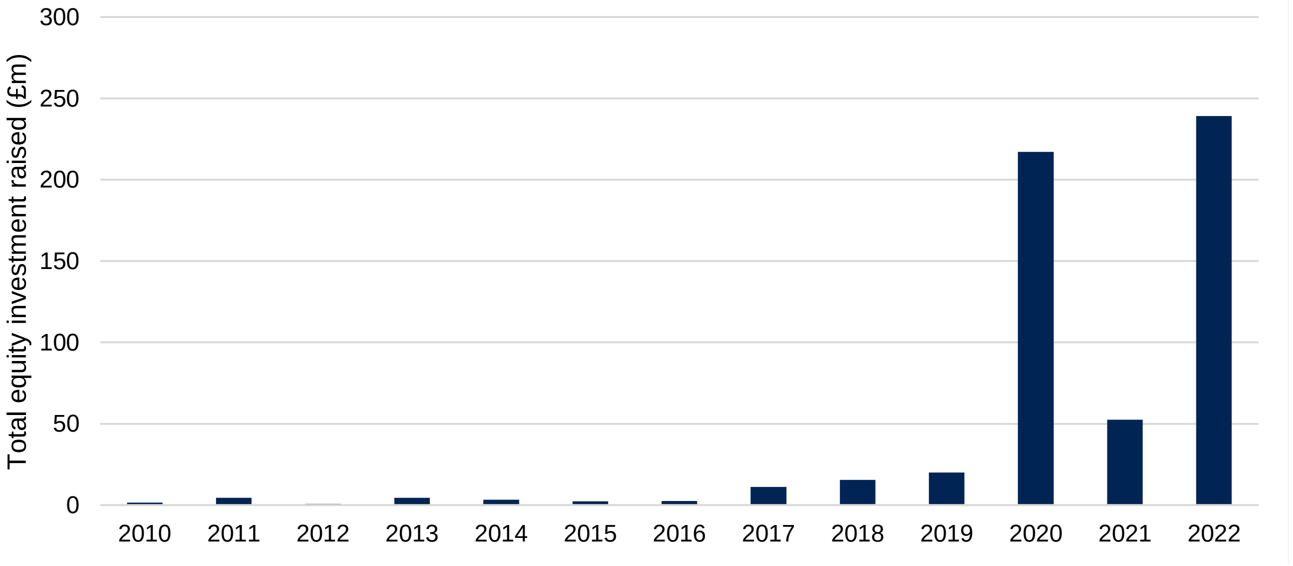
- **Reverse merger to access capital markets:** One deal was reported in this category. V2G technology company Nuvve entered a business combination agreement with Newborn Acquisition Corporation, investing around £44.5m in the process, raising around $18m PIPE and bridge financing in the process. This deal will allow the newly formed company Nuvve Holding Corp. to be traded at the US stock exchange. Again, PFER funding is likely not to have had any influence on this deal.

Angel and Venture Capital

While PFER was primarily focused on demonstrating and proving new local energy business models, technology developers participated in all of the competitions to develop or refine the physical and software technologies underpinning smart local energy systems. Data from Pitchbook showed that **a total of 24 companies secured follow-on funding from angel investors, VC funding or other forms of early-stage private equity funding after being awarded grant funding** through PFER (by December 2022). These companies **collectively raised a total of £514.19m in equity funding over 48 funding rounds.**

Companies supported by PFER were especially successful in raising funding during 2020 and 2022 (see Figure 5.4). In 2020, participants supported through the programme had raised more than £230m in private funding. This was largely driven by one late-stage VC fundraising of £180m by Riversimple. Participants were even more successful in raising funds in 2022, attracting £240m in VC, largely driven by one investment in Gridserve Sustainable Energy Limited worth £200m.

Figure 5.4: Equity funding raised by companies supported by PFER from angel investors, VC funds and other private investors (e.g. equity crowdfunding)



Source: Pitchbook.

More than 76 percent of the fundraisings (£399.3m) were by projects involved in the Detailed Designs competition, driven largely by fundraisings by Riversimple (£0.5m equity crowdfunding in mid-2020, £180m late-stage fundraising in late-2020 and £1.75m equity crowdfunding in mid-2021) and Gridserve Sustainable Energy Limited (£10m investment at venture stage in 2021 and £200m investment at venture stage in 2022). The remaining fundraisings by this group were notably smaller (ranging from £0.05m to £1.4m). **Firms that attracted follow-on funding were primarily technology developers** ranging from vendors producing hydrogen vehicles (Riversimple) to software providers developing solutions for optimisation of energy assets (Conigital and Opus One Solutions).

Firms involved in the Demonstrator strand of PFER collectively raised 11 percent of all early-stage private investments (accounting for £56.8m) over 17 funding rounds. The firms concerned were a diverse mix of smaller companies providing key technologies underpinning the Demonstrator project across the supply chain. These included developers of digital platforms underpinning the project (e.g. Habitat Energy and Piclo), installers (Kensa Contracting), and developers of energy storage systems (Connected Energy, Moixa, Pivot Power).

Press releases associated with these deals suggests that funding will be deployed to fund scale-up and international growth (rather than further investment in technology development). While it is not possible to attribute these outcomes directly to their participation in the Demonstrator programme without further evidence from those involved, on the surface, it suggests that these firms have been able to demonstrate the viability of their business model.

There was also evidence that firms involved in the Collaborative Research and Development competition strands were able to attract private investment since being awarded PFER funding. **Participants funded through the KTC competition have collectively leveraged £42.3m in follow-on funding over 21 funding rounds.** The leading companies included ev.energy (a developer of a software platform for managing EV charging across the grid, which closed five deals between 2020 and 2022 amounting to £22.0m), Evergreen (a renewable energy installation firm specialising in heat pumps and solar panels, which raised £7.7m over four funding rounds) and Minibems (a software and service platform for the performance, operation and financial management of heat networks). Deals in this category are further explored in Table 6.3.

Table 5.3: Companies raising notable levels of VC funding (£2m or more)

Company	Amount raised since grant award	Innovate UK project(s)
Gridserve Sustainable Energy: Builders and operators of hybrid solar farms to generate energy that can be delivered across the UK through its Gridserve Electric Highway to its Electric forecourts.	£210m	REWIRE DD – Gridserve are undertaking R&D into new data driven applications of their existing propositions (EV Electric Forecourt).
Riversimple: manufacturer of hydrogen-powered fuel cell electric vehicles.	£182.7m	Milford Haven DD – Under the detailed design project, Riversimple is responsible for leading on the engagement with private users of cars and small commercial vehicles to test its transport as a service business model.
Ev.energy: Developer of an energy intelligence software to manages EV charging across the grid by scheduling and optimizing charging times and loads, allowing drivers to reduce costs and carbon emissions through a user-friendly app.	£22.0m	Under the KTC, ev.energy is building upon its existing EV smart-charging solution to enable households to provide grid services, reducing the cost of EV ownership, improving the reliability of the electricity system and avoiding costly network investments.

Connected Energy: Provider of second-life battery energy storage systems for electric vehicles.	£21.55m	Under the SmartHUBS Demonstrator project, Connected Energy were responsible for developing the second life batter energy storage system at Halewick Lane.
Kensa Contracting: Operator of a specialist delivery contractor designed to the installation of ground source heat pumps in large-scale new build and social housing retrofit programs.	£11.95m	Kensa Contracting is providing its ground source heat pump heating system to approximately 100 properties under the Demonstrator ESO project, which is expected to increase the cost savings to consumers whilst reducing the grid impact of electrification of heat.
Gridserve Sustainable Energy: Builders and operators of hybrid solar farms to generate energy that can be delivered across the UK through its Gridserve Electric Highway to its Electric forecourts.	£10m	REWIRE DD – Gridserve are undertaking R&D into new data driven applications of their existing propositions (EV Electric Forecourt).
Moixa: Developer and manufacturer of home battery systems intended to offer smart solar batteries. The company's energy storage systems leverage artificial intelligence to learn about each owner's energy use and develop a unique charging plan to meet their needs and maximize savings.	£18m	West Sussex demonstrator – Moixa were an integral part of this demonstrator project, developing the aggregation system for the energy assets that were planned to be installed. KTC – Moixa will use their existing GridShare platform to develop an integrated software platform that can monitor and forecast energy demand and optimise the portfolio of assets on-site.
Evergreen Energy: a renewable energy installation firm specialising in heat pumps and solar panels.	£7.7m	Domestic Infrastructure and Network Optimisation KTC – Evergreen is responsible for software development, project management and analysis, as well as provision of a Virtual Power Plant software platform to enabled dynamic load balancing at the local network level.
Piclo: Developer of an energy management platform designed to make electricity grids efficient, reliable, and sustainable. The platform uses flexible energy markets to balance the grid from technologies such as electric vehicles and battery storage.	£6.2m	Piclo are working closely with the TRANSITION project and LEO looking at how their Piclo Flex and other digital platforms can support flexible energy trading.
Grid Edge: Developer of AI-driven energy management technology intended to intelligently control and optimize building energy loads.	£4.5m	GreenSCIES DD – GE are leading the project's flexibility package, developing the algorithms, machine learning code models for the integrated control system essential to the designs local energy network.
Habitat Energy: specialised in storage optimisation and trading, renewables and co-located storage, and portfolio and risk management.	£3.5m	Under the ESO Demonstrator project, Habitat Energy is responsible for developing the algorithm that helps Pivot Power maximise its revenues by forecasting energy prices and executing trades.
Mind Foundry: developer of AI solutions that help organisations in the public and private sectors tackle high-stakes problems, focusing on	£3.4m	MEDApps Geospatial solution for EV Chargepoint Infrastructure – Mind Foundry are building an energy-focused geospatial system that will enable the user to visualise

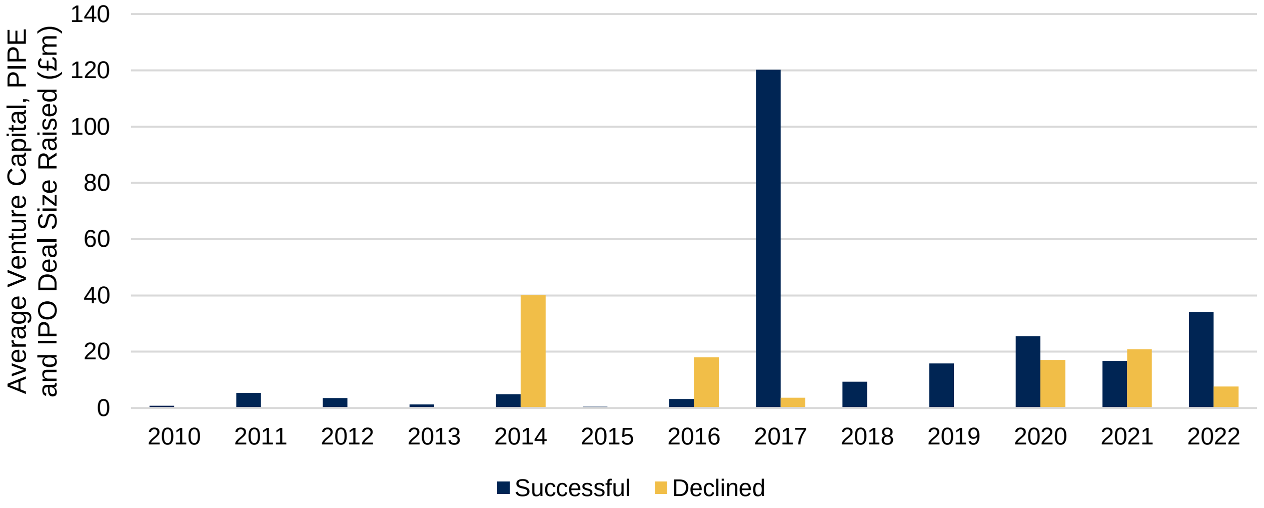
human outcomes and the long-term impact of AI interventions.		overlays of multivariate spatially and temporally varying data, model and predict trends and correlations, infer across areas of sparse data collection, and model the effects of changes on the system such as varying supply, demand or infrastructure.
Conigital: Conigital have developed their own propriety algorithms to empower those businesses to manage their fleets and operations more effectively and efficiently.	£3.0m	Zero Carbon Rugeley DD – Congitial is responsible for developing an AI-optimised real-time operation platform to coordinate energy supply, energy demand and flexibility services in the Zero Carbon Rugeley detailed design.
Minibems: software and service platform for the performance, operation and financial management of heat networks.	£3.0m	Heat networks as a flexible grid asset KTC – Minibems is responsible for adding a new software and service layer onto its existing product offering, to deliver enhanced features and cost savings without any changes to its existing controllers. This software will use AI to learn the thermal behaviour of buildings and how this is influenced by heating demand in individual apartments.
H2GO Power: Technology developer providing solutions that harness hydrogen energy from renewable sources to help meet decarbonisation targets.	£2.39m	Fast-Start HyStERIAA – The HyStERIAA project aimed to develop a technical and commercial feasibility study into large-scale hydrogen storage system that is safer, lighter and half the volume of commercially available pressure tanks.
PulsiV: Developer of a technology harnessing the principles of high frequency, pulsed-power extraction techniques, to establishing a new, unique method of harvesting more efficient energy.	£2.2m	Fast-Start (Solar Energy Inverter Maximiser) – developed an innovative process that allows an increase in the energy extracted from photovoltaic modules by extracting energy that is currently lost through heating effects.
Guru Systems: Developer of an analytics platform intended to improve efficiency and change the future of heat. The company's platform gives complete visibility of heat networks and other utility performances to help improve the efficiency of networks and fix problems early while reducing operating costs.	£2m	KTC (Guru Engage) – Project objectives include a complete redesign of Guru's existing in-home display hardware and user interfaces to include smart heating controls, environmental sensors, language support, flexible payment, and household cost projections based on customer and system data.
PowerVault: Powervault is a new home electricity storage product which helps all households use energy more efficiently.	£4.68m	SHOCENSI KTC – Powervault is responsible for assessing the feasibility study of a new technology development that seeks to create an intelligent platform to be installed in a home, controlling the load of multiple vectors and optimising them against local and national price signals, selecting the best actions to take in order to maximise net benefit for the user and system.

In addition to the larger, later stage deals highlighted in Table 6.6, seven companies closed smaller investments (typically angel or seed investments). These included carbonTRACK (which closed a £0.32m deal in August 2021, the fourth and final fundraising for the firm since 2014), Power Transition (developer of a microgrid management platform to allow prosumers to trade excess energy generation), and EB Charging.

Follow-on funding

When accounting for all equity investment deals where the investment amounts are known (VC, PE Growth, PIPE and IPO), the data suggests that in the majority of the years since the start of ISCF PFER in 2018, **successful applicants have attracted more average private equity funding than declined applicants** (see Figure 5.5).[75] This suggests that **firms awarded funding through PFER were more likely to secure further private equity funding and raised funding in larger amounts than the comparison group of declined applicants**.

Figure 5.5: Average Venture Capital, PIPE and IPO Deal Size Raised, 2010 to December 2022 (£m, firms awarded PFER grants and declined applicants)



Source: Pitchbook, Ipsos analysis.

A series of econometric analyses[76] comparing successful and declined applicants for funding were completed to quantify the net impact of PFER on levels of private equity fundraising attracted following their applications. These models sought to control for differences between firms that were and were not awarded funding and shocks affecting all firms (e.g. the COVID-19 pandemic).

It is noted that the analyses explored the **net additional impact** of PFER in supporting funded firms leverage follow-on private equity investment (VC, PE Growth, PIPE and IPO). It aimed to establish what proportion of the overall follow-on investment can be attributed to PFER directly. A series of econometric analyses comparing successful and declined applicants for funding were completed to quantify the net impact of PFER on levels of private equity fundraising attracted following their applications. These

[75] 4 deals for declined firms were excluded in this analysis, as they heavily distorted the average deal size and true behaviour of investment in declined firms. These were:
Cognizant - £1.126bn – 2016
Octopus Energy - £475m – 2021
Octopus Energy - £458m – 2022
Octopus Energy - £225m - 2021

[76] Accompanying technical details can be found in Annex B.

findings confirmed that PFER had a significant effect in leveraging private funding into SLES technologies:

- **Average amount raised**: **Each PFER grant was estimated to increase private equity fundraising by 7.5 to 17.8 percent** by December 2022. Based on average post-award fundraising of £7.8m, this was equivalent to an additional £0.58m to £1.39m per firms awarded a grant.

- **Total amount raised**: Aggregating these results across the total number of awarded firms, it was estimated that **ISCF PFER leveraged between £94m and £225m in equity investment** across the population of firms awarded grants.

- **Leverage ratio**: Allowing for the £87.57m in public spending on projects across the Demonstrator, Fast-Start, Concept and Future Design, Detailed Design, KTC Key and MEDA/MEDApps competitions, it was estimated that **PFER led to an additional £1.07 to £2.56 in additional equity investment per £1 of public funding**. This indicates that PFER has proven itself a relatively efficient instrument for leveraging private investment.

The full results of the econometric analysis are presented in Table 5.4.

Table 5.4: Estimate impact of PFER on equity investment

Controls	Econometric Model One	Econometric Model Two
Firm fixed effects	Yes	Yes
Time fixed effects	No	Yes
Results		
Estimated % effect on post-award fundraising (per firm)	17.8***	7.5*
Implied average effect per firm (£m)	1.39	0.58
Estimated private funding leveraged (£m)	224.5	94.0
ISCF PFER funding spent by December 2022 (£m)	87.57	87.57
Estimated leverage ratio (£s of private investment per £1 of public spending)	2.56	1.07

*Source: Ipsos analysis. Leads and collaborators included in the analysis. All declined applicants used as control group used in this analysis. *, **, *** indicates whether the estimated coefficient was significant at the 90, 95, or 99 percent level of confidence.*

5.6 Recommendations

Evaluation finding	Recommended action	Responsible parties
Modelled impacts of place-based approaches indicate significant environmental, economic and social benefits of SLES scale up	DESNZ should consider the recommended actions provided through research produced by organisations such as EnergyREV, ERIS, Regen, PwC and Chris Skidmore's Independent Review of Net Zero to provide overarching strategy and vision for energy system transformation (particularly on the role of decentralised energy).	DESNZ
Evidence created by funded projects and ERIS suggest wider environmental and economic benefits of SLES scale up.	Innovate UK should encourage the sharing of evaluative findings related to the PFER Challenge with central Government, Ofgem and the wider public, including final positions of demonstrator and detailed design business models and research outputs by EnergyREV's.	IUK

6 Create real world proving grounds to commercialise new products and services

A core objective of PFER was to create real-world proving grounds to accelerate new SLES products and services to full commercialisation. To achieve this, PFER funded firms through the Fast-Start and Key Technology Component competitions to develop technologies that can be integrated in the rollout of SLES, providing funding to 27 projects. It also funded Demonstrator projects to develop software technologies that integrate different components of a local energy system. Projects funded under these competitions were expected to lever additional R&D into technologies needed to enable SLES and increase their technical maturity.

PFER also funded the MEDA competition with the aim of creating an open energy data architecture and platform for energy system organisations to share and trade energy sector data. PFER subsequently funded nine projects through the MEDApps competition to create novel SLES products and services that utilise the MEDA platform.

This section provides a final assessment of the outputs and outcomes of the programme in accelerating the ***technology development*** (see programme output 2 in the programme level Theory of Change summarised in Figure 2.1) and commercialisation of novel technologies funded through the Demonstrator, Fast-Start, Key Technology Component, MEDA, MEDApps and the Open Digital Solutions competitions. This section draws on monitoring data and case study research with projects exploring progress achieved.

6.1 Key findings

- PFER funding helped funded firms mature their core technology offering and develop new products and services that are ready to commercialise and be integrated into smart local energy systems. Comparisons to unfunded project proposals indicated that these results would not have been achieved in the absence of the programme. The Demonstrator projects reached the highest technology readiness levels across the PFER portfolio, proving the technical viability of integrating SLES energy vectors to operate in new markets. Project ESO made significant progress with development of its integration technology: the Optimisation and Trading Engine (OTE), while Project LEO successfully developed its Minimum Viable System market platform that enabled it to procure DSO flexibility services as part of its trial work.

- While PFER has supported firms with developing their core technology, it has not quite reached its ambition to develop and commercialise 10+ products and services (by the project end, seven technologies had been brought to market). This was due to the short timescales of some of PFER's R&D strands (MEDApps and Fast-Starts) and relatively early-stage of technologies funded. Nevertheless, PFER funding has enabled projects to attract sizeable amounts of follow-on funding (collectively raised a total of £514.19m in equity funding), some of which was allocated for further product testing. The investment community's inclination to allocate capital is evident and emphasises the need for Innovate UK and DESNZ to continue to support in SLES R&D activity, particularly those needing to bridge the "valley of death" required to prove investability.

- The majority of funded technologies moved beyond the proof-of-concept stage to the point of either small or large-scale testing and validation, demonstrating progress towards technological maturity. In cases where technologies did not progress as planned, this was mostly due to issues relating to complexity (poorly defined technological scope coupled with a number of stakeholders aiming to achieve rapid progress at pace), policy and regulation (such as the Electricity Licence Exempt Supply (LES) and Licence Exempt Distribution (LED) regulations which removed SLES exemptions), supply chains, market acceptance and data access. This broadly mirrors the barriers facing SLES innovators developing novel business models, highlighting several important cross-cutting themes that require attention from central Government and Ofgem.

6.2 Technical progress in developing technologies being funded through PFER

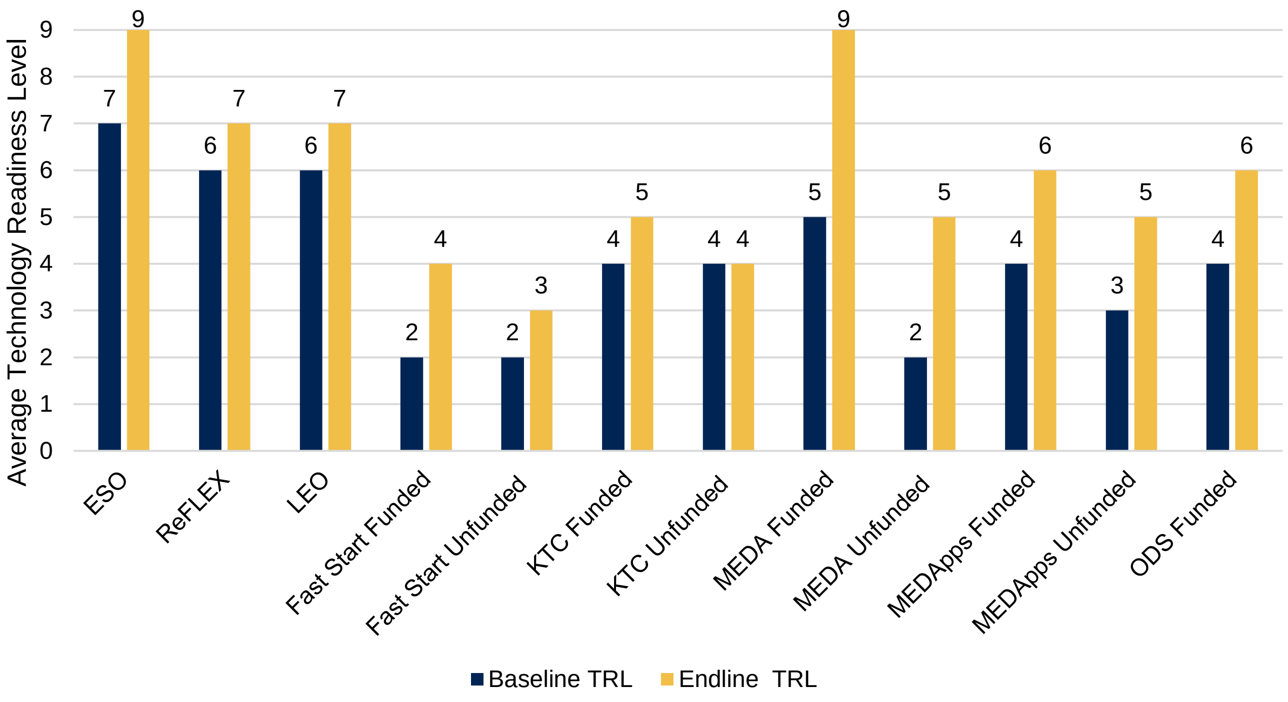
6.2.1 Technology Readiness Levels

Funded projects across all areas of the PFER Challenge that involved some form of product/process development (Demonstrators, Fast Starts, Key Technology Components, MEDA and MEDApps) were able to progress their technologies.

Where it was possible to compare between funded and unfunded projects by Competition, there is evidence of funded projects making comparatively greater gains in their average technology readiness over the funding period. Both Key Technology Component and Fast Start funded projects progressed their technologies on average one TRL more than unfunded projects over the lifetime of the Challenge. Meanwhile, MEDA progressed one TRL more than unfunded MEDA projects (Figure 6.1).

Demonstrator projects undertaking some form of product development achieved some of the highest technology readiness levels by the end of the Challenge. This was to be expected given the focus of these projects was to undertake full-scale demonstrations of their proposed business models. The Icebreaker One project funded through the three-phase MEDA Competition also made significant gains over the funding period. The remaining projects achieved comparatively lower final TRLs, in part due to the relatively early-stage TRL that these projects were funded at.

Figure 6.1: Innovation Accelerator, Key Technology Components, MEDA, MEDApps and Demonstrator Baseline and Final Technology Readiness Levels



Source: PFER baseline and endline, Innovate UK project close-out questionnaires, case studies, and MI review. Base = (Demonstrators baseline and endline n=3; Fast Start baseline and endline funded n=17; Fast Start unfunded baseline n= and unfunded n=2; Key Technology Components funded baseline and endline n =16; Key Technology Components unfunded n=6; MEDA baseline and endline funded n=1; MEDA baseline and endline unfunded n=5; MEDApps baseline n=5, endline n=9; MEDApps unfunded baseline n=10, endline n=5; ODS funded baseline n=6; ODS funded endline n=6).

6.2.2 Progress against objectives

Table 5.1 overleaf provides an overview of R&D Competitions funded through PFER and progress made against their project-level objectives.

Table 6.1: Overview of progress against technical objectives

Strand	Overview of R&D funded	Progress against objectives
Demonstrators	The Demonstrator projects involve some technology development, primarily in asset integration software technologies (such as ESOs Optimisation & Trading Engine to automate grid battery dispatch with a merchant energy trading model.	Demonstrator projects were able to progress their core SLES technologies against their original technical objectives, overcoming significant challenges associated with large-scale demonstration. ESO made significant progress with development of its integration technology: the Optimisation and Trading Engine (OTE), led by Habitat Energy went live in June 2021 (TRL 9). As such, energy was formally traded and revenues were flowing. ESO's other key technology component was the hybrid flow battery. The project faced delays in developing the flow battery in its full form due to COVID-19 and supply chain challenges. As a result, the project was unable to integrate the flow component of the battery with the energy management system to enable it to operate in its target markets, though this will happen in 2023. Nonetheless, the endeavour has significantly contributed to Invinity's progress in flow battery development and deployment. This has facilitated the demonstration of their modular manufacturing and deployment process while simultaneously accumulating a substantial project pipeline globally that surpasses that of other businesses. Lastly, ESO showcased the technical feasibility of smart-controlled heat pumps which enabled additional demand flexibility. Project LEO (TRL 7) has successfully developed its Minimum Viable System market platform that enabled it to procure DSO flexibility services as part of its trial work. While the P2P trading platform was developed in line with its original objectives, market appetite to sell services through the platform was not sufficient for this aspect of the project's business model to be deemed commercially viable and was later dropped. ReFlex made modest progress against technical objectives. The Integrated Energy System (IES) which was the envisaged as the core technology integration output of ReFLEX has emerged in the final stages of the project as not functional (there is no

Strand	Overview of R&D funded	Progress against objectives
		project output to appropriately assess the endpoint TRL[77]) whilst Flexigrid, the core electricity integration technology has developed (c.TRL 6 to c.TRL 8) but is not yet fully operational as originally conceived. A core achievement of ReFlex has been increased penetration of EV / EV chargers through facilitation and demonstration of their feasibility as a flexible grid service across residential, public and commercial settings given local curtailment volumes. (TRL9).
Fast Starts	Most Fast-Start projects were physical asset technologies aiming to offering new, intelligent ways of storing energy, generating power, or improving overall efficiency of existing processes. Examples including a novel coating for heat exchangers to be used in absorption heat pumps and a new process that extracts more power from photovoltaic modules on solar panels. The remaining projects involved software development, including a self-learning platform that helps customers reduce their energy consumption and a peer-to-peer trading platform.	Fast-start close-out reports showed projects were relatively low maturity (TRL1 to 3) when they were awarded funding. Thirteen of the 17 funded projects progressed their technologies in line with the targets outlined at the project application stage. Projects advanced an average of 2 TRLs. A notable success included development of a solar energy micro-inverter able to deliver more energy than incumbent players (Solar Energy Inverter Maximiser project). Some projects did not meet technical objectives due to failure of technology hypotheses. In some cases, firms were able to successfully pivot to new objectives. MultiSAVES achieved technical delivery outcomes progressing the interface technology between building management systems (BMS) and energy management systems (EMS) at Oxford University Bodelien Library Store from TRL c.1-2 to c.TRL 3-4) eventually facilitating their collaboration with the PFER LEO demonstrator project.

[77] The IES was only at a concept stage at the beginning of the ReFlex project (TRL2). Interim findings were that the IES was progressing in line with the overall project plans, however this has not been realised at project end.

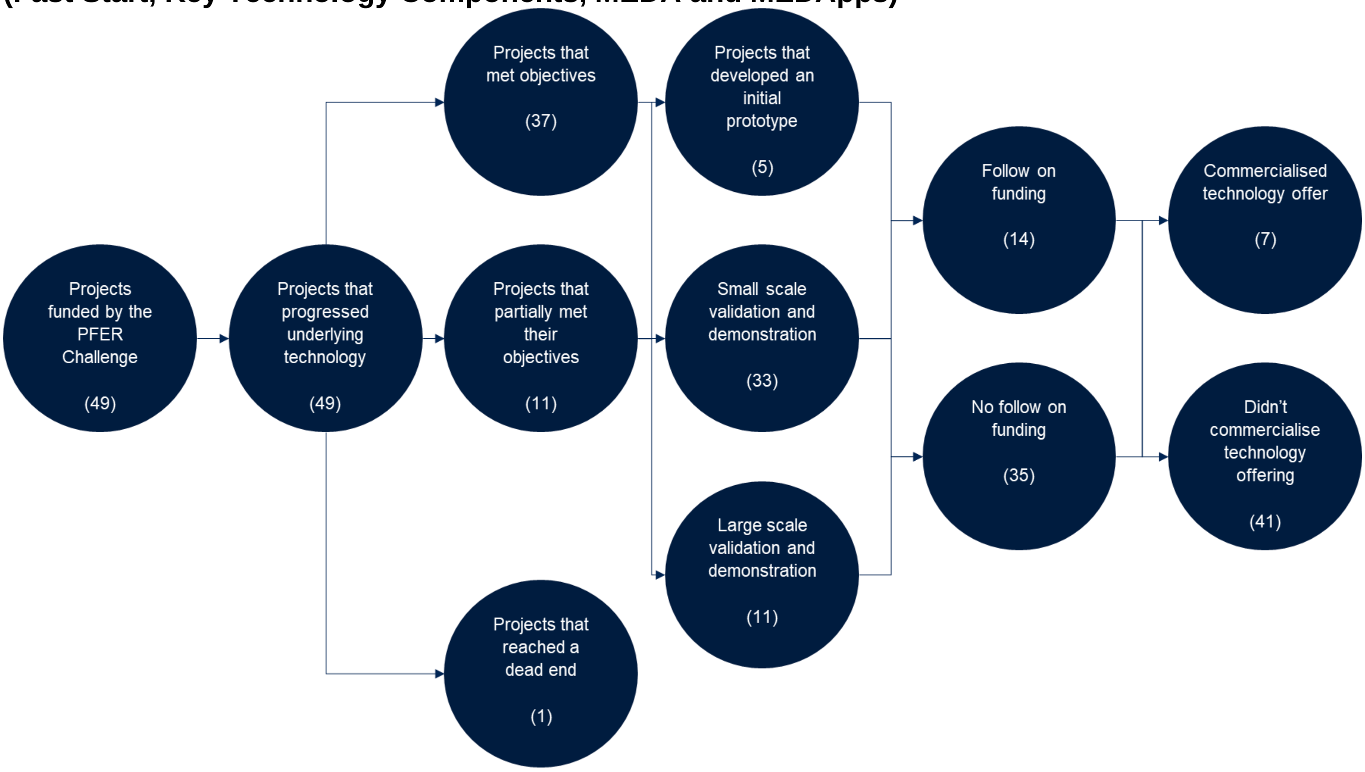
Strand	Overview of R&D funded	Progress against objectives
Key Technology Components	Projects have a strong focus on software to support SLES delivery. Some of the more common technologies being explored included machine-to-machine communications and advanced distribution management systems. Examples included a control system for district heat networks that integrate smart consumer controls with big data and flexible energy operations and a virtual networking monitoring system based on voltage readings from EV chargers.	The majority of funded projects progressed their technologies in line with the targets outlined at the project application stage and TRLs have (on average) advanced from 3 to 5. RailCharge moved from early stage technology readiness to completing much of the underlying proof of concept work. Orbit, the PAYG technology associated with the Sycous Open Protocol Cloud Metering for Heat Networks project has developed from TRL c1-2 to reach rolled out onto a first test site with a client (TRL c7-8). Some projects have faced barriers that have hindered testing of technologies in real-world environments. This was typically caused by restrictions introduced to manage the COVID-19 pandemic. For example, the PESO project faced delays in installing its main solar installation at an international port, while the Urban-X project saw reduced use of Evs during its trial period. In one case, COVID-19 led to the insolvency of a funded firm, resulting in early project termination.
MEDA	The MEDA Competition followed a three-phase process that ended in one project (Icebreaker One) being funded to develop the data architecture and governance framework for accessing and sharing energy sector data.	Projects funded under the MEDA competitions progressed throughout the various phases of this programme strand, and culminated in the establishment of an open energy exchange platform, now commercial and a foundation of open data sharing thinking across the industry.
MEDApps	MEDApps projects are intended to valorise the data architecture developed under the Icebreaker One/MEDA Competition. It follows a two-stage competition process involving an initial feasibility and a second phase to	All projects funded under phase one of the competition were able to progress their underlying technology against their original objectives, moving through the proof-of-concept stage into alpha product development. Phase Two projects that received follow-on funding to their phase one products achieved significant technological development. Several projects were able to undertake multiple product iterations and piloting of their products in operational environments.

Strand	Overview of R&D funded	Progress against objectives
	undertake prototype development and testing. Projects had a strong focus on developing products that would support other organisations looking to deploy smart local energy system solutions.	'AI Generative Design Tool for Low-Cost District Heating Networks' and 'uSmart:Zero' provided Local Authorities with access to their solutions, enabling meaningful user testing and opportunities to grow their network of potential customers. 'Geospatial Solution for EV Chargepoint Infrastructure' completed its product development and developed a go-to market strategy with sales close in a number of cases.
Open Digital Solutions	The Open Digital Solutions challenge aimed to find solutions that promote collaboration on digital components, enhance the quality and security of digital solutions, and encourage interoperability among organizations and solution providers. The projects include new, open technology solutions for applications such as solar power forecasting and management and heat exchanger design	All projects funded under the Open Digital Solutions Competition were able to progress their underlying technology against their original objectives, moving through to prototype development that range from testing in artificial environments to real-world environments. Projects progressed on average 2 levels from TRL 4 to TRL6. Some projects have been able to pilot their solutions with real-world users, as was the case for the 'Open Source Plumbing Controller' project which ran field trials for its open source plumbing controller.

6.3 Exploitation and commercialisation

The PFER Challenge has been effective in achieving its *technology development* output (see Figure 2.1) of supporting projects develop new products and services that are ready to commercialise. **PFER-funded firms have achieved technological progress across the competitions funding technology development**. There have also been some modest commercialisation and economic outcomes achieved among these firms during the lifetime of PFER (see Figure 6.2). As more time elapses, further exploitation and commercialisation of the PFER portfolio is expected.

Figure 6.2: Outcomes for funded demonstrator and innovation accelerator (Fast Start, Key Technology Components, MEDA and MEDApps)



Source: PFER baseline and endline surveys, InnovateUK project close-out questionnaire, case studies, MI review, Pitchbook. The following classes were used in classification: TRL 1-3 (developed an initial prototype), TRL 4-6 (small-scale validation and demonstration), TRL 7-9 (large scale validation and demonstration).

- **Key Technology Component projects have achieved strong technological progress, in some cases reaching high technology readiness levels to the point where they are able to commercialise their innovation**. All except one project have developed a prototype that has established small- or large-scale validation and demonstration of the technology. **There are signals of market acceptance and demand, as demonstrated by several projects successfully commercialising, achieving direct sales of the technology and/or leveraging additional investment** into the funded firm.

- Work undertaken via **the MEDA competition has led to the creation of an open energy data architecture and platform which is now live and actively recruiting participants** to share and trade energy sector data. This was a key outcome for the Challenge in its efforts to bring about improvements in data visibility, infrastructure and asset visibility, system and operational optimisation across the energy sector. **This has led to significant momentum across the**

energy sector and Government, with key players from across the energy supply chain having signed up to the initiative.

- **MEDApps projects have achieved strong technological progress** and have successfully established some small- and large-scale validation and demonstration of their technology. **A small number of these projects have been able to secure follow on funding**. However, no MEDApps projects have been able translate their technological progress and demonstrations into successful commercial opportunities as of yet. **Several projects are expected to commercialise their offering as they conclude their final product testing** (in some cases with prospective clients).

- While **Fast-start projects have progressed their underlying technology over the lifetime of PFER funding, only one project has been able to reach the stage where they were able to commercialise their outputs**. This was largely a result of the relatively early stage that these projects started at when PFER funding commenced. As a result, there was limited evidence of any commercialisation outcomes for this cohort of projects by the end of their project. Some funded **firms have however been able to leverage significant additional since being awarded PFER funding**. There is a clear linkage between the focus of firms leveraging investment and applicability of their technological solutions to SLES, such as solar PV investment technology and hydrogen production to be used as an energy storage or used in industrial processes.

- **Open Digital Solutions projects have achieved good technological progress over their PFER lifetime**. Projects have made considerable progress in developing open-source solutions; several projects have been able to propose business mode options that support scaling of their open solutions. Projects are yet to explore ways to monetise their offering at this stage. **There is limited evidence of commercialisation and exploitation though this was to be expected given the duration and scope of the competition to develop an initial offering**.

On the route to exploitation and commercialisation, projects tended to explore different sectors, industries and locations which would be either appropriate for commercialisation and replication, or a good potential partner for introducing/establishing the technology in the market. Examples of these commercialisation outcomes included:

- **Product sales: Seven firms spanning the Key Technology Components, Fast-Start and MEDA Competitions formally commercialised their product/service** as evidenced by having sold one or more units of their technology funded through PFER. For example, partners from the Smart Home Control for Energy System Integration (SHOCENSI) project have completed and signed multiple business agreements with large energy supplier companies and other technology vendors to sell their Powervault technology. O**ther projects are in discussions with potential customers to set up flexible purchasing agreements and contractual frameworks to provide their products more widely**. Projects are expected to commercialise more of their PFER funded products and services post-PFER once they have completed further testing in real-world environments. For example, the MEDApps projects have achieved substantial technological progress during PFER with examples of real-world piloting of their product with potential customers. If successful, some of these firms are anticipated to become revenue-generating.

- **Intellectual Property**: Whilst a number of projects brought background IP into the PFER funded activities, there are a number of projects across the PFER portfolio that have had IP right granted. **A total of 26 IP right have been granted, of which the majority were trademarks (9 granted), registered designs (5 granted), copyright material (4 granted), and patents (5 granted).** One example includes that of Hydrogen Storage to Energise Robotics In Air Applications (HyStERIAA) which filed a patent on the material for its main reactor. It should be noted that this type of commercial outcomes is not likely to have spilled over into the MEDA and MEDApps projects as these were mostly developing novel services that utilised assets that couldn't be protected through traditional IP rights.

- **International partnerships: There is evidence of new partnerships being formed between organisations participating in the KTC and Detailed Design competitions and international collaborators**. For example, following on from the work delivered under the Greater Manchester Local Energy Market Detailed Design, the Greater Manchester Combined Authority has entered into an agreement with Daikin, a low-carbon specialist, to deliver Daikin air to water heat pumps for social housing across Manchester[78]. Meanwhile, ev.energy (lead partner of the 'Maximising Grid Services in Electric Vehicles' KTC) has partnered with California-based Smartenit to launch a low-cost, smart EV charging cable.[79]

6.4 Barriers to progressing underlying technology/project challenges

Barriers to technology development were similar to those present for developing business models (see chapter 4): namely, complexity of project design and the wider regulatory regime. Other common barriers to progressing underlying technology included:

- **Commercial barriers**: Integration technology necessarily requires targeting of defined commercial offerings in order to be deemed effective. **Commercial benefits were not sufficiently well defined or understood** (even at conceptual level) prior to project delivery. Together with a partial understanding of how much it would cost to deliver/install of assets (e.g. batteries, vehicles), **developed technologies were not always fully aligned with commercial needs or did not have a clear commercial propositions**.

- **Low take up and market acceptance**: Projects that were successful in getting to market found that **the customer base was not yet aware of the benefits from SLES products**, limiting further technological progression. The Project LEO P2P platform was successfully developed and deployed in a real-world environment but dropped due to low market take-up within the market. GIRONA also found that technological progression was slowed by a lack of knowledge and experience of renewable energy solutions in its target market.

- **Supply chain delays**: The impact of COVID-19 was experienced by projects at different stages. Hypervolt evidenced supply-chain shortages and slower than expected car deliveries, which

[78] Daikin X GMCA partnership announcement (2023) GM Green City. Available at: https://gmgreencity.com/daikin-x-gmca-partnership-announcement/
[79] Ev.energy partners with Smartenit to launch low-cost, Smart EV charging cable to promote equitable access (no date) Smart EV Charging App. Available at: https://www.ev.energy/blog/ev-energy-partners-with-smartenit-to-launch-low-cost-smart-ev-charging-cable-to-promote-equitable-access

impacted the roll-out of EV charging technology. However, projects also found that with COVID-19, finding appropriately priced suppliers to provide suitable inputs to designs proved challenging, especially as many designs were high tech bespoke items.

6.5 Lessons learned

Similar lessons emerged among projects funded to develop SLES technologies to those funded to develop new SLES business models (see section 4.6). In particular, complexity of projects (a number of stakeholders aiming to achieve rapid progress at pace) and regulation (there is a strong need for the policy and regulatory environment to align with SLES markets). Other lessons include:

- **Commercial proposition of technology needs to be clearly defined**: Projects with a clear (and simple) commercial proposition were able to target further technological progression in the pursuit of commercial goals. **Without a targeted commercial proposition, technological progress typically stagnated** (especially in projects that were closer to demonstration and real-world scale up). **Regulators have a critical role to play in creating certainty and focal areas for SLES actors to develop clear business models around**. A key exception was the RESO project which achieved project success but 'technological development' in this project was an integration enabling eco-system rather than software or hardware that automates integration.

- **Local Authorities can facilitate SLES if sufficiently empowered and in partnership with other actors (including private sector)**: RESO and GreenSCIES demonstrated that **the local authority plays an important role in bringing together stakeholders and rooting the SLES in the locality.** They can intervene where markets are weak, such as by carrying out the necessary and urgent activities for SLES where businesses struggle to capture value and by de-risking projects. **However, the local authority still requires technically minded (often private) stakeholders to drive forward R&D in the space as they are not always sufficiently empowered with the necessary technological skills** (e.g. Local Energy Area Plans) and in many cases, adequate capacity resources to lead technological development in SLES.

- **Need for Built Environmental improvements slows benefits of retrofitting:** Technical integration of assets requires that those assets are 'integration-ready', whilst also ensuring that SLES do no purely cherry pick easy to reach customers whilst overlooking more vulnerable customers who typically live in properties which both are most likely to bring significant carbon, cost and warmth benefits but may require more costly initial retro-fit work to make them viable participants in a SLES. However, projects also identified that the new-build sector is the most appropriate and accessible target market for bringing low-carbon energy to residents and businesses.

6.6 Recommendations

Evaluation finding	Recommended action	Responsible parties
Technological development that focuses on the needs of consumers and which is linked to a clearly defined business model is more likely to lead to yield commercial outcomes.	Future IUK/ DESNZ programmes that fund novel technology development should ensure projects are selected against some criteria that highlights thinking or evidence of market need and appetite.	IUK, DESNZ

Adoption of SLES-enabling technologies (in particular demand-side approaches) continues to be a barrier in scaling up SLES business models. Such approaches are intrinsically linked with place-based initiatives.	DESNZ /IUK programmes should fund novel technology development of SLES-enabling technologies with the aim of investing in products that can be bring down unit costs for consumers that in turn supports widespread adoption of SLES-enabling technologies.	IUK, DESNZ
Successful technology developers faced a challenge in educating their customer base about the benefits of smart local energy system products which limited further technological progression.	DESNZ /IUK should work with industry stakeholders to develop and launch awareness campaigns to educate businesses on the benefits of participating in energy flexibility markets. Campaigns could be delivered through various channels, including social media, webinars, industry events, and publications.	IUK, DESNZ
Local Authorities can play a crucial role in facilitating the development of Smart Local Energy Systems (SLES) by bringing together stakeholders and de-risking projects where markets are weak. However, they may not always have the necessary technological skills or capacity resources to lead technological development in this area, and therefore need to partner with technically minded private stakeholders.	HMG should invest in capacity building for Local Authorities to develop the necessary skills and knowledge to lead technological development in SLES. This could involve providing training and support for Local Authorities on topics such as Local Energy Area Plans, technology assessment, and project management. HMG could also provide financial support for Local Authorities to hire technical experts and other professionals to support their work in developing SLES.	HMG
	DESNZ /IUK should consider funding joint initiatives between Local Authorities and private sector stakeholders to drive R&D forward in the space in the future.	IUK, DESNZ

7 Prove investable, scalable local business models

PFER supported early trials and large-scale demonstration of SLES business models through the Detailed Designs and Demonstrator projects.

As outlined in the programme Theory of Change (See Figure 2.1), **the Demonstrator, Concept and Future Design and Detailed Design activities were expected to produce direct outputs in the form of demonstrating that such business models are workable in terms of technical and commercial viability**. They were intended to explore how far SLES can generate benefits on a local scale in terms of customer energy bills and utility, reductions in local upgrade costs and actual or potential for emissions reductions. The projects were also expected to generate evidence on where regulation or existing market structures are barriers or enablers to implementing local energy systems and propose (or test) solutions to overcome the barriers. Other competitions under PFER did not focus on actively trialling or demonstrating novel business models and are not included in the following analysis.

This section discusses how PFER helped prove the ***validation of business models*** (see programme Output 1 in the programme level Theory of Change summarised in Figure 2.1). It draws on baseline and endline survey data, a review of management information and case study interview data for the Demonstrator, concept and future design and detailed design projects.

7.1 Key findings

- PFER funding helped mature the business model of all three Demonstrator projects and several earlier stage projects funded under through the Detailed Designs competition (and comparisons to unfunded project proposals indicate that these results would not have been achieved in the absence of the programme). Findings from ERIS' technical evaluation also showed that SLES have the potential to reduce greenhouse gas emissions by 2 to 108 percent and user bill savings by up to 57%. While these estimates are based on modelled projections of the energy system up to 2030, these findings demonstrate the potential of SLES to help the UK's energy systems undergo a significant transformation towards achieving its objectives of carbon reduction while improving outcomes for consumers.

- PFER demonstrated commercial viability of funded SLES models in parts. The LEO and ESO Demonstrators were able to test the technical viability of their SLES business models. Project ESO was able to test the profitability of its proposed business model which was a key success of the Demonstrator strand. Project LEO failed to prove the commercial viability of its component parts due to failure of the project to progress as fast as anticipated, as well as markets proving to be not yet ready to engage in the peer-to-peer trading aspect. Stronger rollout of distributed energy resource assets is needed across the network to enable business models similar to LEO. Project ReFLEX failed to test their SLES model due to issues encountered in integrating flexibility services with the network's management system.

- Full commercialisation of the proposed business models continues to be inhibited by the wider regulatory and market environment. Future scale-up of SLES models will depend on several factors including changes in regulation and policy, capacity, and capability of local authority staff to mobilise SLES' and increased business readiness of SLES initiatives. This highlights the need for regulatory and policy changes to create a more favourable market environment for SLES, as well as increased capacity and capability among local authority staff to implement and manage SLES initiatives. Addressing these barriers is crucial for unlocking the potential of SLES to drive sustainable economic growth, reduce carbon emissions, and improve energy resilience at the local level.

7.2 Progress in implementing the business models being tested through PFER

Proximity to market was assessed by mapping the starting point of projects to the Commercial Readiness Level (CRL) scale[80]. This provided a framework for understanding the development of new business models from initial work to explore applications, use-cases and market constraints (CRL1) through to widespread deployment (CRL9). Consultations and an analysis of project proposals and exploitation and the baseline survey work were used to establish the baseline CRL of Demonstrator projects. In the case of Concept and Future Designs and Detailed Designs, the review validated responses provided by projects via the baseline survey with a review of project proposals. Where the project involved more than one business model, the average CRL was reported.

The business models across the four PFER Challenge funded Demonstrators were at varying levels of maturity at the point they were awarded funding. As would be expected, the Concept and Future Design and Detailed Design projects displayed a lower maturity given the latter were paper-based feasibility studies with no major trial activity funded.

7.2.1 Demonstrator projects

The Demonstrator projects tested the viability of three overarching business model archetypes: Virtual Power Plant (ReFLEX), Private Network (ESO) and flex-enabled business models (LEO). Several smaller business models were incorporated within each business model archetype and tested during the PFER Challenge. **Across each of the three completed Demonstrator projects, the overarching business model archetypes matured since the evaluation baseline**. By January 2023, the Commercial Readiness Levels associated with these business models had reached between 4-8.

The Smart Local Energy System Demonstrators exhibited a high degree of complexity and novelty, presenting significant challenges in their delivery due to the existing market structures. Consequently, **a key outcome for these Demonstrators during the PFER Challenge was the acquisition of knowledge that could improve regulation and policymaking**, thereby facilitating the successful implementation and expansion of future SLES projects (see Theory of Change Annex A). The Demonstrators proved important mechanisms for testing the feasibility of novel SLES business models. Throughout their delivery, **the demonstrators were able to provide important lessons learned for future innovators in this space**, as well as help identify barriers to deployment that have fed back to key stakeholders across government and Ofgem. **Several learnings have already led to policy and regulatory impact** (see sections 7.3 and 7.4 for a complete overview of policy and regulatory outcomes spawning from the PFER programme).

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[80] Annex IV contains the Commercial Readiness Levels used for the purposes of this study.

A key outcome for the PFER Challenge Demonstrators during the lifetime of the Challenge was to **generate evidence of the commercial viability of different business models and extend beyond issues of technical feasibility to examine benefit to the consumer (e.g. bill reductions), willingness to pay, and expected rates of return**.

In terms of progress in commercial maturity of the proposed business models, **all three completed projects made strides towards mature commercial propositions with users recruited and actively using services across the demonstrator sites**. Due to delays onset by COVID-19 and supply chain disruption, projects were not able to undertake the full 12 months of demonstration originally anticipated.

Two of the three completed projects undertook several phases of demonstration that tested participation in new energy markets and were able to provide the evidence of the commercial viability of participating in these markets. **Revenue streams were identified, and pricing strategies were formulated and tested**, with newly formed sales agreements in place across these sites. **The level of progress in actually proving the commercial viability of the business models varied; this was largely driven by the type of markets that projects were operating in.** ESO for example, proved its lithium-ion flow battery was able to make a profitable return in well-established merchant trading and frequency response markets. Project LEO made some progress in testing the viability of operating in DSO markets but has yet to develop a financially attractive proposition. This is to be expected given the nascent nature of these types of markets. The project aims to undertake more extensive testing of its proposed model in future iterations of the project.

As would be expected at this stage of the Challenge, **full commercialisation of the proposed business models continued to be led by the wider regulatory and market environment**. For ReFLEX, the core value proposition for domestic battery installation and solar business model was significantly impacted by the TCR regulation; under the regulations, a Last In First Off rule meant that consumers that houses with solar would not be able to export any power to the property if their asset required curtailment of power to the grid. This diminished the value proposition that previous market arrangements allowed for domestic batteries installation as part of the prototype FlexiGrid offering. Similarly, some markets, in particular the LEO Peer-to-Peer trading market, did not prove commercially feasible due to low market maturity and take-up of the services offered through the demonstrator. This was largely due to an imbalance of assets owners selling and purchasing spare capacity.

Energy Superhub Oxford

The ESO project aimed to demonstrate scalable solutions for electric vehicle charging, battery storage and provision of electrically supplied heat. **Project ESO was able to reach a high commercial maturity. The project made in-roads in developing its core value proposition and was able to successfully integrate components of power and transport into a single system. By the end of ISCF PFER, the project reached CRL 8, showing a notable improvement in the commercial maturity of the project**.

The project was able to develop its value proposition significantly over its demonstration phase. The project was clear on its target markets with a suite of openings for revenue generation, all of which was captured in the Optimisation and Trading Engine (OTE). **During the demonstration phase, the project was able to identify and test the commercial viability of operating in two key markets: merchant trading and frequency response (including dynamic containment, dynamic regulation, dynamic operation).** The lithium-ion part of the 50MW super battery was live and operating in these markets and considered to be **highly profitable**, despite only being at 40% capacity. This represents a major milestone as it is the first battery storage system directly connected to the transmission network in the UK. Proving the OTE and super battery to work in its near-final form in a range of operating environments was key to demonstrating the overall ESO business model, at least in regard to operating in the two aforementioned markets. Battery storage represents a viable investment case for investors willing to take merchant risk, however transmission use of system costs are not yet optimized for ideal location of such batteries which should be considered as a separate asset category in grid code, not as generators, as at present. Moreover, in terms of transport integration, the project successfully connected EV charging infrastructure to the battery. The connection fee pricing and revenues were established with agreements signed with Oxford Council and charge point operators.

A noteworthy achievement of the ESO project was the establishment of a 6.9 km 'private wire' cable extending from the National Grid Connection at Cowley to the Redbridge Park and Ride. Owing to its direct connection with the transmission network, the private wire was capable of delivering considerable power quantities. It presented a cost-effective and timely substitute to distribution network connections for public and fleet EV consumers. EDF Renewables, the owner of this constructed infrastructure, operated on a business model that provided capacity for substantial power to customers. Because of the private wire, the Redbridge Superhub emerged as the first transmission-connected charging hub in the UK, potentially supplying up to 10MW for ultra-rapid charging.

Integration of the flow battery aspect of the super battery faced delays due to COVID-19 and supply chain challenges as well as some development issues. Once fully operational, the flow component of the battery was used as an extension to the regular 50MW battery. Delays to the integration of this aspect of the battery did not restrict the markets that the battery was able to operate in, though it had implications on the carbon savings of the project. This may be expected given it was the first integration of the flow component of the battery.

Some aspects of the transport network were also not finalised by the end of PFER; for example, project ESO built a sub-station that would allow the Oxford bus company to electrify their fleet provided through power enabled by the ESO project[81]. While the project was clear on its revenue streams from this, agreements were still not in place with the bus company.

Similarly, as the OTE was transmission-based, the heat pumps were not incorporated into the ESO model. The project therefore did not envisage the heat aspect of the ESO project to be included in future replications. Nevertheless, ESO did set out to test and demonstrate the ability to optimise the use of heat pumps for time-of-use pricing. Overall, tenants expressed high levels of satisfaction with their new heating and hot water systems, the installation process, and customer support, while some reported significant savings on their energy bills.

Project LEO

Project LEO aimed to deliver a new flexible energy market in Oxfordshire that makes use of distributed energy resources (DERs) such that asset owners have financial incentives to join the DSO flexibility market. Key to this was SSEN's role as Distribution System Operator (DSO), rather than a traditional

[81] It should be noted this aspect of the transport network was not included in the original scope of the project and hence it was not expected that this part of deployment would be completed within the project timelines.

Distribution Network Operator (DNO). SSEN had already received significant Ofgem funding for the DSO aspect of work[82] prior to PFER. At the start of the project, the overall CRL of the business model was two, reflecting the novelty of the flexible marketplace. **By the end of ISCF PFER, the project reached CRL 7, showing a notable improvement in the commercial maturity of the project**.

The project developed its value proposition through piloting different DSO flexibility markets and amending its performance criteria to better reward DERs and revising its baselining methodology to better help assets owners understand how much flexibility they were able to provide. Over the course of PFER, the project was also able to form close partnerships with key stakeholders across the value chain, including with flexibility service providers, despite some challenges faced in creating a viable peer-to-peer (P2P) market.

A comprehensive customer value proposition model has been developed, including a detailed understanding of the system design specifications. Through phased trials, the project was able to pilot various markets for DSO flexibility, including sustained export peak management, dynamic constraint management and secure constraint management at various time horizons (day-ahead and week-ahead). **A key learning related to the low volume of flexibility services that they were able to provide**; DERs should instead consider stacking DSO services at different time horizons as this reduces the overall revenue risk, by reducing the reliance on one revenue. The presence of flexibility markets holds the promise of encouraging potential flexibility providers to engage. Nevertheless, the establishment of markets and the delineation of services alone are insufficient. Many flexibility providers, especially those operating on a large scale, lack expertise in energy markets and are primarily occupied with their primary occupations. Therefore, aggregators and other third-party entities play a crucial role in enabling the participation of these individuals in flexibility markets.

The attainment of significant levels of local flexibility relies on the cultivation and acquisition of new skills. These skills must be directed towards clearly defined roles. It is essential to establish a robust knowledge "ecosystem" wherein stakeholders can exchange information, share knowledge, and comprehend each other's duties and obligations.

In terms of product development, **the project successfully developed its Neutral Market Facilitator platform with the actual system proven to work in its near-final form under a set of operating environments**. The platform was integrated with third party market platforms (Piclo) to enable flexibility providers to bid for DNO services. While the project made progress in changing the incentives to participate in DSO flexibility services, **the P2P trading aspect of the project was not commercially viable in its final form**. Though there was a large interest in organisations selling their capacity, there was not much interest from organisations buying this capacity. This was largely due to the nature of P2P; partner assets were needed in the same vicinity of the network to trade energy. Due to low numbers of asset owners in the market, this hindered the viability of project LEO’s P2P market. Ofgem’s review of REMA into local distribution network led markets may go some way in helping alleviate this problem in the future.

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[82] Named project Transition

ReFLEX

The aim of Project ReFLEX was to establish a virtual energy system in Orkney. ReFLEX proposed to deploy PV battery systems and integrated with the ‘Flexigrid’ software optimisation system installed across all of these assets. ReFLEX anticipated to form a single Integrated Energy System (IES) that integrated the ‘Flexigrid’ PV battery assets, electric vehicle charging stations, existing domestic electric heating systems and a new commercial combined and heat (CHP) system. ReFLEX aimed to achieve sustainable business models through EV leasing, off-street EV charging, novel electricity tariffs and a fully electric pay-as-you-go car club.

ReFLEX reached some modest commercial maturity by the end of PFER, achieving CRL4 by the end of ISCF PFER. Possible revenue streams were identified by the project (EV leasing, off-street EV charging, novel electricity tariffs including white labelling and a fully electric pay-as-you-go car club). Approximately 1,000 domestic users were recruited into its online platform. However, only a small number of these recruited users were able to take up services offered by ReFlex. The mobility element of the offer was where key commercial progress occurred in the form of the car club PAYG EV car club.

The revenue stream associated with Flexigrid, **the PV battery offering did progress technically through the project but was not successfully demonstrated at scale** as an ability to fully engage and resolve regulatory challenges with the local DNO (SSE-N) rendered the central PV and battery service offering unfeasible and led to its removal from scope.

A key success of the ReFlex project has been the end user engagement and emergence of ReFlex as a one-stop shop for information and guidance around energy in Orkney. In addition, other non-project providers in the local area have seized on greater consumer awareness to begin selling similar PV battery systems into the community.

The core IES business model/ technology did not make any substantial progress during the project with significant descoping of project work packages throughout the project. The core challenge that was never overcome during the life of the project was the ability to integrate the IES into the constraint management of the local network, despite attempts made by the DNO to enable this. This may have been due to the original conception of the IES being overly ambitious and not designed in knowledge of connection restrictions dictated by the DNO to manage constraints as an active network managed area..

SmartHUBS

A fourth demonstrator was initially funded, before its funding was discontinued following challenges with co-financing requirements. Specifically, there was a lack of understanding across the consortium around public procurement requirements, which resulted in lengthy explorations of different Special Purpose Vehicle to meet co-financing thresholds – however none of these alternative models could be aligned with public sector procurement rules. This resulted in significant delays to installing technological assets and ultimately led to the IUK funding for the project being discontinued.

7.2.2 Concept and future design and detailed design projects

Projects that successfully applied for funding from PFER through Detailed Designs or Concept and Future Designs competitions reported higher average increases to their commercial readiness than those that were unsuccessful. For Concept and Future Design, funded projects progressed three levels more along the CRL scale between the project start and endline compared to unfunded projects. Meanwhile for Detailed Designs, funded projects progressed two levels more along the CRL scale compared to unfunded projects.

The average baseline CRL for Concept and Future Design projects was similar across funded and declined firms. As to be expected, Detailed Design projects (funded and declined firms) had relatively higher baseline CRL positions compared to Concept and Future Design projects. This reflects the Competition's call for proposals from organisations that had developed their SLES model beyond the stage that most Concept and Future Design projects were at.

Across both competitions, the commercial maturity of funded SLES models progressed comparatively greater than their declined counterparts, suggesting positive outcomes emerging from involvement in the PFER programme.

Figure 7.1: Baseline and Endline Commercial Readiness Levels of Demonstrators, Detailed Designs (funded and unfunded) and Concept and Future Design (funded and unfunded) projects

Source: PFER baseline and endline surveys, case studies and MI review. Bases: Demonstrators (baseline and endline scores n=3); Funded Detailed Designs (baseline and endline scores n=10); Unfunded Detailed Designs (baseline and endline scores n=3); Funded Concept and Future Designs (baseline and endline scores n=11); Unfunded Concept and Future Designs (baseline and endline scores n=10).

Projects that were delivered at a smaller scale typically involved less technical integration, fewer stakeholders and stakeholder interactions, a simpler customer offer, and a simpler energy context. Whilst these projects may appear to have been more successful in developing a commercial proposition and progressing through higher CRLs, **the underlying revenue models were typically closer to existing business-as-usual and demonstrated less innovation in the space**.

Case studies provided evidence on the variety of outcomes achieved as a result of PFER funding. The nature of outcomes varied across projects, mainly influenced by the following project characteristics:

- **Scale**: A key difference between the detailed designs was the scale at which they are intended to operate; targeting individuals or collective groups. Approaches taken by projects varied between system-level (designing a governance structure capable of integrating the necessary elements of a SLES); mid-level (focusing on a particular vector in the system and designing the infrastructure to combine it into the incumbent system); and component-level (such as developing specific system integration solutions that would enable linking up between different vectors in the system). **Those developing mid-level or component-level approaches were able to identify revenue streams within the project lifetime (due to their relative simplicity) while system-level approaches were more wide-scale, making it challenging to develop discrete commercial offerings.**

- **Target clients**: Differences in scale necessitated differences in the target customer groups. The range of detailed design projects and their scale was important for exploring how this factor affected business model development and feasibility. **System-level approaches were inherently focused on place-based solutions and thus most applicable to place-based clients such as local councils and local infrastructure and service providers.** The novelty of such approaches supports the wider sentiment around the need for localised energy markets. Mid-level approaches benefited individual organisations that could implement vector-level solutions into their existing infrastructure. **Component-level approaches were more able to sell their solution to a wider range of customers, given they were considered more 'off-the-shelf' solutions that can be plugged into clients' systems**.

- **Addressing the changing energy market**: The overall energy landscape has influenced the framing of commercial offerings by the detailed designs. The UK's drive toward net zero carbon has increased environmental reporting requirements for many private and commercial entities, accelerating the potential benefits that could be achieved through successful delivery of SLES components. Furthermore, **changes in the relative cost of energy had given some projects further leverage to market their solution**, particularly those which were predicated on an initial investment that pays for itself in the long term due to the resulting savings.

- **Stakeholder engagement**: Variations in stakeholder interaction has also impacted business model development, particularly around the ability to identify the stakeholders with the potential to affect project design or delivery, and then engage with them effectively. **Projects which had a relatively straightforward stakeholder base were better able to identify business models that satisfied stakeholder requirements compared to projects with more varied or less-engaged stakeholders**. In contrast, large-scale engagement with a variety of stakeholders is necessary for market-level interventions. While large scale projects struggled to develop an over-arching business model, **multi-stakeholder projects engaging with energy sector and public stakeholders have emphasised the need to incorporate regional planning into energy system design**. Better regional integration of system assets, rules and players as a result of this engagement will facilitate and cascade the development of new SLES business models.

7.3 Projected systems change and environmental outcomes

Energy Systems Catapult produced an Energy Outcomes Evaluation Project Evaluation Dashboard as part of their role as Energy Revolution Integration Service. A report for each demonstrator and detailed design project was produced in late 2022. Each report included ex-ante estimates of local emissions savings and energy bill savings associated with the delivery of the project, forecasted for 2032.[83]

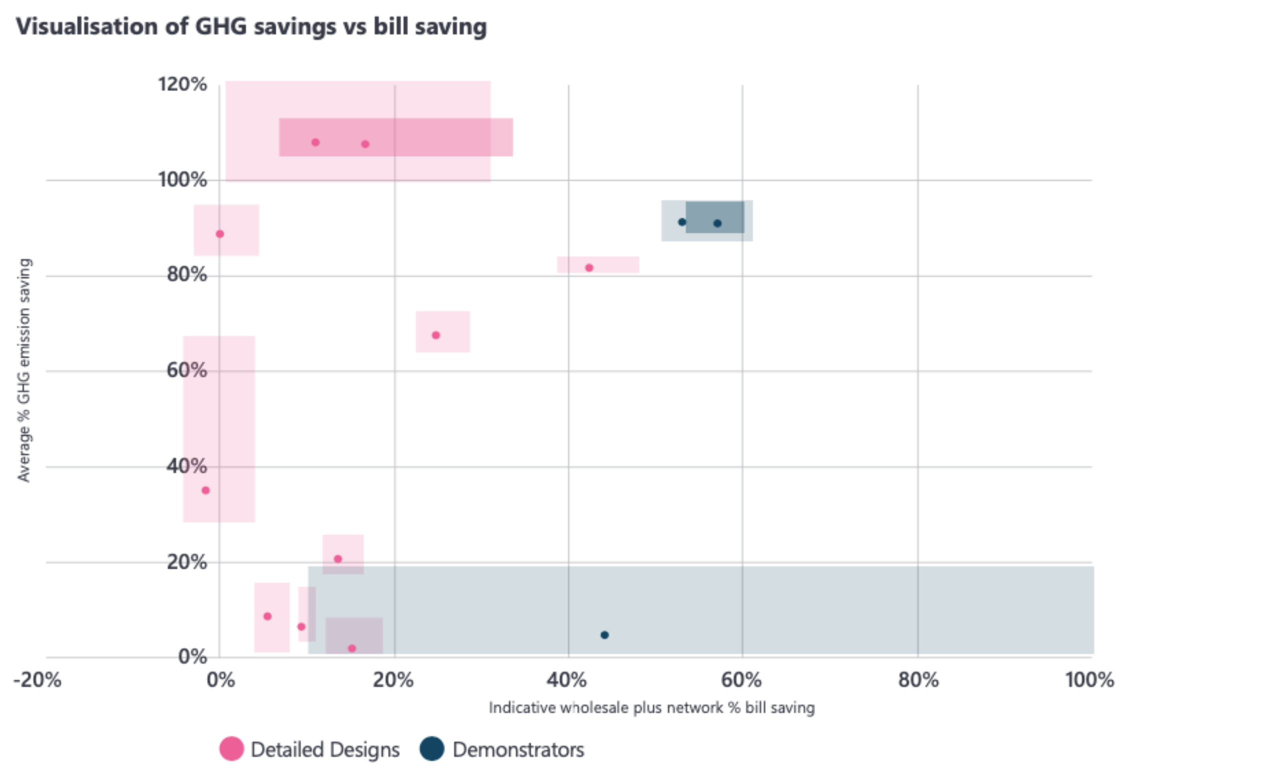
Overall, **savings on both GHG emissions and consumer bills are feasible in a SLES**, with evaluation data not showing evidence of a trade-off between GHG reduction vs participant cost- saving. There is no evidence from this evaluation that there is a trade-off to be made between bill savings for participants and GHG emissions reduction (see Figure 7.2); the evaluation instead suggests that **projects can**

[83] Using information gathered in the production of the Energy Outcomes Evaluation Project Evaluation Dashboards, Energy Systems Catapult produced a report that sets out findings of the Catapult's assessment of quantitative greenhouse gas and cost savings to participants across the portfolio of PFER. It is one of three reports by ESC evaluating 10 detailed designs and three demonstrator projects funded by the PFER challenge. The 13 projects evaluated are a subset of the full PFER portfolio. The report describes the quantitative evaluation of each project's potential impact on greenhouse gas (GHG) emissions and participant bills in 2032. The other reports produced by Energy Systems Catapult focus on i) Public awareness and appeal of SLES and ii) Why SLES? This section synthesises the key findings from the report. The ESC ERIS documents report an independent assessment commissioned by Innovate UK of a smart local energy system project. There is no commercial or contractual linkage between this dashboard and the project being evaluated. Included are modelled projections of the potential performance of the project in 2032, based on data, strategies and sector landscapes available at the time of production. Although quantitative, the figures presented should be treated as indicative and guiding, rather than being absolute, as should always be expected from long-term strategic predictions. Quantitative surveys were undertaken in 2021 and 2022, representing real data collected from a nationally representative sample of households. A review of project documentation available, with respect to the current sector landscape. No account is made in any section for sector landscape, strategy or technological changes (particularly in policy and regulation) that might take place after the production of this document. These caveats in the reports apply to both emissions reductions and bills savings

achieve savings in GHG emissions and deliver bill savings to participants concurrently. SLES is projected to provide large GHG savings, with either low or high energy cost savings.

Figure 7.2: Visualisation of average GHG % reduction vs average bill reduction (energy + network)

Note: Each point is a project; shaded rectangles represent ranges of outcomes resulting from Monte Carlo analysis



Source: Bills and carbon impact of Smart Local Energy Systems, Energy Systems Catapult (Feb 2023)

The evaluation identified some projects are projected to deliver large GHG reductions alongside smaller bill reductions; however, there were no projects that were projected to achieve large bill reductions alongside small GHG reductions. There were several projects are projected to deliver large (>50%) reductions in both GHG emissions and bills.

Those projects where the fuel used to provide mobility or heat to consumers changed between counterfactual and factual 2032 scenarios are projected to deliver the most substantial reduction in both GHG and users' bills. Where a SLES focused on enabling local markets and flexibility, the projected direct impacts on consumer bills and GHG savings were lower than for projects that focused on technology substitution, although these projects are projected to achieve some direct savings.

7.3.2 Modelled changes in CO_2

Overall, **the evaluation provided ranges of projected greenhouse gas savings from 2% to 108%** (with the greater than 100% saving representing net export of zero carbon energy).

Across all dashboards, the sizeable projected GHG reductions found are usually due to technological substitution between factual and counterfactual scenarios. (i.e. a switch from petrol or diesel cars to electric vehicles or from gas heating to a heat pump). The project-specific determination of the counterfactual technology mix has a significant impact on projected GHG savings.

7.3.3 Modelled bills savings

Overall, **the evaluation provided ranges of projected user bill savings ranging from 0% to 57%**. There is wide variation in the projected effects of the projects on participants' bills. Again, where large energy cost savings are projected, this is largely due to the switch away from fossil fuels to electricity. While this effect is less pronounced for bills than GHG emissions, the projected price of petrol, diesel, and gas in 2032 as compared to electricity across all potential scenarios means that the technology switch will yield bill savings on wholesale energy cost.

7.4 Exploitation and commercialisation of ISCF PFER Demonstrator and Detailed Design business models

7.4.1 Replication of PFER-funded SLES

A key outcome of the PFER Challenge and for individual Demonstrator, Concept and Future Design and Detailed Design projects was to validate their proposed business models in an effort to raise investment and replicate their models in other locations across the UK. Given Demonstrators and Detailed Designs concluded their work towards the end of the PFER Challenge, projects were not expected to have secured replication plans until after the Challenge was closed.

The achievement of the long-term policy objectives of PFER will be partly dependent on how far the systems being trialled have been or will be replicated in other locations in the future. Replication occurred through two main mechanisms:

- **Direct replication**: Of the three demonstrator projects, **one project (ESO) had plans in place to replicate elements of its PFER-funded ESO demonstration** (their flagship large-scale battery had been built in Kemsley, with several other locations already in the pipeline). EDF Renewables has already committed almost £200m of investment funding to replicate the transmission-connected model at five other sites in the UK, while Invinity is deploying the flow battery in other projects both in the UK and internationally. Further demonstration work was needed to commercialise the proposed business models for the remaining two demonstrators before they could develop any replication plans.

- Findings from the **detailed design case studies found that replication of commercial business models was not typically listed as a key output** of the detailed design projects with projects focused on assessing implementation of technical outputs and planning viable business models in a specific place-based context. **Projects that focused more on developing technical solutions (defined earlier as component-level approaches) were more able to commercialise their offering within the defined timescales**, largely due to the fact they could adapt their solutions to a wider range of target customers.

- **Indirect replication**: Replication may also have occurred less directly where firms shared the knowledge-based outputs of the project within relevant communities. For example, **project LEO's SSEN have agreed to partner with Dundee City Council to partner on the Regional**

Energy System Optimisation Planning (RESOP) project[84]. It is also feasible that others could seek to imitate the business models being tested through PFER without directly engaging with any knowledge-based outputs produced by the programme (a 'crowding-in' effect). For example, ReFLEX has developed a strong community profile that has generated interest and demand for the individual components of the initial ReFLEX offering. this resulted in leveraging additional private local installation of PV and battery systems.

Table 7.1: Number of confirmed demonstration sites for Detailed Design smart local energy systems at application and endline, by applicant type

Number of confirmed replication sites at time of application	At point of application		At endline	
	Successful (n=10)	Declined (n=6)	Successful (n=10)	Declined (n=3)
0	7	1	5	2
1-2	2	5	2	1
3-5	0	0	1	0
6 or more	1	0	1	0
Don't know/ refused	0	0	1	0
Mean number of confirmed sites	1	1	2	1
Maximum number of confirmed sites	11	2	12	2

Source: Ipsos MORI baseline and endline survey and Innovate UK monitoring reports. N represents the number of projects included in the final analysis. As scale up and replication were not objectives for Concept and Future Designs projects, comparison between baseline and endline is not reported on.

7.5 Barriers to progressing tests of commercial viability

Several barriers to progressing the commercial viability of business models funded through the PFER programme emerged:

- **Unfamiliarity with new markets and business models**: The relatively nascent nature of SLES markets (and more generally flexibility markets) meant market actors (e.g. flexibility providers) were unaware of how some of the markets facilitated by the demonstrators in particular operated and their role in providing services within this market. Project actors were also **challenged by lack of incentive mechanisms available from other actors in the energy system that reflected the value created** (e.g. load balancing and reduction of curtailment), which led to difficulty in commercialising solutions to fully capture the value creation.

- **Complexity**: Projects have faced various levels of internal and external complexity. In the case of demonstrators, complexity stemmed from legal and administrative processes associated with onboarding their target customers into the SLES system. Such complexity appears to have discouraged some market actors from participating in the new market introduced by the projects. **Demonstrators also faced complexity in commercialising their business model in its**

[84] The project aimed to develop a whole system planning tool that will be able to model outcomes of future scenarios to better support informed local decision making as regards to decarbonising heat and transport.

entirety due to multiple revenue streams needed for the project to turn a profit. This was a particular issue for ReFLEX whose difficulties in engaging with the local DNO led to disputes and delays, and eventually the abandonment of a significant revenue stream. Lastly, **complexity emerged through the need to serve a wide geographical scale and diverse range of actors, creating challenges for the detailed designs especially, to define a commercially viable solution**.

- **Data access[85]**: **Data access and sharing remains a barrier to SLES scale up**, despite significant efforts undertaken by PFER and, more widely, BEIS (see section 7). Several types of data have been highlighted as important by the Energy Systems Catapult in their review of the MEDApps Phase Two projects[86]:

    - **Electricity network data** (low voltage electricity network topology, monthly capacity constraints of the electricity distribution substation and their supply regions and time-series of half-hourly demand data from LV substations) were **especially difficult to access and in some cases not available for certain areas**. Limited access to this data restricted those aiming to create a digital twin of the power grid or undertake any kind of system optimisation or balancing.

    - **Smart meter data** can be accessed at pre-defined spatial resolution through UCL's Smart Energy Research Lab for research purposes. **Inability to access this data at postcode level is likely to provide problems for future SLES innovators that wish to develop novel commercial offerings**. For example, this type of data was not available at the desired geographical granularity which strongly impacted the usefulness of the final output of the 'uSmart:ZERO' project.

- **Alignment of SLES solutions with existing technology**: Prospective participants (i.e. electricity system users such as businesses, universities and other large-building occupants) noted concern that there may be technical barriers to participation in the demonstrator business models. **Issues noted included incompatible equipment, timings for flexibility services not aligning with asset use, assets not accessible or are outside the trial area, remote controllability of assets/communications outages, metering requirements, understanding which assets are capable of providing flexibility**. Issues were also raised by households as to practicality; urban environments have little space for new technologies to be deployed, while Evs and hybrids may not be an appropriate choice for staff who may be called out on business at night – thus would not be possible to charge vehicles overnight.

- **Resource and skills**: At present, central government is responsible for energy system planning and operation which is limiting the direction and resources available to scale up SLES. **Local authorities play a critical role in delivering large-scale energy system transformations, however, often lack the resource and skills.** This challenge was overcome by some projects which outsourced some of the specialist tasks to external contractors, however some projects

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[85] PFER has recognised this and has tackled aspects of data access and sharing. This is further explored in Chapter 7.
[86] Such issues may be resolved through BEIS' Digital Spine Competition that aims to enable a minimal layer of operation critical data to be ingested, standardised and shared in near real time across industry.

were not able to readily access funds to do so, leading to delays to the project and in one case led to a reassessment of the design of one aspect of the work package. **In the future, national government could devolve energy system planning powers to local authorities and require more intense engagement and planning of SLES in their areas**. This should only be done with appropriate support by government to provide the resources and capabilities to local authorities.

- **Policy and regulatory barriers**: As to be expected with large-scale demonstration projects such as those funded through PFER, **several policy and regulatory risks relating to SLES emerged**. The rapidly changing regulatory environment had several long-term implications. **The value of flexibility to actors in different locations and times should be clearly signalled**. There remained uncertainties about this issue however, for example settlement of transactions within a local energy market, between local markets, and between local and national markets still posed operational, policy and regulatory challenges. **Other issues included front-of-meter and behind-the-meter levels disputes as well as approval to operate in financial markets** (primarily related to providing credit agreements). For case study Detailed Design projects, the License Exempt Supply & Distribution regulation created fundamental problems for delivering original designs and respective commercial models.

7.6 Lessons learned

The following lessons relate to the commercial viability of, and investment case for SLES models tested through the PFER programme and how the programme contributed to progressing the viability and investability of said models:

- **Regulatory changes needed to allow SLES to scale**: The ability of SLES to scale requires sustainable revenue streams for providers. This in turn requires a regulatory environment that supports the development of viable commercial business models. **Future regulation should be aligned to business models that encourage the 'prosumer' model.** This could involve re-considering the powers of DNOs to intervene in private electricity generation (specifically, in controlling generation behind-the-meter). Business models that rely on the ability to manage self-consumption and imports from the grid cannot be fully leveraged under this kind of regulation, so it is not likely that integrated clusters or networks of private generation facilities will emerge. Taken one step further, private generation facilities could be incentivised to form clusters that optimise energy use and storage at the aggregate level.

  Energy storage business models are best leveraged when energy charges vary between peak and off-peak periods. Without this arbitrage in providing flexibility, there is less incentive for end users to install intelligent generation and storage technologies that can reduce demands on the grid during peak times. The uncertainty around market design discussed here and in detail in chapter 2 has also dampened investor confidence. Some of the proposed solutions introduced in REMA may go some way in creating more local-led markets that could facilitate this arbitrage (see section 2.2.1.)

- **Household and business readiness of SLES initiatives**: **User acceptance for consumer level smart energy tools and local generation has increased** – as evidence by the user surveys undertaken as part of ESO and ReFLEX. However, **this has not translated into widespread adoption of SLES and its component technologies**. A wider consumer survey undertaken by ESC corroborates these findings and suggests that **appeal in the general idea of SLES adoption has increased over time, particularly in PFER project areas**. Adoption of SLES-enabling technologies is also strongly linked to household readiness for SLES. Recent increases in energy costs have both raised the profile of solutions that reduce energy consumption and improved the underlying proposition for customers (like insulating homes and installing heat pumps) or dependence on the grid (like PV and battery installation) at the individual level.

In addition to households, businesses have a growing role to play in SLES markets as flexibility providers. Flexibility service providers however, particularly smaller providers, are unlikely to see energy as their primary concern and do not understand well the logic behind flexibility trading at present. Addressing this issue of unfamiliarity is critical if new markets introduced by SLES, in particular DSO flexibility services, are to be taken up by smaller flexibility service providers.

- **Complexity of SLES models**: Investors are attracted to large, simple projects. However, **the current number of actors and systems required for a SLES to operate complicates the development of simple, profitable business models**. Furthermore, the infrastructure required to deliver large scale SLES is often publicly owned. Therefore **business and public organisations must align and agree on the co-benefits before progress can be made**. Analysis of the demonstrator and detailed design projects indicates that projects which can prove profitability of individual components of their SLES (as in the case of ESO) are more likely to successfully replicate and scale their SLES business models.

7.7 Recommendations

Evaluation finding	Recommended action	Responsible parties
Place-based net-zero initiatives represent value to local and national energy systems. The current policy and regulatory framework, however, does not incentivise commercially viable business models for flexibility.	Innovate UK, DESNZ and Treasury should consider the recommended actions provided through research produced by organisations such as EnergyREV, ERIS, Regen, PwC and Chris Skidmore's Independent Review of Net Zero to address the policy and regulatory barriers still persistent in place-based approaches to Net Zero.	IUK, DESNZ, Treasury
Clear need for decentralised / local energy market coordination with powers devolved to local actors / authorities		
The complexity and ambition of PFER Demonstrators imply the importance of scoping out in detail the technological, commercial, regulatory and financial aspects of their 'real-life' implementation.	Future Government programmes funding large-scale demonstration of energy system innovation should: ▪ Replicate the stage-gate process adopted by PFER. ▪ Be phased into a scoping phase, with Government providing seed funding to detail out financing and partnership arrangements as well as regulatory requirements, and an implementation phase, focussing on the 'real-	IUK, DESNZ

	life' demonstration of technological and commercial viability.	
Businesses and households have a growing role to play in SLES markets. Willingness to engage appears to be linked to the evidence-base around SLES markets and whether or not they have been sufficiently tested.	Innovate UK should encourage the sharing of evaluative findings related to the PFER Challenge with central Government, Ofgem and the wider public, including final positions of demonstrator and detailed design business models and research outputs by EnergyREV.	IUK
The Challenge highlighted the importance of demonstration in real world environments that allowed for interactions between technology, markets and consumers	Future Government programmes funding SLES scale up should ensure funding is allocated to large-scale demonstrations that enable testing in real-world environments.	IUK, DESNZ
While PFER has sought to address some of the issues around data access in the energy industry, access to energy data for infrastructure management and energy planning remains a barrier.	Ofgem should consider the recommended actions provided through research produced by organisations such as EnergyREV, ERIS, Regen, PwC and Chris Skidmore's Independent Review of Net Zero to address these issues.	Ofgem
Progress was made in the de-risking of SLES investment throughout PFER, particularly through demonstrations that contribute to a growing evidence base which spurred investor confidence.	Representatives from across the finance community should be engaged in a number of ways in future IUK/ DESNZ programmes that fund place-based net-zero initiatives, such as: ▪ At the policy design phase, ensuring programmes are attracting project proposals that will meet the needs of their intended market and de-risk aspects unsuitable to be funded by commercial markets; ▪ At the project selection phase, such that there is sufficient focus on assessing the commercial maturity of proposals; ▪ Post-funding phase, new projects could include an investment board which provides strategic input at all phases of the project to ensure market alignment and readiness.	IUK, DESNZ

8 Conclusions

This section presents the conclusions and recommendations from the final evaluation of PFER. It highlights key points of interest from the assessment of the programme outcomes and presents a summary of recommendations based on the evaluation undertaken.

PFER has been designed around a complex and innovative premise, tackling the system-level requirements and approaches needed for a such a place-based transition towards Net Zero. The programme committed £102.5m to demonstrate integrated intelligent local systems which can deliver power, heat and transport to customers in cost-effective, innovative ways. Its objectives were to:

- By 2023, prove[87] investable, scalable local business models using integrated approaches to deliver cleaner, cheaper energy services in more prosperous and resilient communities that also serve to benefit the energy system as a whole.
- Unlock 10x future-investment in local integrated energy systems versus business as usual in 2020s.
- Create real world proving grounds to accelerate new products and services to full commercialisation.
- To build UK leadership in integrated energy provision.

Evidence gathered through the PFER programme has demonstrated the essential nature of place-based integrated energy systems to support centralised delivery of net zero. Several benefits of SLES rollout have emerged over the course of PFER; a technical evaluation of Demonstrators and Detailed Design studies indicated significant environmental and societal benefits of PFER's place-based approaches to achieving net-zero. Research from the programme itself has highlighted the social costs and benefits from place-based approaches to meeting the Climate Change Committee's Sixth Carbon Budget with estimates in the region of £137bn in investment cost saved while generating an additional £431bn in energy savings and wider social benefits.

The scale of new SLES opportunities has grown substantially since the start of PFER. The programme has contributed significantly to this shift in momentum around place-based energy and local planning for delivering Net-Zero. A major contributor to this was the work undertaken via the PFER Challenge which led to improved understanding of place-based delivery of net-zero projects and programmes and has grown the evidence base around both the implementation and the benefits of smart local energy systems.

While there are various policy and regulatory barriers still to overcome, the PFER programme was highly effective at identifying key barriers as the programme evolved and adapted quickly to try to remedy some of these issues. Moreover, the insights it has generated both in relation to benefits but also barriers to implementing SLES have proven essential in improving the understanding of place-based delivery of

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[87] As per the PFER Business Case, 'proving' business models is defined as developing a business model which integrates local energy markets in way consumers find financially rewarding and easy to engage with, and the finance community wish to scale and replicate across the UK.

net-zero project and programmes. This was a key success of the programme and will support the legacy of the programme after it has finished.

PFER has provided the necessary environment for organisations to come together to provide novel integrated energy solutions that would not have occurred otherwise and in doing so has helped build capacity, create new partnerships and encourage ongoing collaboration across industry with a shared goal. PFER’s Demonstrators set out to deliver ambitious and complex SLES plans and have faced significant challenges throughout the programme’s lifetime. Whilst to an extent some issues were anticipated, several new challenges emerged that had significant knock-on effects for project delivery and testing of new business models and markets. These issues primarily revolved around existing market structures and regulation that allowed for PFER projects to access benefits of consumer flexibility, impacting the value signals for flexibility trading and feasibility of revenue streams, as well as integrating flexibility services with the network’s management systems. The overall effects of this were slower than anticipated progress by Demonstrators in proving their commercial model and removal of certain parts of their business model that had proved to be non-viable. This highlights the importance of running large-scale demonstration programmes such as these, in revealing both anticipated and unforeseen issues. Despite these challenges, Demonstrators were generally able to prove the technical viability of their technical assets (providing integration services), indicating that the technology readiness of these types of assets does not pose an immediate barrier to participating in SLES markets.

Notwithstanding the difficulties faced by PFER’s Demonstrators and Detailed Designs, where projects were able to demonstrate commercial viability and provide evidence of profit generation, this led to plans to replicate the business model in other locations across the UK, demonstrating an interest from other regions to implement integrated systems such as those funded under PFER where there are fewer or no regulatory risks to implementation. For most projects however, further demonstration work is still needed to prove overall viability of the model before their propositions can be replicated elsewhere.

Regarding product development, PFER funding has helped firms to mature their core technology offering and develop new products and services that are ready to be commercialised. Though the programme has not brought the level of new products and services to market as originally anticipated, it has proven itself to be a useful instrument for leveraging additional private investment into firms to develop their products further. This interest from the investment community to provide private funding in PFER products and services is indicative of a wider appetite to invest in solutions that can enable SLES solutions. It is worth noting, many of the same issues facing the Demonstrators and Detailed Design studies are also relevant to SLES technology developers, highlighting several important cross-cutting themes that require attention from central Government and Ofgem.

Several outcomes and impacts from the programme are not expected to materialise until after the end of PFER and should be evaluated as part of any follow-up evaluation work commissioned. Nevertheless, PFER funding has been shown to support firms increase their turnover, generating an additional £68m in income estimated to be directly attributable to the programme. Significant effects of grant funding on employment and productivity were not detected, potentially due to the nature of firms supported and the short amount of time elapsed for such effects to materialise. It was also shown that funded firms were able to lever additional R&D spend to develop new SLES products and services compared to unfunded firms. This presents a strong rationale for future support from Innovate UK or Central Government to provide CR&D grant funding as a way of generating additional R&D investment that can support the Government’s wider Clean Growth strategy.

To continue the progress made by PFER and encourage the rollout of SLES solutions, the evaluation team have provided a selection of recommendations throughout this report. Innovate UK, DESNZ and Ofgem should consider the findings contained within this report alongside the recommendations provided in the wider research and evaluation reports commissioned by Innovate UK to provide a strong vision for energy transformation (particularly on the role of decentralised energy) and address the main policy and regulatory barriers highlighted by the Demonstrator and Detailed Design projects. Moreover, future government-funded programmes of a similar nature would do well to replicate elements from the PFER programme's design to streamline project delivery and maximise value-add from the interdisciplinary aspect of the programme.

Econometric Methodology

Analysis of the impact of PFER funding on firm level turnover, employment and productivity was conducted in the Secure Research Service (SRS), using the Business Structure Database (BSD), an ONS database that contains a snapshot of the Inter-Departmental Business Register (IDBR), which is a live register of data collected by HM Revenue and Customs via VAT and Pay As You Earn (PAYE) records. The econometric analyses consisted of pooled OLS regressions and fixed effects regressions. These analyses seek to establish the net impact of PFER grants on employment, turnover, and productivity of firms awarded grants using administrative and other types of secondary data. Similarly, an econometric analysis was conducted on the investment outcomes that PFER funding has led to, using Pitchbook data. These models sought to control for differences between firms that were and were not awarded funding and shocks affecting all firms (e.g. the COVID-19 pandemic). For this analysis, fixed effects OLS regressions were run.

The analyses employ statistical methods comparing the performance of firms awarded grants to a comparison group of firms that applied for, but were not awarded, funding. Other statistical techniques were considered, such as a combination of propensity score matching (PSM) and difference-in-difference (DiD). In this type of modelling, the sample of successful and unsuccessful applicants would have been ‘matched’ to ensure that they shared similar observable features prior to their application for funding (such as their size, sector, baseline levels of R&D spending, and TRL of the underpinning technology). This technique attempts to reduce the bias due to confounding variables by accounting for the covariates that predict receiving the treatment. This would involve applying statistical methods (such as a probit model) to explore the observed differences between successful and unsuccessful applicants and using these results to ‘match’ individual members of the two groups. The step above would only produce unbiased estimates of impact if there are no unobserved differences between successful and unsuccessful applicants that are also connected with the outcomes of interest. Difference-in-difference regressions would then have compared the change in the outcome variables between their application for funding and late 2021. These models would implicitly control for any unobserved differences between the two groups that do not change with time.

However, due to the small sample size of firms (254 companies combined in both groups for the SRS analysis), these methods were considered unfeasible. The fact that the ‘treatment’ year varies and could be anything from when a firm was awarded funding in 2018 to 2021, or even multiple years, would have further led to a loss of sample size had a staggered DiD approach been taken.

Data

Economic outcomes

The data driving the econometric analyses was collected by Innovate UK as part of their monitoring information of PFER applicants. It included:

- The year(s) the business applied for PFER funding
- The funding amount provided, if successful
- The scores the business received on their first successful application and first unsuccessful application, if applicable

This data was imported into the SRS, with a successful matching rate of about 86 percent to the IDBR – of the 310 companies brought into the SRS, 266 were able to be matched. Organisations that are registered for VAT or pay at least one member of staff through the Pay As You Earn (PAYE) tax system, will appear on the BSD, so it may be that a number of companies that were too small to appear on the BSD were in our sample, leading to a small drop in sample size. As alluded to, the Business Structure Database is annual snapshot of the Interdepartmental Business Register, providing measures of employment and turnover for all firms registered for VAT and PAYE, and covers 99 percent of economic activity in the UK. The underlying data is drawn from both administrative data (VAT and PAYE returns to HMRC) and ONS' regular surveys (the Business Register Employment Survey and the Annual Business Survey). Data was extracted for the 2010 to 2021 period, giving a total of 2135 observations over the period.

The data (particularly observations of turnover) is associated with reporting lags, and in some cases, measures of turnover may be two years out of date. Given the concentration of grants in the later years of the timeframe of interest, this is likely to lead to an understatement of their effects on turnover.

Investment outcomes

The investment impact analysis looked at all relevant deal types, including all VC, PE, PIPE and IPO deals. The data driving the investment impact analysis was via Pitchbook, and consisted of 313 successful and unsuccessful PFER applicants. This was turned into a panel dataset to track changes from 2010-2022 for each firm.

Econometric approach

Selection bias

A credible quantitative assessment of impact requires comparisons between those benefitting from PFER grants and an appropriate group of firms that did not, to help determine what may have occurred in its absence. As grants were awarded on a non-random basis, the selection of this group needs to address the potential issues of bias caused by 'selection into treatment'.

Applicants 'self-select' by submitting applications for grants and will differ from non-applicants in systematic ways that influence the outcomes of interest. As an example, firms applying for grant funding may have a greater focus on (and more significant capacities to deliver) research and development as part of their underlying business models than non-applicants. In these cases, comparing firms awarded grants to non-applicants would overstate the effect of the grants, as the latter would be less likely to raise obtain alternative funding to progress their R&D activities regardless of the funds awarded through the Prospering from the Energy Revolution Industrial Strategy Challenge Fund. Similarly, some self-selection bias is likely to be introduced when exploring investment outcomes as those which applied would be more likely to have developed products that have reached sufficient technical maturity to attract onward investment.

To address this problem the following approach was adopted:

Unsuccessful applicants: The allocation of funding to PFER projects involved a competitive application process. The issues identified above can be addressed by drawing a comparison sample from the pool of unsuccessful applications for funding. As successful and unsuccessful applicants can be assumed to share similar characteristics motivating their application for support, this ameliorates some of the sources of bias that could distort results.

Econometric model

While the selection of comparison groups as described above helps address some sources of possible bias, there will be residual concerns regarding possible differences between groups of applicants that could distort comparisons (particularly since the dataset constructed contained little information on the characteristics of firms). Further steps to minimise possible sources of bias were taken by specifying the following econometric model:

$$Y_{it} = \alpha + \beta A_{it} + \partial X_{it} + \alpha^i + \alpha^t + \varepsilon_{it}$$

This model describes the relationship between the outcomes of interest (e.g. employment) for firm i in year t (Y_{it}) as a function of the cumulative number of PFER grants received (A_{it}). As A_{it} is a cumulative value, the coefficient β measures the long-term effect of the programme. Where data permitted, controls were also added for the sector and region of the firm (X_{it}). The model is also given a fixed effects interpretation, allowing for both any unobserved differences between firms that do not change with time (α^i) and any unobserved time specific shocks (α^t) affecting all firms in the same period (e.g. a general improvement in fundraising conditions). All models were estimated with robust standard errors. Similarly, the model was also run as a function of the cumulative grant amount (A_{it}) across the four years (2018-2021). We would expect higher cumulative grant amounts to be associated with better firm performance.

Results

Table 8.1: Estimated impacts of PFER grants on employment, turnover and productivity

Model (~)	Controls				Estimated impact (%)					
	Control sample	Firm fixed effects	Year fixed effects	Sector and region	Turn..	St. Err	Emp.	St. Err	Productivity	St. Err
PFER										
#1 (2,003)	Unsuccessful applicants	Yes	Yes	Yes	0.730***	0.00	0.000480***	0.00	-0.0000297	0.669
#2 (2,003)	Unsuccessful applicants	Yes	Yes	Yes	-161,138	0.192	-96.62	0.280	-53.21	0.262
#3 (2,003)	Unsuccessful applicants	Yes	Yes	Yes	-0.000	0.664	-0.000	0.245	0.000	0.967
#4 (2,003)	Unsuccessful applicants	Yes	Yes	Yes	0.0158	0.790	-0.0219	0.364	0.0377	0.492

*Source: Business Structure Database, Office for National Statistics, Ipsos analysis. (~) Number of observations in parentheses. *, **, *** indicates whether the estimated coefficient was significant at the 90, 95, or 99 percent level of confidence. Models 1 and 2 refer to the treatment variables being cumulative grant funding in £ and cumulative number of PFER grants, respectively. Models 3 and 4 refer to the fixed effects regressions with model 3 including the treatment variable as cumulative grant funding in £, and model 4 the number of cumulative grants as treatment variable. Models 3 and 4's treatment variables were taken in log form.*

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- Ipsos' standards and accreditations provide our clients with the peace of mind that they can always depend on us to deliver reliable, sustainable findings. Our focus on quality and continuous improvement means we have embedded a "right first time" approach throughout our organisation.

ISO 20252

This is the international market research specific standard that supersedes BS 7911/MRQSA and incorporates IQCS (Interviewer Quality Control Scheme). It covers the five stages of a Market Research project. Ipsos was the first company in the world to gain this accreditation.

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ISO 9001

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ISO 27001

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Ipsos is required to comply with the UK GDPR and the UK DPA. It covers the processing of personal data and the protection of privacy.

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