Power to (some of) the people

Fraser J.F. Stewart

September 19, 2023

Power to (some of) the people?

Inequalities in the uptake of low-carbon energy technologies, and how to fix them at a local level

Fraser J.F. Stewart

A thesis presented for the degree of Doctor of Philosophy.

School of Government and Public Policy,
University of Strathclyde,
McCance Building, 16 Richmond St, Glasgow, G1 1XQ.

Funded by the Economic and Social Research Council.

Abstract

Low-carbon technologies such as solar PV and heat pumps have a crucial role to play in the net zero energy transition. Beyond reducing emissions, these technologies can provide substantial social and economic benefits to people who install them in their homes, including reduced bills, new income and improved health and well-being. For these benefits, however, research demonstrates that more affluent households have been able to access low-carbon technologies at a far greater rate than lower income groups even where government financial support is in place, creating a stark inequality issue. At the same time, local energy approaches - such as community energy or smart local energy systems - are demonstrating innovative new ways of delivering clean energy and its associated benefits to people and places. At the heart of this thesis are thus two key questions: (1) What has driven inequalities in low-carbon technology uptake so far? and (2) what are the opportunities from local energy approaches to rectify these?

To answer these questions, this thesis takes a mixed methods approach, using a combination of quantitative analysis, participatory action research, interviews and case studies. It finds crucially that that inequalities in the uptake of low-carbon technologies at the household-level are not simply financial, but are also driven by powerful social and informational forces. Using novel statistical techniques, I show that these forces have combined to create an inequality "trap" that has locked-in and accelerated inequalities in low-carbon technology uptake over time. It then applies distributional quantitative analysis to community energy projects across in Scotland and finds that, contrary to inequalities at the household-level, community energy has tended to be more redistributive, bringing the benefits of those technologies into low-income areas often as a priority. This suggests that community energy could have a key role to play in delivering more equitable net zero energy policy. Finally, it unpacks new innovations in local energy systems in low-income areas specifically, and explores how these innovations can be leveraged to overcome key barriers to uptake for low-income communities and ultimately support a more just energy transition.

[*This page intentionally left blank*]

Preface

I come from a working class community in Forfar, in the North-East of Scotland. My mother was a single parent who trained as a nurse when my brother and I were only young, and my Grandfather worked in the local textiles factory that my Grandmother cleaned at night. I've never known my biological father, although that's never really bothered me at all.

Growing up in that kind of community, we experienced many of the social issues that still persist all-too-sharply today. We lived hand-to-mouth most months in fairly abject poverty, enduring all of the struggles that accompany life in an area of high deprivation. My brother and I have both had dealings with police at various points in our lives; virtually all of our family and friends have had to claim social security for extended periods of time; and we've lost several loved ones to either prison, violence, mental and physical health or some combination of each. Many of these losses are too recent for comfort.

I do not write this in search of any sorrow or sympathy - this is not a unique experience and plenty others have it worse. I write this to give context to why I have pursued the topic of this thesis and the work that I now do in this space. More than climate or even clean energy, the driving passion of this work has been an attempt to alleviate poverty and inequality, in the hope of making life a bit brighter for communities like my own. While I care deeply about the climate crisis, then - it is the single biggest issue we face on the planet today -, I have always seen it as an opportunity to do something more in the process. We are at a formative moment in history, where just about everything we do *has* to change in some form or other to combat the climate emergency. Energy, housing, economics, jobs, industry, land, transport and everything in between is under review and redesign.

While we all now more or less agree on this, a narrative has emerged in certain politicised corners of the press that this redesign (in the UK at least) is somehow an imminent danger to the working classes and marginalised people everywhere. I do not believe this for one second to be true.

Because not only can we not hope to meet our climate targets without those communities on-board, but net zero is a unique chance to redesign all of those things to be both greener *and* fairer; a set of new tools with which we can help to address some of those historic, intergenerational issues of poverty, inequality and social injustice head-on. We can create cleaner energy that is more affordable for people to alleviate financial hardship; we can make homes healthier and more efficient to bring down bills and improve physical and mental health; we can create an expansive, low-carbon public transport network that not only encourages people to leave the car at home, but that connects people and places together. We can use this formative moment to create something bigger than even just a clean energy system, to truly unlock the massive benefits on offer for people in diverse working class, low-income and marginalised communities (and everyone in between) across the board.

Net zero thus isn't a threat to the working classes or people on low-incomes. It's the biggest open goal we've had in generations to actively make life better for people everywhere. That is not to say that it will be easy or that net zero will be naturally fairer by virtue: making sure everyone can reap that value will require serious attention to social justice and addressing the barriers people face to participating in the net zero transition more directly. The upshot of this, however, is that if we get it right, we can create a clean energy system that is far greater than the sum of its parts.

So this is what this thesis aims to do, in its own small way at least - help inform a net zero transition that benefits those typically excluded people and places directly. To this end, I have focused specifically on low-carbon technologies in households and communities, which is for a key reason. As we transition our homes to low-carbon technologies such as heat pumps and solar panels, there are diverse direct social and economic (as well as environmental) benefits on offer from reduced bills to more efficient buildings and even new revenue from the flexibility or export these technologies can offer. These benefits could be transformational to someone living in poverty or struggling with their energy bills and the wider social, mental and physical impacts thereof. However, not everyone is equally well-placed to access those benefits. The predominant way of supporting uptake of low-carbon technologies is to provide grants and subsidies for people to install them themselves. Yet lower income groups face a number of barriers that mean even well-targeted grants or subsidies will struggle to reach them effectively. Prior research (and personal experience) shows that it's more than simply money.

As such, this thesis quantitatively demonstrates the multi-faceted nature of socioeconomic inequalities in low-carbon technologies, and explores more holistic, local energy approaches such as community energy and smart local energy systems as one potential way to overcome them, with the overall aim of supporting the design of policies and initiatives to more effectively deliver benefits to communities that have so far been largely excluded from the value on offer as we set about cleaning up our act. The hope is that the research here can help unlock those new technologies and innovations to do some social as well as environmental good, helping to enable a more just and prosperous energy transition.

Thesis journey and impact

The thesis itself has been very much a moving target. At its conception in 2018 - pre-COVID and pre-energy crisis - the principles underlying it seemed a little less urgent. The hope was to explore inequalities in the energy transition, specifically in those low-carbon technologies, and unpack potential ways to overcome them in local places and communities within a reasonably comfortable timeline. With the energy crisis, however, inequalities within the energy system and society more broadly have been written clearer than ever, and the urgency of addressing them feels infinitely more pressing today.

Throughout the thesis timeline, I worked on several "real-world" projects focussed on helping low-income communities and those in fuel poverty to participate and benefit from the energy transition. This included but is not limited to establishing a community energy project spanning two deprived areas of Glasgow, and being appointed to the Scottish Government's statutory Fuel Poverty Advisory Panel to help guide policy to eradicate fuel poverty in Scotland by 2040 in line with net zero targets. I have also worked with dozens of other communities across the UK on these types of issues specifically. This wider experience with low-income communities has undoubtedly helped to inform the thinking in this thesis and keep it grounded in reality.

In all honestly, it also delayed the completion of the thesis to a large degree. The original plan was to submit in early in 2022. All empirical work was completed by then (two of the three chapters are already published as solo-authored articles in *Energy Policy*, with another collaboration on the thesis topic published in *Energy Research and Social Science*) but life, as it does, intervened. Early in 2022 my funding came to an end, leading me to take up a full-time-and-then-some job with Regen - a non-profit centre for energy expertise, working on a just net zero transition in the energy system.

In this new role, I head-up Regen's work on just transitions. Learnings from my doctoral research have very much been applied here, informing projects on smart local energy systems, innovation with energy networks, heat and energy efficiency strategies, community energy, and in direct engagements with Ofgem and BEIS. We are currently leading a project commissioned by Scottish Government, exploring local and community energy in Scotland as part of the Scottish Government's Energy Strategy and Just Transition Plan, where much of this analysis is being applied and replicated. Although the thesis itself has been on the back-burner through much of 2022, its empirical findings have helped shape thinking and influence on a number of issues. Beyond even its being published in reputable journals, its learnings are thus having some practical policy implications.

This brings us to today, and the "finished" thesis that you are reading now. I will not lie and say that it has been forensically engineered together in social isolation through every waking second of the last 4-5 years. It has not. Circumstance demanded otherwise although this, I would argue, is to its benefit. It is not a product of thousands of consecutive solo late nights and burned candles. Rather, it is the product of diverse experiences, dynamic context and evolution. As we talk more about supporting people in the long-term with net zero technologies and a decarbonising, decentralising energy system, against the backdrop of rising prices and social injustice, I only hope that it can be of some use.

Acknowledgements

There are dozens of people I would like to thank for their role in helping this thesis become what it is today, and in making its completion possible. To do this justice would take a thesis in itself, and so I will endeavour to keep this section brief and meaningful.

First, I would like to thank everyone at the University of Strathclyde for their enduring faith over almost 10 years. In particular I'd like to thank my supervisors Dr. Sebastian Dellepiane-Avellaneda and Dr Rebecca Ford, who have been an unerringly positive influence and source of inspiration. I'd like to thank the extended Government and Public Policy department, and extend that to the Centre for Energy Policy and the Electrical Engineering departments for the opportunity to work across diverse disciplines and with a range of wonderful people. Strathclyde is a uniquely incredible school and I will be forever grateful to have gotten to be a part of it.

I'd also like to thank the phenomenal people at Glasgow Community Energy and in every community I've had the honour of getting work alongside these last few years. Few things can give heart and sustenance like working with dedicated and passionate people and there's nowhere like the community space for that: folk doing thankless work with little recognition for the right reasons. May we all aspire to be more like them in future.

Speaking of thankless work, I'd like to thank my wife Eilidh, without whom I'd no doubt still be a guy on the dole, bouncing between the bookies and a pub somewhere, annoying the bar staff about the state of the world and those Tory ******** at Westminster (although I do still get to do this as a treat in my time off). Her encouragement and patience clearly knows no bounds and none of this would be possible without her. I'd also like to extend that to my family, friends and acquaintances and everyone else back home who have been so thrilled to see one of their own somehow blag their way into a PhD programme.

There's a misperception I think, about small towns and poverty and how people from those places never want to see you do well. I joke about Forfar in a self-deprecating way, it was tough growing up there, but in truth I've never felt more enriched than when I've been among people from home who have never been anything other than imminently encouraging. Without that experience, without that encouragement and sense of belonging, I would not have the heart to be here. For keeping me grounded, for spurring me on, for always reminding me why we're doing this at all, I cannot begin to express my gratitude. If any of this helps

make life a little bit better in even one home or community or place like ours - or makes someone from there feel like they can get on the pitch and have these conversations - it will have been worth it.

And if not, well, it's been a good laugh.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The transition to net zero energy is among the biggest challenges we face today. Across the UK and indeed around the world this is a key priority for policymakers, to meet essential climate change targets and enable the social and economic value that this transition likewise has to offer (UK Government 2023). In light of the current energy and cost-of-living crises, which have been largely driven by the skyrocketing price of fossil fuels (Cornwall Insight 2022), the need to transition to cleaner forms of energy such as wind, solar, electric transport and heat - and to reduce our energy demand through things like energy efficiency and retrofit - has become even more apparent.

With these modern crises, another pressing issue has been brought to light: that is, the issue of justice. Throughout the energy and cost-of-living crises, soaring bills have undoubtedly hit those socially and economically disadvantaged in society the hardest. In 2022, energy bills rose from roughly £1,200 per year to almost £3,000 (Cornwall Insight 2022). People who were already struggling to make ends meet have found their bills increase to unmanageable levels, leading many to suffer serious health impacts as a result of under-heating their homes, with a stark knock-on effect onto their ability to pay their rent and mortgages, feed their families, and to a wider social spiral of poverty, addiction, ill mental and physical health, homelessness and destitution (Citizen's Advice 2022).

This is at least in part because those are the people least able to afford to insulate themselves - metaphorically and literally - from rising prices, either financially in their ability to absorb higher costs or in their ability to transition away from gas onto cleaner energy sources like heat pumps or solar panels. This struggle to transition to low carbon technologies is a vital issue. Based on years of research and experience, there is an understanding now that clean energy in people's homes and communities can have considerable positive impacts - socially, economically, and environmentally. Solar panels and battery storage, particularly those which export energy to the grid, can create massive savings and even generate new income (B. K. Sovacool, Barnacle, et al. 2022; UKRI and Regen 2022a); energy efficiency measures such as insulation and double-glazing can reduce bills and create healthier homes (Xu and Chen 2019); heat pumps (although expensive under the current price of electricity) can likewise work out cheaper than gas boilers or oil in off-grid areas (Rosenow 2022; Sunderland and Gibb 2022).

For these benefits, those on the lowest incomes and on the margins of society have yet to benefit at any scale from these technologies or the wider net zero transition. Such technologies and measures can be expensive to install and difficult to access even when government support is in place, causing real barriers to participation for millions of people, while groups such as those on low incomes, diverse working classes, people with disabilities and people of colour in particular have been far less engaged by policymakers in the net zero conversation compared to more affluent people and places (Stewart 2022). In turn, we have struggled to design policies or processes that adequately enable people from those backgrounds to meaningfully participate in and benefit from the things we ultimately need to do to combat the climate emergency (K. E. Jenkins et al. 2020; McCauley et al. 2019a; Stephen Hall et al. 2021).

With these inequalities in sharp focus, the need for a just energy transition has perhaps never been so pertinent. The idea of a "just transition" - that is, a transition to net zero energy that ensures those at the margins of society are not further penalised or, better still, benefit directly as a priority in the energy transition (Heffron and McCauley 2018) - has started to gain considerable traction in policymaking circles and the wider energy sector (Ofgem 2022a; UK Government 2023; Scottish Government 2023; Scottish Power 2021). Given the extant benefits on offer, securing a fairer and more just transition presents a significant opportunity to not only meet our climate change targets, but to do so in a way that actively addresses these inequalities, to support those in fuel poverty and improve health outcomes by reducing bills and creating more comfortable homes, create new income and employment opportunities, and to ultimately build an energy system that truly works for people and planet.

1.1 Inequalities in low-carbon technologies

Research has repeatedly identified stark inequalities in who benefits and how from low-carbon technologies like solar panels or heat pumps in the UK and other places (Lukanov and Krieger 2019; Sunderland and Gibb 2022; B. K. Sovacool, Hess, et al. 2020a; K. E. Jenkins et al. 2020; Akizu et al. 2018; Knox et al. 2022). More affluent households and groups have consistently benefited from these technologies while lower income groups have been largely excluded. This is for a few key reasons. More affluent groups tend to own their homes, making the process of installation more straightforward, while they are also more likely to be able to afford any up-front costs in the first place.

Governments have provided financial support to people who want to install these technologies in their homes. Until now, people have been largely expected to take action themselves, with the key policy driver of low-carbon technologies in UK households coming from grants and subsidies such as the feed-in tariff, Renewable Heat Incentive (RHI) and Green Homes Grant. Such grants and subsidies serve a purpose in encouraging those so inclined to install new technologies themselves. However, this also means that those who can afford any up-front costs and who own their homes have been able to benefit from reduced bills etc, while those on lower incomes have been mostly excluded. Even with dedicated financial support in place then, low carbon technologies and their benefits have flowed mostly into middle class, higher income households.

In light of the energy crisis, not only are lower income households penalised under the current energy system and in the energy crisis, but they are thus being left behind in the transition to low-carbon technologies required to meet net zero and make us more resilient to international price shocks. With grants and subsidies for heat pumps and electric vehicles now being designed with calls for priority for low-income households (Sunderland and Gibb 2022), understanding the current barriers to access is crucial to overcoming them and ensuring that everyone can reasonably participate in that new value. This is a critical problem to solve for two key reasons. First, as we transition to net zero, there is a risk of making social and economic inequalities worse if we do not ensure the benefits are shared fairly across society. Second and more simply, we cannot hope to fully transition to net zero without helping those millions of households in low-income, marginalised and excluded communities to transition as well.

The upshot of this is that, by helping those households and communities to transition as a priority, there is scope to create far great social and economic good in the process: lower bills and new income, reduced deprivation, poverty alleviation, healthier homes, along with wider second-order benefits such as less reliance on the NHS and social care by mitigating the impacts of fuel poverty and reducing emissions (Ford et al. 2021). As such, understanding inequalities in the uptake of low-carbon technologies and innovative ways to rectify them is crucial to enabling a just transition at the scale and pace required to combat the climate crisis and enable the extant benefits on offer across the board.

1.2 Local energy systems

One opportunity for redressing inequalities in the net zero transition is via local energy approaches (Ford et al. 2021; UKRI 2022; Arvanitopoulos, Wilson, and Ferrini 2022; Watson et al. 2020; Regen 2019). Rather than relying solely on large-scale renewable energy generation like on- or offshore wind farms, local energy approaches bring energy generation, storage and demand technologies down to the local-level (UKRI 2022). This could be in the form of a neighbourhood with solar panels connected together using a microgrid or private wire, for example, or a more traditional community energy system whereby a group of local people fund and own an asset like a wind turbine to supply and bring benefit into local areas (Berka and Creamer 2018; Berka, MacArthur, and Gonnelli 2020; Creamer et al. 2019; Milchram 2021).

More recently, innovations in "smart local energy systems" - systems which bring together electricity generation, storage and demand across electricity, heat and transport at anywhere from neighbourhood to whole cities - have been trialled by projects such as the Prospering from the Energy Revolution programme (UKRI 2022; UKRI and Regen 2022b). Research from the likes of the EnergyREV consortium and PwC has shown that such local approaches can create significant bill savings for people and for energy networks and government, predominantly through avoiding expensive, large-scale network upgrade costs, which can in turn be passed on to citizens and communities (PwC 2022; Aunedi and Green 2020). A more diverse, decentralised, clean energy system is also less susceptible to international price shocks, and can support new social and economic opportunities, such as income for local initiatives, local growth and development, and addressing fuel poverty (Banks and Sarah J Darby n.d.; Ford et al. 2021; UKRI and Regen 2022a).

By doing energy more locally, there is scope to leverage these benefits to support a more just net zero transition. This is because local energy systems can be tailored to better suit local need, while the revenue and savings generated by these systems can also be passed on to those in lower income groups who arguably need it most (UKRI and Regen 2022b; Knox et al. 2022). By doing energy more locally, those systems can also crucially be designed to support typically excluded people to transition/benefit from that transition, since in theory local groups and organisations are better-placed than national policymakers to engage with and understand the needs of diverse groups of people who have been excluded so far. In theory, this also allows other groups and organisations - such as a community energy group or a local authority, for instance - to shoulder the financial and procedural burden of funding and installing new technologies in the first place, overcoming some of the key barriers people currently face.

Innovation in the local energy space thus has the potential to enable a fairer, more inclusive energy transition. That is not to say that local energy is fairer by default, of course: issues still exist in terms of who gets to participate in local energy system trials and innovations, while even more traditional community energy projects have tended to be dominated by more affluent, white, middle class groups in the UK (Berka and Creamer 2018). Yet more localised energy approaches still present an opportunity to bring the energy transition closer to people and, with the right incentives and motivations, to bring the benefits of low-carbon technologies to groups and communities who have so far found themselves excluded from much of the value on offer.

1.3 Research approach

This thesis thus brings together these two expanding fields, to better understand how inequalities in the uptake and benefit of low-carbon technologies can potentially be rectified through innovations in the local energy space. At the heart of this thesis is one key research question: how can low-income and typically excluded households benefit from low-carbon energy technologies as part of a just transition? This is then divided into to two sub-questions: (1) What has driven socioeconomic inequalities in low-carbon technology uptake so far? and (2) what are the opportunities from local energy approaches to rectify these?

Using a mixed methods approach, this thesis unpacks social and economic inequalities in uptake of low carbon technologies in Scotland, and explores how different local energy approaches may ultimately enable a fairer energy transition. These questions are tackled in three empirical chapters - two of which have already been published as solo-authored, standalone journal articles in *Energy Policy.* The first chapter unpacks inequalities in the uptake of low-carbon technologies at the household-level, using novel quantitative techniques to show that inequalities are not simply financial but have a strong social element as well - combined, these factors have created an inequality "trap" that has persisted and accelerated inequalities over time. The second chapter then uses distributional analysis to explore who has benefited from community energy projects so far, whether this distribution is in any way fairer than household-level uptake, and how community energy could bring the benefits of low-carbon technologies into typically excluded households and communities. The third chapter then looks at three recent local energy systems in low-income areas specifically, to explore their models, actors, benefits and motivations, and how they might be enabled to support a just energy transition more widely going forward.

1.3.1 Understanding inequalities

Before exploring local energy approaches to support low-income areas, the first empirical contribution of this thesis unpacks inequalities in the uptake of low-carbon technologies - specifically household solar panels under the UK feed-in tariff - to understand how these inequalities arise and endure. The purpose of this work within the thesis is not just to identify inequalities in low carbon technology uptake (which it does), but to attempt to outline exactly *how* and *why* these inequalities have emerged, to lay a more robust foundation for potential solutions in later chapters. In January 2022, this paper was accepted straight to publication in *Energy Policy* with no revisions at peer review stage.

Previous research has found that socioeconomic inequalities in the uptake of low-carbon technologies and access to grants and subsidies to support this are a result of more affluent households having the up-front financial resource required to fund installations (Akizu et al. 2018; Lukanov and Krieger 2019). They also tend to own their homes, making installation more straightforward in terms of access and legality. However, I hypothesise that inequalities are not simply about money or tenure but about key social and informational forces too, such as peer diffusion and policy literacy, which combine to create a "trap" which locks those inequalities in and accelerates them over time.

This "feed-in tariff trap" theory is tested using a novel application of piecewise structural equation modelling (Jonathan S. Lefcheck 2016a; Johnathan S Lefcheck 2019) which, at the time of writing, has not previously been used in energy policy literature. Bringing together data from over 21,000 feed-in tariff installations with the Scottish Indices of Multiple Deprivation (SIMD) across 6,976 geographic data zones from 2009-2020, I find strong evidence for this inequality trap, suggesting that socioeconomic inequalities are not simply a function of money but have key social dimensions which have caused them to widen considerably over time.

These findings are crucial to the rest of the thesis: knowing that inequalities have key social and informational dimensions means that rectifying inequalities are not simply a matter of giving people more money, providing new low-income priority grants or making low carbon technologies cheaper - important as these things may be. Instead, helping low-income households to benefit from low-carbon technologies and alleviating these inequalities may require more dedicated support with legal, technical and policy processes, or a removal of that burden altogether by actors and organisations with greater resource, expertise and capacity.

1.3.2 Community energy for a just transition

Following from this opening empirical work, the second chapter then explores community energy as a potential way to remove that burden and bring the benefits of low-carbon technologies into those communities (this paper was published likewise in *Energy Policy* in late 2021). In theory, community energy organisations have the capacity to navigate finance, grant applications, legal and technical issues and so on that serve as barriers to uptake among individual, lower-income households. They also have access to more substantial funding streams to conduct larger-scale energy projects. Although benefit from community energy projects tend to be more holistic than direct - that is, the benefits are realised in the wider community rather than in specific households on their bills, for instance - this could be one avenue by which value is brought in to typically excluded areas.

Using the same data as the first empirical chapter, I analyse the distribution of benefit from low-carbon technologies under the UK feed-in tariff across the 6,976 SIMD data zones in Scotland between 2009-2020. I find that community energy projects, particularly community solar, have indeed prioritised low-income areas, helping to bring often considerable amounts of new revenue into those areas for local development, with an increasing focus on social justice and tackling fuel poverty.

The implications of this are substantial. Knowing that community energy groups have had some success in bringing benefits into typically excluded areas (many also provide ongoing fuel poverty and energy advocacy services) presents an opportunity for policymakers to leverage motivated groups and organisations to support excluded people and places into the net zero transition. However, community energy organisations are largely still voluntary and, since the winding-down of the feed-in tariff in 2020, no longer have the same revenue-generating opportunity or business model. As such, there is a need for policymakers to explore how best to support community energy as part of a more just energy transition going forward, including helping community energy organisations to professionalise at-scale, and considering how they might sit within the current fuel poverty and grant and subsidy landscape.

1.3.3 Social innovation in local energy systems

The third empirical chapter finally springboards from these empirical findings to explore three different models of local energy using a social innovation lens, to understand how different types of local energy system have been brought into low-income areas and the opportunity to expand on these for a just transition going forward. The aim of this chapter within the thesis is to build on the findings around community energy and unpack how other, more novel local energy models have been brought to life in low-income areas specifically, to help those areas and people benefit from low-carbon technologies and opportunities.

With these local energy systems, similar to the community energy example, different actors and organisations such as local authorities can again take the lead to overcome the financial and social barriers that stop low-income households participating themselves while passing on the extant benefits on offer. With an often diverse pool of stakeholders such as local authorities, energy networks, and community organisations, and with a wider range of business model options compared to traditional community energy, local energy systems such as those included here could be a lucrative tool for helping low-income communities benefits from low carbon technologies for a more inclusive energy transition.

Using participatory action research, semi-structured interviews and desk review, this chapter thus compares three different recent local energy systems - a traditional community energy project in Glasgow, a smart solar and storage initiative providing flexibility to the grid in social housing in Aberdeenshire, and peer-to-peer trading in a high-rise block in Brixton - to understand the different models, technologies, actors, benefits and motivations thereof through the lens of *social innovation theory.* Social innovation refers to innovations that redistribute the risk-benefit balance in innovation projects as a means to providing social good (rather than return on investment, for example) first and foremost. While financial return is still a consideration for some actors, the cases included here very much fit the social innovation ethos, with diverse sets of actors pooling together to bring the benefits of local energy into communities that are often excluded.

Through this lens, I find that certain local energy innovations have been hugely beneficial both for local communities more widely and for typically excluded households, and while prioritising social good on the surface, these have not been acts of charity: actors involved have distinct and diverse motivations which can be leveraged in policy and regulation to help incentivise local energy innovation in low-income areas on a wider scale going forward, to bring the benefits of low-carbon technologies to people currently on the margins of the transition.

1.4 Findings and contributions

This thesis is designed to help understand inequalities in the uptake of household-level low-carbon energy technologies and measures, and to inform policy that ensures the benefits of those technologies and measures can reach people who have been excluded so far, to make the net zero energy transition more equitable across society.

Beyond the individual methodological and empirical contributions of each chapter, the overarching contributions of this thesis are three-fold.

First, using novel statistical techniques, this thesis demonstrates that the socioeconomic inequalities in the uptake of low-carbon technologies and in the net zero transition more broadly are not simply a result of a few different factors, but that financial, social, individual and informational forces have combined to effectively created an inequality "trap" that makes it difficult for even those people who want to access new technologies or assistance to do so, widening inequalities in the process. As such, simply providing more financial support is unlikely to rectify those issues. In designing policies to help households and communities to transition to net zero, knowing the more nuanced nature of these barriers can help to shape appropriate solutions that more effectively address them. This is applicable not just to solar PV or generation technologies, but also to heat pumps and retrofit in particular which have similar costs and processes (i.e. installation in someone's home) associated with them.

Second and following from this, this thesis challenges the notion that community energy has been purely a middle class preoccupation, showing that community energy groups have been proactive in bringing the benefits of their projects and technologies into low-income areas, successfully absorbing the financial and social barriers that many excluded households face to individual uptake. With their local connections and mission-led motivations, this presents a new avenue which policymakers can leverage to better share the benefits of net zero energy. With the appropriate policy and financial support, community energy organisations can likewise not just help to bring holistic benefits into communities, but help households directly, supporting more national efforts to deliver key energy support to people who need it.

Third and finally, this thesis highlights how different models and motivations of different actors can be leveraged to encourage the benefit of local energy systems in low-income areas. Knowing the motivations of different actors involved in local energy systems, and the diverse benefits on offer for people but also energy networks, governments, local areas, technology businesses etc, there are lessons in these findings that can help design policy and regulation that not just makes it easier for typically excluded people to access technologies themselves, but that incentivises networks, technology developers, local authorities and others to prioritise low-income areas in their local energy thinking and implementation.

Combined, these contributions provide robust empirical lessons which can help to shape a more just net zero energy transition for people and places. At a time where inequalities in the energy system are more stark than ever, and where the need to transition feels especially urgent, these lessons can support policymakers to build an energy transition that leaves nobody behind, and that truly unlocks the massive social and economic potential of the formative moment we find ourselves in.

Chapter 2

Understanding inequalities in the uptake of low-carbon technologies

The first empirical contribution of this thesis explores socioeconomic inequalities in the uptake of low-carbon technologies at the household-level using novel statistical techniques, applied to the example of the feed-in tariff. The purpose of this chapter is to fully understand what those inequalities look like and the causal mechanisms that have driven them so far, to lay the foundation for more informed ways to break those inequalities and deliver benefit from low-carbon technologies to low-income people and places in the chapters that follow. This paper was published in *Energy Policy* in 2022, accepted straight to publication with no revisions at the peer review stage.

2.1 Introduction

With the "just transition" to net zero now front-and-centre of national and international energy ambitions, understanding who gets to access and reap the benefits of clean energy policies across societies is crucial to ensuring that this transition is both fair and equitable (Colli 2020; European Commission 2020; Heffron, McCauley, and Rubens 2018; K. Jenkins 2018; McCauley et al. 2019a). Low-carbon technology grant and subsidy schemes, such as feed-in tariffs, have been especially effective in encouraging citizens to reduce the carbon footprint in their homes through installing small-scale, clean energy generation technologies like household solar PV and wind turbines (Castaneda et al. 2020; Cherrington et al. 2013). Such schemes incentivise the uptake of these technologies by providing finance to install new technologies and in some cases paying people for the clean electricity that they generate, which in turn can provide substantive social and economic benefits for participants (Balta-Ozkan, Yildirim, and P. M. Connor 2015; Curtin, McInerney, and Johannsdottir 2018; Grover and Daniels 2017; Hitaj and Löschel 2019; Winter and Schlesewsky 2019). Beyond mitigating CO_2 emissions, research suggests that these technologies can provide people with additional income, reduce energy bills and help to alleviate fuel poverty, with related second-order benefits for health, social capital and wellbeing (Berka and Creamer 2018; Kosugi, Shimoda, and Tashiro 2019; Kucher, Lacombe, and S. T. Davidson 2020; Richler 2017; Waal 2020).

For these benefits, however, accessing grants and subsidies for low-carbon technologies can be expensive in time, knowledge and money (Coffman et al. 2016; Fikru 2020; Lukanov and Krieger 2019; Sunter, Castellanos, and Kammen 2019). Making use of these schemes generally requires people to own their homes, while most still also incur some upfront time and financial cost, or payback of finance (Rai, Reeves, and Margolis 2016; Richler 2017; Sommerfeld, Buys, and Vine 2017). As such, higher income groups are distinctly better placed to access and benefit from low-carbon technology grants and subsidies than those living on lower incomes or experiencing poverty and deprivation, creating a persistent and pervasive issue of inequality and energy justice (Max Lacey-Barnacle 2020; McCauley et al. 2019a; B. K. Sovacool, Lipson, and Chard 2019). Research has confirmed that this inequality exists in a number of places, with lower income groups and communities found to be less likely to access and benefit from domestic energy initiatives in the US, Australia, Italy, Tokyo, Switzerland, Sweden, the UK and others (Coffman et al. 2016; Fikru 2020; Kucher, Lacombe, and S. T. Davidson 2020; Li and Yi 2014; Kwan 2012; Lukanov and Krieger 2019; Sunter, Castellanos, and Kammen 2019; Wolske 2020). This inequality poses a fundamental problem for governments concerned with ensuring a "just" transition: because technologies supported by grants and subsidies can often have substantive social and economic benefits for users, the concentration of those benefits within mid- and high-income groups risks repeating and further exacerbating existing socioeconomic disparities.

Understanding how these inequalities emerge and evolve is thus essential to ensure that policies designed to promote the uptake of new, low-carbon technologies do not simply become mechanism of replicating or exacerbating existing injustices. In addition to cost, however, informational barriers also exist around accessing such schemes, such as knowing about the policy in the first place, how to initiate action, where to find up-front finance if required, technical capacity and knowledge of the installation process, along with who to approach as trusted installers and intermediaries to conduct the work. One way in which these informational barriers can be overcome is through peer diffusion. Previous empirical research has found consistently that areas with already-high rates of uptake are more likely to see more people install new technologies than places where uptake has not previously occurred, through the influence of early adopting peers and neighbours who can help to inform others about relevant bureaucratic processes, connect them with experienced actors, convey the benefits and reduce informational uncertainties (Bach, Hopkins, and Stephenson 2020; Bollinger et al. 2012; Busic-Sontic and Fuerst 2018; Carattini, Péclat, and Baranzini 2018; Korcaj, Hahnel, and Spada 2015; Rai, Reeves, and Margolis 2016; Richter 2014; Snape 2016; Thormeyer, Sasse, and Trutnevyte 2020).

While typically held apart in empirical work, however, it follows that peer diffusion can contribute to widening socioeconomic inequalities in low-carbon technology access, since higher incomes within a group or area increases the likelihood of uptake in the first instance, *which in turn creates scope for peer diffusion to take place.* Combined with socioeconomic circumstances being persistent over time, these factors create an environment whereby early inequalities can be locked in, leaving social and economic benefits of the policy concentrated strongly within already higher-income groups at the perpetual exclusion of those on lower incomes (who arguably stand to benefit the most from payments or savings). Considering these factors together is essential to creating a more complete picture of the social and economic forces that cause inequalities to emerge and widen not just in feed-in tariffs but in any low-carbon technology policy, to ensure policymakers are equipped to create more inclusive net zero energy initiatives going forward.

To help understand this process, this paper thus advances a novel “feed-in tariff trap” theory, which posits that socioeconomic factors and peer diffusion combine to effectively “trap” socioeconomic inequalities in low-carbon technology uptake over time. Using a combination of mixed effects and piecewise structural equation modelling, this theory is tested on 21,206 household-level solar PV and wind feed-in tariff installations across 6,976 data-zones in Scotland between 2009 and 2020. Analysis shows that (1) household solar PV and wind are adopted consistently in higher-income areas, (2) peer diffusion is strongest in areas with high early adoption rates, and (3) socioeconomic conditions are extremely temporally stubborn. These findings lend considerable support to the feed-in tariff trap theory, revealing that that financial and social factors which drive access inequalities are interlinked and temporally persistent, with stark implications for anyone concerned with ensuring that the design of policies geared towards net zero are fair and equitable in future.

This paper makes two significant contributions to the literature. First, it demonstrates that inequalities in low-carbon technology uptake are not simply a static function of disparate economic or social mechanisms, but that these factors are both connected and stubborn. This is important: subsidised initiatives which rely on people accessing services themselves are vulnerable to this combination of deprivation and diffusion creating similar inequality traps, and so understanding this relationship can help to avoid such issues in future, particularly as new schemes like Scottish Government support for low-carbon heating and energy efficiency come into play. Second, it introduces a novel piecewise structural equation approach, which can be a powerful tool for more robustly unpacking causal mechanisms and complex theories within the wider energy policy field (Jonathan S. Lefcheck 2016b). To the author’s knowledge, piecewise structural equation modelling has not yet been applied within mainstream energy policy literature, and so this serves as an innovative and powerful contribution for promoting novel theory-testing approaches that are often found lacking in the discipline (B. K. Sovacool, Hess, et al. 2020b).

2.2 Theory

Both income and peer diffusion have been found to be separately important mechanisms in driving the uptake of household solar PV and wind technologies under low-carbon technology grants and subsidies. Income has been found to be an especially powerful determinant of household solar PV uptake in a number of locations. People with higher incomes and in higher-income areas have been found to be more likely to adopt household solar PV than lower income groups in the US, Australia, Italy, Tokyo, Switzerland, Sweden, the UK and others (Coffman et al. 2016; Fikru 2020; Kucher, Lacombe, and S. T. Davidson 2020; Li and Yi 2014; Kwan 2012; Lukanov and Krieger 2019; Sunter, Castellanos, and Kammen 2019; Wolske 2020), revealing a fairly widespread and entrenched socioeconomic inequality. Beyond financial means alone (which are of course fundamental), this disparity is linked to a number of different mechanisms. Lower income groups are less likely to own their homes and often live in built-up urban areas, creating issues of capacity for installation both legally and physically, while people who live in poverty are often more concerned with more immediate basic needs like affording food and housing, in addition to dealing with the psycho-social stresses that poverty itself can create (McDonald et al. 2020). Under these conditions then, and with the often steep up-front costs of installing new energy systems, finding the time and resources to navigate policy, finance, technical and installation processes can be a monumental challenge. Recent environmental justice research reveals that these inequities can also have gendered, racial and health dimensions (Lukanov and Krieger 2019).

Beyond these well-established socioeconomic inequalities, however, significant informational barriers also exist in accessing low-carbon technology grant and subsidy initiatives: people interested in the policy require some degree of political efficacy to know how to initiate action, while knowing how to then navigate the installation process, which suppliers can be trusted, and who to contact regarding finance, tariffs and payments can be unclear in the first instance (Rai, Reeves, and Margolis 2016). One way in which these informational barriers can be overcome is through peer diffusion (Alipour et al. 2020; Wolske, Gillingham, and Schultz 2020; Bach, Hopkins, and Stephenson 2020; Balta-Ozkan, Yildirim, and P. M. Connor 2015;

Bollinger et al. 2012; Korcaj, Hahnel, and Spada 2015; Busic-Sontic and Fuerst 2018; Richter 2014; Thormeyer, Sasse, and Trutnevyte 2020; Carattini, Péclat, and Baranzini 2018). Peer diffusion refers to the diffusion of ideas, practices or behaviours through social interactions within shared networks and communities (Bollinger et al. 2012; Wolske 2020). This may be between neighbours, within similar social groups and networks of both place and interest, or through digital communication (Kloppenburg and Boekelo 2019). In terms of low-carbon technologies, people within similar communities or social networks are more likely to install new technologies where neighbours, friends or other members of that network have already done the same (Bollinger et al. 2012; Noll, Dawes, and Rai 2014; Rode and Weber 2016), or where other charities and organizations are present and working to actively raise awareness (Balta-Ozkan, Yildirim, P. M. Connor, et al. 2021). Members of a network, neighbourhood or community who have their own systems can stimulate diffusion by reducing uncertainty associated with technical, bureaucratic and financial processes, helping others within the network to overcome informational barriers, while the visible presence of installations within an area can also help generate wider interest.

Empirical quantitative research into the effects of peer diffusion thus finds that previously installed low-carbon technologies within in an area is strongly linked to the likelihood of future installations within the same area (Bollinger et al. 2012; Richter 2014). This has been found consistently at the neighbourhood, post-code and county levels across various contexts (Bach, Hopkins, and Stephenson 2020; Noll, Dawes, and Rai 2014; Rai, Reeves, and Margolis 2016; Thormeyer, Sasse, and Trutnevyte 2020). While limitations exist in explaining diffusion beyond defined spatial units (since social networks are rarely confined to single geographical areas), evidence suggests that peer diffusion within geographic units is strong and persistent (Carattini, Péclat, and Baranzini 2018; Thormeyer, Sasse, and Trutnevyte 2020.

2.2.1 Feed-in tariff trap

For this individual importance, however, it makes sense for these two factors to be considered together, especially for schemes such as the feed-in tariff and other low-carbon technology grants and subsidies, which rely on people opting-in and initiating action themselves. Since peer diffusion relies on there being people within a neighbourhood or community who have already accessed support, and since higher income groups are more likely to access the low-carbon technologies at higher rates overall, it stands to reason that peer diffusion could effectively lock in or even exacerbate socioeconomic inequalities in these technologies over time. Put practically, higher incomes/lower levels of poverty and deprivation increase the likelihood to access support for low-carbon technologies in the first place, which in turn helps to reduce informational barriers within communities and neighbourhoods; create a network of trusted installers and intermediaries; reduce technical and policy uncertainties and ultimately create the potential for peer diffusion to happen (Rai, Reeves, and Margolis 2016; Rode and Weber 2016; Wolske, Gillingham, and Schultz 2020). Conversely, in areas of higher poverty and deprivation, the scope for adopting new technologies is restricted by issues of ownership, poverty stressors and priorities and financial capacity, which means that the scope for diffusion to take place in future is also limited as a result: those networks are not established, and so informational barriers remain. This creates a *double disadvantage* for groups and areas experiencing higher levels of poverty and deprivation, in that two avenues for potential uptake are subsequently restricted. It thus follows that areas with lower levels of deprivation are more likely to access initiatives such as the feed-in tariff and in turn reduce informational barriers within these areas, compared to areas with higher levels of deprivation, low levels of adoption and subsequently limited scope for diffusion.

Rather than the independent effects of these mechanisms, then, the intrinsic link between the two creates an environment wherein inequalities can be accelerated. The "feed-in tariff trap" theory presented here thus aims to unpack this relationship. In essence, it posits that income and poverty levels predominantly determine the likelihood of uptake within a given locality, which in turn allows for peer diffusion to take place. If inequalities emerge among early adopters, then these inequalities can be compounded by peer diffusion. Combined with the temporally enduring nature of socioeconomic conditions (i.e. high-income areas tend to remain high-income areas while low-income areas tend to remain low-income over time), these effects create an inequality "trap", whereby more affluent groups benefit from both socioeconomic capacity and the subsequent peer diffusion effects, while deprived groups are limited on both fronts, leading to extremely stubborn inequalities in low-carbon technology uptake over time. Figure 2.1 visualises this model more clearly.

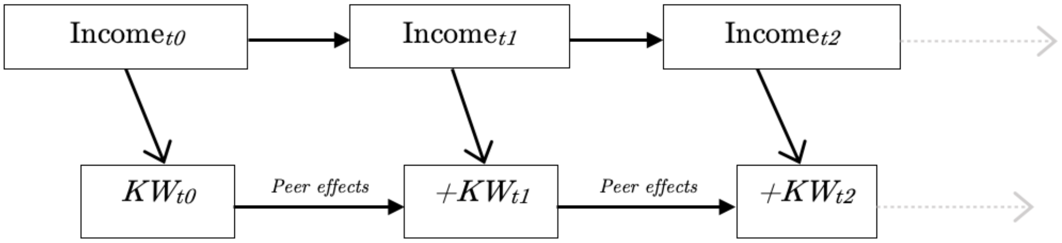


Figure 2.1: Feed-in-tariff trap.

In this figure, the horizontal arrows represent the link between each factor and the same factor at the previous time point (KW represents installed low-carbon technology uptake within a given area). The diagonal line represents the link between income and uptake. Across all time periods, lower income/higher levels of poverty and deprivation are associated with lower likelihood of household-level low-carbon energy being installed. Previous levels of uptake in an area then affect the likelihood of uptake in future through peer effects such as learning and word-of-mouth from neighbours, social networks and community members. Socioeconomic conditions as represented here by income is then linked to socioeconomic conditions within an area at $t-1$, $t-2$ and so on. This final link is critical: the trap theory does not simply suggest that poverty or income and peer diffusion are both important determinants of low-carbon technology uptake at any time point, but that socioeconomic conditions are also extremely temporally stubborn. Because of this stubbornness, these inequalities can deepen and grow.

These relationships are finally hypothesised as:

Hypothesis 1: *Higher-income areas are likely to have higher levels of domestic low-carbon technology uptake than more deprived, lower-income areas.*

Hypothesis 2: *Areas where low-carbon technologies have already been installed are more likely to see new uptake than areas with no prior installations.*

Hypothesis 3: *Previous income levels strongly predict future income levels.*

2.3 Model

To test the feed-in tariff trap theory, piecewise structural equation modelling (SEM) was selected as a method with unique capacity for unpacking its component parts. Structural equation modelling is a form of path analysis that resolves complex multivariate relationships between variables (Johnathan S Lefcheck 2019). In terms of theory-testing, SEM is a powerful tool for understanding relationships beyond regression analysis alone (Bollen and Pearl 2013; Shipley 2016). This is because variables in SEM can take the form of both predictors and responses: SEM lends itself especially well to testing cyclical, bidirectional, cascading or mediating effects with several output variables, where traditional models tend towards more straightforward, independent linear analysis (Grace 2008). In the case of the feed-in-tariff trap, relationships are expected between the same variables across several time points as both predictor and response. SEM is thus preferred over a series of basic multiple regressions (although these are also tested for robustness across a number of different multi-level specifications, with results included in the Appendix).

Also known as confirmatory path analysis as initially proposed by Shipley (2004), Piecewise SEM is a particularly effective and computationally efficient version of SEM where latent variables are not incorporated (Jonathan S. Lefcheck 2016a; Shipley 2016; Stenegren et al. 2017), with in-built ability to deal with hierarchical and multi-level models. The root of piecewise SEM is a set of equations representing the individual paths between observed variables within the theoretical model, that are then pieced together and assessed for model fit within a single causal framework (rather than simply running a series of independent or multiple linear regressions on various different dependent variables). In this case, the theoretical model is captured in the paths outlined in the hypothesized “feed-in tariff trap” from Figure 2.1. The equations representing the paths between these variables in the trap model are given in section 4.4.

Within that causal framework, piecewise SEM goodness-of-fit procedures consider the entire model together, rather than solely the statistical significance of single variables, meaning that the full theoretical model is tested for significance, rather than individual variables in isolation. That is, piecewise SEM goodness-of-fit measures test for significance in all possible directional relationships and pathways between all variables within a model, identifying spurious or "oversaturated" models using d-separation tests, and so models need to be carefully specified from robust and considered theory-building processes in advance (Zur, Aballea, and Sherman 2018). All specified response variables within the model are given coefficients and R^2 figures to assess significance of and variance explained by the specified relationships.

2.4 Data

With government bodies such as the Just Transition Commission dedicated to ensuring an equitable path to net zero (Scottish Government 2019), Scotland is a useful case in which to examine these inequalities. Through the Community and Renewable Energy Scheme (CARES), the Scottish Government have made a concerted effort to promote the growth of local, community and small-scale energy systems under the feed-in tariff. The rapid growth in wider local energy systems from 204MW at the start of the decade to over 896MW installed capacity today is the result of ambitious targets (1GW installed capacity by 2020, 2GW by 2030) which were extended after the initial target of 500MW installed capacity by 2020 was surpassed 5 years early (Energy Saving Trust 2015). For this impressive feat, however, analysis conducted in 2013 suggested that income inequalities in access to local- and household-level energy were already emerging (Haggett et al. 2013). Given the rapid expansion since then in solar PV and given Scotland's vast natural capacity for wind, there is distinct potential for this inequality to have grown considerably.

The Scottish Government also collects highly localised data on poverty and multiple deprivation, providing an opportunity to understand this relationship in more depth at a high resolution. Two key datasets were thus combined for the analysis: the Scottish Indices of Multiple Deprivation (SIMD) and OFGEM feed-in tariff registration information.

2.4.1 Scottish indices of multiple deprivation

The SIMD data is collected by the Scottish government every 4 years and includes 38 indicators of deprivation across 7 categories of income, employment, health, education, crime, housing and access to services (Scottish Government, 2020). This data is divided into 6,976 data-zones: small-scale areas of 500-1000 people, which then fit into electoral wards (3-5000 people) and local council areas. Prominent differences exist across local authority areas in particular: different councils can differ starkly in their geographic and demographic make-up, bureaucratic process, executive and council partisanship and available funding. To account for these unobserved differences, random effects were applied with the piecewise SEM model using random intercepts on local authority areas. Random intercepts allow for the baseline of the model to vary across local authority areas and account for these unobserved differences. These were deemed an appropriate inclusion over fixed effects through a Hausman test. Four waves of the SIMD were combined for use in this analysis: 2009 – the year before the feed-in-tariff was introduced, 2012, 2016 and 2020 – the most recent year available.

2.4.2 Feed-in tariff registrations

The feed-in tariff (FiT) was selected as the predominant example of a grant or subsidy policy for low-carbon technology uptake in the UK in recent years. Feed-in tariffs have been a powerful policy option for governments concerned with promoting citizen-led uptake of small-scale renewable energy generation in a number of places and with great success in doing so in pure generation terms (Allan and McIntyre 2017; Balta-Ozkan, R. Davidson, et al. 2013; Bayer and Urpelainen 2016; Cherrington et al. 2013; Hitaj and Löschel 2019; Sommerfeld, Buys, and Vine 2017; Winter and Schlesewsky 2019). Now replaced by the Smart Export Guarantee (Ofgem 2020b), the UK feed-in tariff was first proposed to help the UK meet renewable targets in line with EU Electricity Directive 2009/72/EC (Grover 2013). Under the policy, energy utility companies pay those who install low-carbon technologies such as household solar PV or wind for the clean energy they generate.

Feed-in tariff data was collected from OFGEM Feed-in Tariff registrations (Renewable Energy Foundation 2020). Data was scraped using Python from a Renewable Energy Foundation (2020) database, which has information on all FiT-registered small-scale renewable energy systems below 5MW in the UK. This information includes post code, size of installation, type of technology, ownership (domestic, community, industrial, commercial), parliamentary constituency and local super output area (LSOA), which corresponds to SIMD data-zones in the case of Scotland. According to Scottish government figures, as of June 2019, there was approximately 731MW installed feed-in-tariff capacity in Scotland (Energy Saving

Trust, 2020). The feed-in tariff data at the point this analysis was conducted accounted for 727.4MW, or 99.9% of that in total. Capacity was aggregated first by installation date to correspond with the waves of the SIMD. Installations pre-2009 (systems installed bfore FiT implementation which were able to be registered retrospectively) were matched to the 2009 wave of the SIMD; capacity installed between 2009 and 2012 were matched with the 2012 wave; installations between 2012 and 2016 were matched with the 2016 wave; and all installations post-2016 were included as 2020. Capacity was aggregated for each data-zone and wave and merged with the SIMD by data-zone. To give a better idea of how the data is combined and the distribution of FiT capacity in Scotland, installed capacity (kW) by data-zone across Scotland is mapped below.

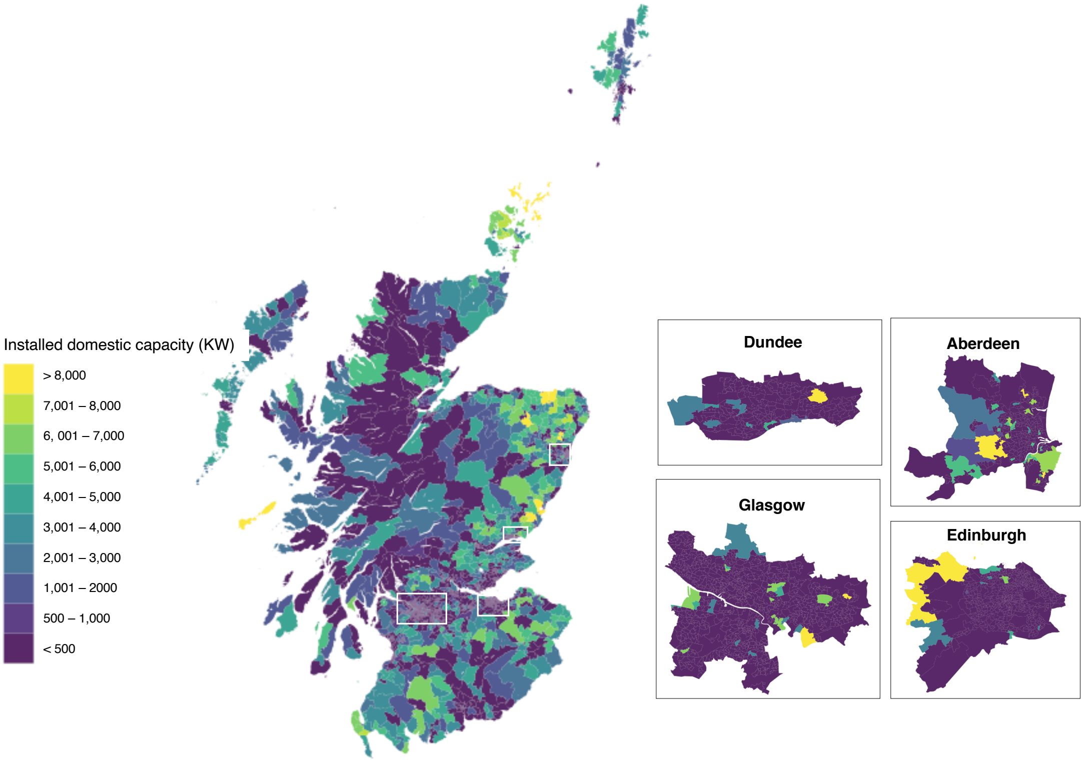


Figure 2.2: Installed domestic FiT capacity in Scotland by SIMD data-zone as of 2020.

2.4.3 Included variables

Within the model there are two key variables: new capacity added (i.e. uptake of new low-carbon technologies), and income deprivation. As per the feed-in tariff trap model from Figure

2.1, these variables are expected to predict one and other across time points, and to function as both dependent and independent variables within the model.

New capacity added

The key dependent variable is a binary response indicating whether or not new domestic energy capacity was added within a data-zone at a given time point i.e. whether uptake of new low-carbon technologies occurred. This was chosen predominantly because it is not anticipated that the relationship between previous and future levels of capacity are strictly linear. Due to the relatively small number of people within data-zones themselves, the amount of capacity that can realistically be added as time goes on naturally decays. A binary variable where 1 = new capacity added and 0 = no new capacity was thus created as a more consistent indicator across all time points.

Income deprivation

The second key variable within the model is level of income deprivation within a data-zone, which is measured in the SIMD as the proportion of people within a data-zone claiming state benefits, ranging from 0-60% of the data-zone population. Income deprivation is selected as the main independent variable for two reasons. First, actual income is not available consistently in Scottish data at this resolution and so income deprivation is the most meaningful measure available. Second and more fundamentally, because income deprivation is specified within the SIMD as the proportion of people within a given data-zone claiming non-pension state benefits, it more closely corresponds with poverty and other measures of deprivation than purely income alone, meaning that the social impacts outlined in the literature review (rather than solely financial aspects) are also somewhat accounted for. Through preliminary data exploration, variance inflation factors showed income deprivation to absorb a vast majority of the impacts of other theoretically interesting deprivation measures. Control variables typically are not included within structural equation models. This is the case here.

2.4.4 Written equations

The basic component equations from the feed-in tariff trap model with the inclusion of random intercepts on local authority areas are specified as follows. The first equation is a generalized linear mixed effects model, where new capacity installed is the key binary dependent variable. The second equation is a linear mixed effects regression where income deprivation is a continuous linear output. PiecewiseSEM has no issue handling both logistic and linear regression within the same model framework.

$$install_{ij,t} = \beta income_{ij,t} + \beta install_{ij,t-1} + u_j + \epsilon_{ij} \tag{2.1}$$

Where

$$income_{ij,t} = \beta income_{ij,t-1} + u_j + \epsilon_{ij} \tag{2.2}$$

The first equation, then, uses new installed capacity as the output variable. In this equation, $install_{ij,t}$ is a binary variable indicating whether or not new capacity was added within a data-zone i at time t; $\beta income_{ij,t}$ is the coefficient on level of income deprivation within a data-zone at time t; $\beta install_{ij,t-1}$ is the coefficient on whether or not a data-zone had new installed capacity at the previous time point to capture peer diffusion; u_j is the random intercept for local authority area j; and ϵ_{ij} are finally the level-1 residuals, which are assumed to be normally distributed.

The second equation is then a linear mixed effects regression with the same basic overview, only with income deprivation as the main dependent variable, and income deprivation at the previous time point as the key predictor. These models were tested independently as mixed effect regressions using the lme4 package Bates et al. n.d., before testing for the full theoretical model when pieced together within the feed-tariff-trap framework. Piecewise SEM analysis was conducted using the piecewiseSEM package in R (Johnathan S Lefcheck 2019).

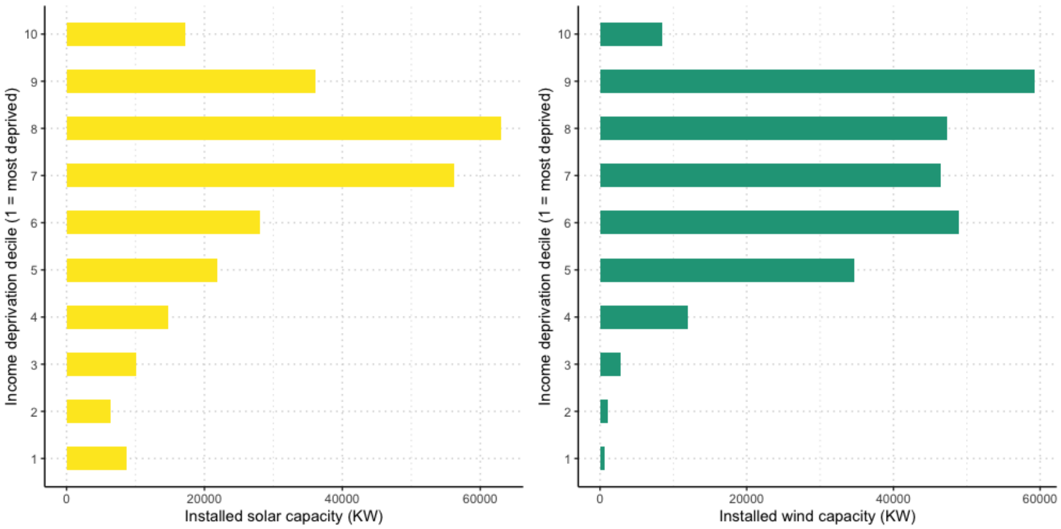


Figure 2.3: KW feed-in-tariff capacity by socioeconomic group.

2.5 Results

2.5.1 Descriptive statistics

Basic descriptive statistics in Figure 2.3 give a picture of the distribution of installed capacity in Scotland, broken down by technology and deprivation groups as of 2020. Within the SIMD, data-zones are ranked on their overall deprivation level, which is determined by the combination of all 38 measures from within the SIMD. This deprivation rank is divided into deciles for visualization.

Figure 2.3 thus shows a substantial disparity across deprivation deciles for both solar PV (left) and wind systems (right), with installed capacity concentrated heavily in medium-high income groups. In both cases, the very lowest income groups lag significantly behind, revealing a fairly stark inequality as anticipated. Also interesting from these descriptive statistics is that the share of installed capacity appears to tail off at the highest group for wind and the upper-middle groups for solar, which is consistent with previous analyses (Grover and Daniels, 2017; Lukanov and Krieger, 2019). This could be for a number of reasons. Given that household wind and solar are often cited as something that could potentially save on energy costs, it may be that those in the most affluent brackets have a less urgent need. It may also be a question of values, although this is not addressed here.

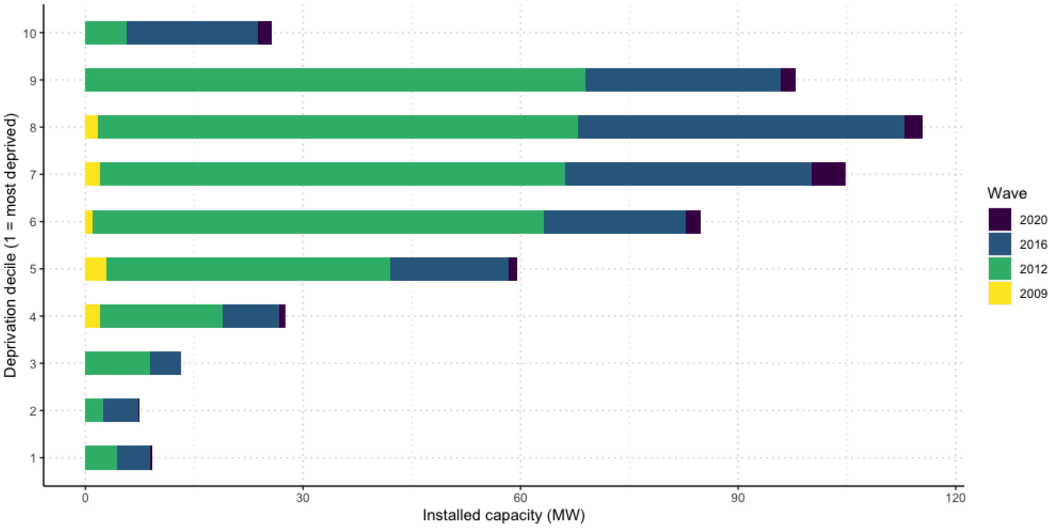


Figure 2.4: MW feed-in-tariff capacity by SIMD wave.

Figure 2.4 then presents the growth in total feed-in tariff installations across each wave of the SIMD, demonstrating how this inequality has expanded over time. As is to be expected, there is a considerable spike in the growth of FiT installations in the 2012 wave immediately after feed-in tariff rollout in 2010. While this is the biggest growth spurt of new installations, between 2012 and 2016 growth is also considerable, particularly in the higher middle groups 7 and 8. Between 2016 and 2020, the number of new installations then tail-off considerably as the policy was wound to a close.

Table 2.1 finally shows the results of the generalized linear mixed effects regression with new capacity installed as the dependent variable. For this analysis, random effects were also added on data-zone to account for there being repeated observations, and on year to account for the decay in uptake over time. From this table, two things are clear. First, the R^2 (variance explained within the model) is increased substantially with the inclusion of mixed effects on data-zones and local council areas. This suggests that differences in local council areas are substantial and so accounting for these with mixed effects is justified. Other model specifications were tested for robustness (no local council effects, solar and wind only) and outputs are given in the Appendix. The relationship holds across all analyses, with the generalized linear mixed effects model showing the strongest fit.

Second, the mixed effects regression output demonstrates that each of the key inde-

	New installed capacity
Predictors	*Log-Odds*
(Intercept)	-3.573***
Income deprivation	-0.597*** (0.069)
KW installed capacity $_{t-1}$	0.536*** (0.103)
Random Effects	
σ^2	3.29
τ_{00} Year	1.07
τ_{00} Data Zone	0.86
τ_{00} Council area	1.17
Observations	20922
Marginal R2 / Conditional R2	0.044 / 0.253

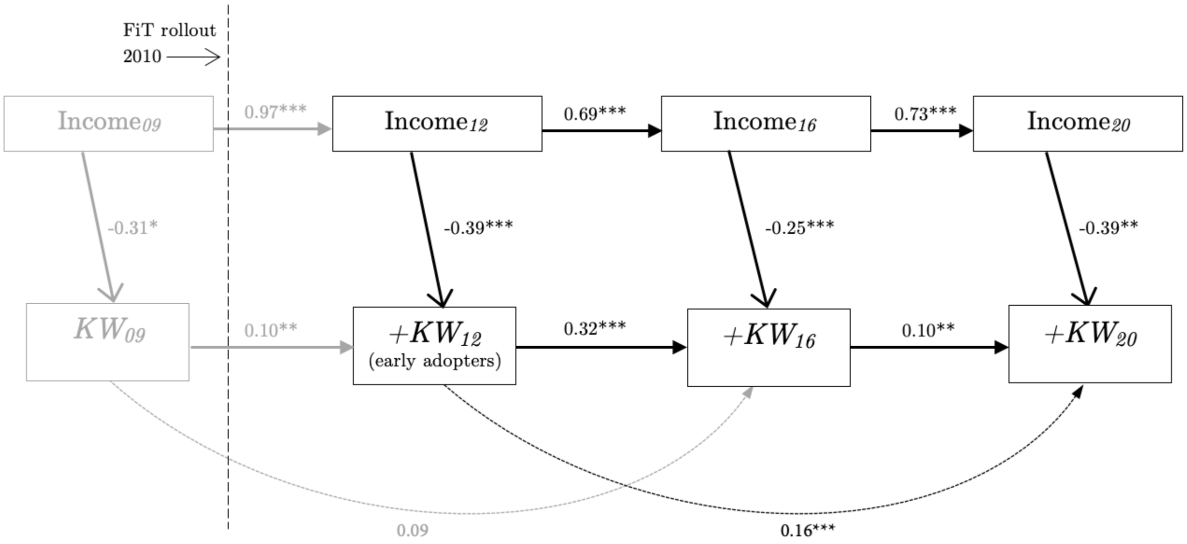
Table 2.1: Generalized linear mixed effects regression.

pendent variables – income deprivation and lagged installation – are statistically significant. This lends tentative support to H1 and H2, showing that higher levels of income deprivation reduce the likelihood of a new uptake under the feed-in tariff (H1), and that capacity being installed in an area already increases the likelihood (H2), both significant at the $p < 0.005$ level. While independently significant, however, what this model does not demonstrate is how these factors link together over time within the feed-in tariff trap model. For this, we turn to the output of the piecewise SEM.

2.5.2 Structural equation model

The piecewise SEM model was specified using the hypotheses and path diagram given in Figure 1. Accepted model fit measures for piecewise SEM are Fisher's C, which gives local estimation for piecewise SEM equivalent to chi-squared ($\tilde{\chi}^2$), and the Root Mean Squared Error of Approximation (RMSEA) (Lefcheck, 2016a; Shipley, 2016). In the case of Chi-squared and equivalents such as Fisher's C for assessing model fit, a p-value of > 0.05 (rather than < 0.05 as is typically the case with p-values) indicates a good model fit, with a higher p-value generally desirable. For RMSEA, the thresholds are < 0.08 for an adequate model fit and < 0.05 for a good model fit. In the model presented, the p-value on Fisher's C is 0.397

(> 0.05) with a RMSEA of 0.011, indicating that the model is a good fit overall.



Fisher's C (χ^2 equivalent) = 16.831 with p-value 0.397 on 16 df.
RMSEA = 0.011 (threshold < 0.08, good fit).
AIC = 76.831
** $p<0.05$ ** $p<0.01$ *** $p<0.001$*

Figure 2.5: Output of piecewise structural equation model.

Figure 2.5 gives the full output of the structural equation model. On the left of the figure, the greyed out sections represent the 2009 wave of the SIMD before the feed-in tariff came into play in 2010, represented by the dotted vertical line. KW_{12} is then the 2012 wave of the SIMD, which is the first wave after the feed-in tariff came into play. This has been labelled the "early adopter" wave to reflect. Standardized estimates rather than unstandardized coefficients are provided to allow us to better compare the magnitude of the effects of each independent variable.

From these estimates, there is considerable support for the feed-in tariff trap. As anticipated, levels of income deprivation are consistently significant determinants of the likelihood of new installations (although somewhat less so prior to FiT rollout), with data-zones with high levels of income deprivation being less likely to access the feed-in tariff than less deprived groups at all time points, lending support to H1. Installed capacity at $t-1$ is then a strong indicator of the likelihood of adding new capacity at t, significant at the $p < 0.001$ level for each of the included waves of data. This is true also of deprivation, with model coefficients suggesting that previous levels of income deprivation are a very strong indicator of future levels, lending support to H2 and H3 respectively.

In terms of the magnitude of these effects, some relationships and time periods have stronger impacts than others. Of these significant causal relationships, the impact of income deprivation on the likelihood of installation of new capacity within a given data-zone is consistent across each time period, ranging from -0.25 to -0.39 respectively, showing that areas with higher levels of income deprivation are significantly less likely to have household systems installed under the feed-in tariff than higher income, lower deprivation areas. The relationship between previously installed capacity on the likelihood of new uptake is also strongly significant, particularly between 2012 $>$ 2016: for this time period, peer diffusion was an even stronger predictor than income deprivation (-0.25 vs. 0.32 respectively). Comparatively, the peer effect from 2016 $>$ 2020 is then smaller, although still positive and significant.

Beyond the direct relationships between immediately prior time points, the analysis also revealed significant effects from previous time points as represented by the dotted lines. Accounting for these effects is important since peer effects may not necessarily be tied exclusively to capacity installed at the immediately previous time point. In the case of installed capacity, significant links were drawn from 2012 $>$ 2016 and 2012 $>$ 2020. Perhaps surprisingly, it is actually the case that installed capacity in 2012 has a stronger effect on the likelihood of new capacity in 2020 than installed capacity in 2016. That is, installed capacity in a data-zone by the *early adopters* in the years immediately after the feed-in tariff was first introduced had a strong direct effect on the likelihood of installations in both 2016 and 2020. While there is some minor effect between the pre-FiT 2009 wave and installations among early adopters, the strongest modelled peer effects stem from this early adopter wave. This suggests that peer diffusion is most prominent in those data-zones with high levels of early adoption.

Finally, Table 2.2 shows the R^2 of each response variable within the model; that is, the amount of variance in each response variable explained by the predictor variables. Marginal R^2 gives the variance in each variable explained before mixed effects are included, while conditional R^2 includes the variance explained with full mixed effects applied. From these results, then, we can see that a significant amount of variance in the response variables are again accounted for within the model. In the case of new capacity being added, deprivation

Response variable	**Marginal R^2**	**Conditional R^2**
KW_{12}	0.07	0.23
KW_{16}	0.09	0.35
KW_{20}	0.03	0.11
Income deprivation$_{12}$	0.94	0.94
Income deprivation$_{16}$	0.87	0.87
Income deprivation$_{20}$	0.94	0.95

Table 2.2: Variance explained by SEM.

levels and previously installed capacity accounts for an average of 23% of variance within the data, ranging from 11% in 2020 to as high as 35% in 2016. These numbers are significantly higher than the respective marginal R^2 figures (KW_{12} jumps from 0.07 to 0.23 with the inclusion of mixed effects, for instance), showing that local council areas do account for considerable variance within the data.

More compellingly explained within the model, however, are levels of income deprivation, which are almost exclusively explained by deprivation levels at the previous time point. At its highest, income deprivation in 2016 explains an enormous 95% of the variance in deprivation levels in 2020; the lowest figure here from Table 1 is still as high as 87%, demonstrating that levels of deprivation are stubborn and consistent over time. This finding lends robust support to H3.

2.6 Discussion

This analysis provides strong evidence for the existence of an inequality trap in the distribution of low-carbon technology uptake in Scotland that is consistent over time. Inequalities exist and have widened in the uptake of household-level energy systems along lines of deprivation, with more income-deprived communities significantly less likely to adopt than areas with lower levels of income deprivation across all timepoints. In addition to this, however, peer effects also appear to be significant and robust across each time period, suggesting that diffusion within data-zones themselves is a strong mechanism in influencing adoption. Critically, income deprivation is a strong indicator of adoption in 2012 immediately after the feed-in tariff was first introduced, which then has strong peer effects at both 2016 and 2020, suggesting that the inequalities that emerged in the immediate years after the feed-in tariff was introduced have been repeating over time, through the heightened influence of early adopters. Combined within the structural equation model, these results suggest that a combination of deprivation levels and peer effects have contributed to widening the gap in low-carbon technology uptake across socioeconomic groups in Scotland. These results thus point to inequalities in access to low-carbon technologies being more than simply a static function of socioeconomic circumstance alone. Rather, income deprivation affects the likelihood of adoption, which in turn plants the seed for peer diffusion to take place and lock in those socioeconomic inequalities over time.

Worth noting finally is something that the SEM model output here does not show, which is the impact of low-carbon technology uptake on income deprivation. This relationship was tested but produced inconsistent and spurious model fit results, suggesting that the relationship is not statistically significant. For the feed-in tariff trap this *is* significant, however. Because installed capacity does not significantly shift the dial on income deprivation within data-zones, and because income deprivation is so temporally stubborn, this suggests that even in data-zones with high levels of installed capacity, those experiencing income deprivation may not be benefiting directly. This potentially signals a dual inequality gap: (1) between deprived and less-deprived data-zones, and (2) between deprived and less-deprived households within data-zones as well. Because actual income levels are not available at this level in Scotland over time, this within data-zone inequality cannot be accounted for, although it is broadly supported in findings from household-level studies in other contexts and locations (O'Shaughnessy et al., 2020).

2.6.1 Limitations

For these results, there are some elements missing from the analysis itself. First and most fundamentally, the proxy used to capture peer effects is just that: a proxy. While useful in lending support to the theorised causal relationships, more dedicated, widespread survey research is ultimately required to capture actual peer diffusion explicitly. Survey research which captures demographic, individual and political information, while not available in Scotland at this spatial resolution, can give a greater depth of understanding not just of the socioeconomic and demographic elements of communities but behavioural and individual information too, which will also have some part to play. Understanding diffusion beyond immediate geography (i.e. through social network analysis) or including the location of energy-related community organizations would also glean deeper insights into diffusion across different groups and locations.

Following from this, where this analysis considers household-level solar PV and wind adoption, it does not unpack personal experience or the diverse challenges that different groups (people with disabilities, migrant communities, or people of colour, for instance) face. Engagement directly with those communities themselves will be crucial to developing a more rounded and complete picture.

2.7 Conclusions and policy implications

These findings have stark implications for energy justice scholars and policymakers concerned with the just transition more broadly. Given the alleged socioeconomic benefits of household-level low-carbon technologies, the "feed-in tariff trap" effect uncovers a potential for inequalities not only to emerge as a result of low-carbon technology initiatives, but for existing socioeconomic inequalities to be further exacerbated as benefits are locked into clusters of higher income, early adopter groups. New injustices may arise as a result, or intergenerational injustices may be replicated as an unintended externality. While the feed-in tariff undoubtedly helped to increase the use of low-carbon energy technologies more generally then, its introduction also created a significant inequality issue, in part because it is a subsidy which relies on individuals opting-in to the scheme and navigating what can be very expensive, complex, resource-intensive processes. Its winding down now leaves the Scottish and UK Governments with an opportunity to design something more deliberately equitable.

This chapter thus shows that avoiding the trappings of the feed-in tariff in future will require not just financial incentives, but consideration of how best to overcome the social, procedural and informational as well as financial barriers for lower-income groups. Dedicated efforts to engage those households and make the process as straightforward as possible - and even to remove the financial and procedural burden on those households altogether - will thus be key to delivering the benefits of low-carbon technologies for low-income areas and households. The following chapters in this thesis explore ways that this could happen in practise, through more local energy approaches.

Chapter 3

Community energy for a just transition

The previous chapter demonstrated that financial, social and informational factors are all crucial to the evolution of an inequality "trap" in the uptake of low-carbon technologies. Overcoming those barriers and breaking that trap will thus require more than simply targetted financial support, but rather support for households to know where to seek skills and expertise, how to navigate grant and subsidy processes, how to overcome legal issues with things like housing tenure, and how to carry through installations in often challenging circumstances.

The following chapter takes those learnings and explores one alternative way that low-income groups may benefit from low-carbon technologies without having to break down all of those barriers themselves: community energy. Within this thesis, community energy is of specific interest. Because community energy groups are comprised of people often with deep expertise and political efficacy, with access to wider finance and legal support too, community energy groups are well-placed to overcome the barriers and forces identified in the previous chapter and bring benefits of low-carbon technologies into low-income areas. Although these benefits may be typically more holistic, there is potential for community energy to play a role in breaking the inequality trap and supporting a more just net zero transition overall.

This chapter thus explores that potential through quantitative analysis of who has benefitted from community energy in Scotland to date, to understand if community energy has managed to deliver benefits into low-income areas, and the implications thereof for designing fairer net zero policies. This chapter was published as an independent article in *Energy Policy* in 2021, after robust peer review and additional modelling.

3.1 Introduction

Understanding who benefits from low-carbon technologies such as household solar PV or heat pumps is crucial to ensuring that the transition to net zero is both fair and equitable (Dolter and Boucher 2018; Grover and Daniels 2017; Lukanov and Krieger 2019; Sunter, Castellanos, and Kammen 2019). Grants and subsidies for low-carbon technologies incentivise the uptake of small-scale clean energy technologies such as household solar PV or community wind by providing interest-free finance and in some cases paying individuals, communities and businesses for the clean electricity that they generate. In turn, this can provide substantive social and economic benefits: research shows that people who access such initiatives can in some cases generate considerable additional revenue, reduce their energy bills, and benefit from second-order effects such as alleviating fuel poverty, improved mental and physical health, social capital and community well-being (Berka and Creamer 2018; Grover and Daniels 2017; Kosugi, Shimoda, and Tashiro 2019; Richler 2017; Waal 2020).

For these benefits, however, research thus far has shown that higher income groups have benefitted at a far greater rate from low-carbon technology grant and subsidy schemes than lower income groups in a number of contexts, giving way to a pervasive issue of inequality and energy justice (Balta-Ozkan, Yildirim, and P. M. Connor 2015; Coffman et al. 2016; Fikru 2020; Lukanov and Krieger 2019; Sunter, Castellanos, and Kammen 2019). This research has taken place alongside extensive work into the benefits of community energy projects (Berka, MacArthur, and Gonnelli 2020; Berka and Creamer 2018; Creamer et al. 2019; Hewitt et al. 2019; M. Lacey-Barnacle and Bird 2018; Peters et al. 2018). Community energy projects have been found to have considerable impacts for the communities in which they are situated in the form of creating jobs, building local capacity and financing local projects through community benefit funds (Berka, MacArthur, and Gonnelli 2020; Berka and Creamer 2018; Energy Saving Trust 2020; Hewitt et al. 2019; Max Lacey-Barnacle 2020; Mirzania et al. 2019; Peters et al. 2018; Waal 2020). Although wider quantitative analysis of the distribution of these benefits is lacking, research has found that, in their role as locally organized intermediaries, community energy groups can help to absorb some of the financial, legal, time and knowledge burdens that have stopped lower income groups benefiting from low-carbon technologies so far (Becker, Kunze, and Vancea 2017; Goedkoop and Devine-Wright 2016; M. Lacey-Barnacle and Bird

2018; Rossiter and D. J. Smith 2018; Simcock 2016).

Because of this, there is scope for community groups to bring some of the benefits low-carbon technologies and initiatives into lower income, higher deprivation areas (O'Shaughnessy et al. 2020), compared to household-level uptake which relies far more on personal socioeconomic capacity and other key social factors as identified in the previous chapter. Previous empirical studies have yet to consider household and community installations together in this way, quantitatively and comparatively, leaving potentially significant differences in who benefits along these lines so far uncovered. Deeper insights into these differences can provide a more nuanced picture of distribution of low-carbon technology benefits from which policymakers can build more equitable and effective initiatives in future. As both the Scottish and UK Governments ramp up their efforts around heat decarbonisation through heat pump roll-out and energy efficiency in particular (**Scottish Government 2022**; UK Government 2020), these findings can provide valuable and pertinent lessons for avoiding potential justice issues while also increasing the scope of uptake in harder to reach areas, households and communities.

The UK feed-in tariff is a particularly timely case in which to explore the distributional implications of low-carbon technology subsidies: the policy has recently been wound down after operating from 2010-2020 (Ofgem 2020a), allowing for ex-post investigation of its impacts. While some research has been conducted into the distribution of feed-in tariff benefits in the UK (including in the previous chapter), this has largely taken place at earlier intermittent timepoints and has likewise tended to focus on household solar PV, without consideration for the role of community energy groups (Cherrington et al. 2013; Grover and Daniels 2017).

Combining large-N, micro-level data from the Scottish Indices of Multiple Deprivation (SIMD) and the OFGEM feed-in-tariff central register, this paper thus investigates the distribution of installations and payments under the feed-in tariff across Scotland from 2010 to 2020. The core research questions are: (1) how have payments under the feed-in tariff been distributed across deprivation groups in Scotland? (2) has the distribution of these payments differed at all between household-owned and community energy installations? and (3) has the distribution of payments differed at all between technology types? These questions are examined using distributional analysis and random effects within-between regression (REWB) on a total of 26,218 feed-in-tariff registered household and community wind and solar installations across 6,976 micro-level data-zones in Scotland. Payments from the feed-in tariff in Scotland are first mapped against SIMD data-zones, and then visualised in a series of charts showing feed-in-tariff payments by deprivation group, broken down by ownership (household, community) and technology (solar PV, wind) type. The REWB regression then tests for statistical significance between levels of deprivation and levels of feed-in tariff payment to each data-zone, likewise disaggregated by ownership and technology type. It finds crucially that payments to household-level installations have flowed heavily into areas of higher incomes and lower deprivation, while payments to community energy systems have flowed predominantly into more deprived areas, particularly in the case of community solar. These findings suggest that community groups can be effective at bringing the benefit of low-carbon technologies into more deprived areas, with crucial lessons for governments considering low-carbon technology uptake schemes going forward.

3.2 Theory and hypotheses

Empirical work into low-carbon technology uptake has found consistently that stark socioeconomic inequalities exist in who accesses and ultimately benefits from such technologies and the grant and subsidy schemes designed to support them. Across countries, middle-higher income groups have benefitted at a substantially greater rate from policies designed to promote the uptake of low-carbon technologies like household solar PV than lower-income groups and areas, revealing a persistent and elusive inequality issue (Balta-Ozkan, Yildirim, and P. M. Connor 2015; Grover and Daniels 2017; Hitaj and Löschel 2019; Lukanov and Krieger 2019; Poruschi and Ambrey 2019). This is due to a few related procedural and economic factors as identified in the previous chapter: accessing grants and subsidies for low carbon technologies can be expensive in time, knowledge and money (Balta-Ozkan, Yildirim, and P. M. Connor 2015; Coffman et al. 2016; Fikru 2020; Sunter, Castellanos, and Kammen 2019; the process naturally requires at least some awareness of technological, policy and legal processes; those installing low-carbon technologies at household-level typically need to own their homes; while the process can also require considerable up-front financial investment (Rai, Reeves, and Margolis 2016; Richler 2017; Sommerfeld, Buys, and Vine 2017). As such, higher income households with the necessary financial and technical capacity are distinctly better placed to access and benefit from grant and subsidy policies designed to promote the uptake of low-carbon technologies than lower income groups.

For this illuminating research, however, prior studies have tended to focus heavily on the uptake of solar PV by people in their homes, at the expense of understanding how this distribution compares to other forms of ownership. Community energy is particularly interesting in this regard. Community energy projects generally take low-carbon technologies - such as wind turbines or solar PV - and installs them in a local place or building. Those assets then generate energy that is either used locally or exported to the national grid for a set price. These technologies are owned and governed by the local community in various configurations, and can generate significant amounts of revenue that in turn can be spent on local initiatives. Increasingly, community energy projects are exploring ways to integrate things like low-carbon heat and energy efficiency into their propositions, and have often turned their revenues towards dealing with social justice and fuel poverty issues, and have expanded into things like retrofit, energy efficiency and transport as well as generation (Berka and Creamer 2018; Creamer et al. 2019; M. Lacey-Barnacle and Bird 2018).

While differing in terms of how the benefits of energy systems are allocated – systems owned by people at the household-level equate to money directly in the pockets of users, whereas the benefits of systems owned by community groups are typically realised through local initiatives and projects –, both household and community energy systems can provide substantial socioeconomic benefits fro low-carbon technologies for those who can access them. Previous research has found that community energy initiatives in the UK in particular have generated considerable revenue for local areas, supporting community projects and local initiatives, creating jobs in maintenance and administration, and strengthening community ties and social capital overall (Akizu et al. 2018; Berka and Creamer 2018; Berka, MacArthur, and Gonnelli 2020; Creamer et al. 2019; Mirzania et al. 2019; Waal 2020).

Who has gotten to benefit from community energy projects more broadly, however, has gone so far unexamined, with existing research tending to be more qualitative and case-focussed in nature. Yet some findings suggest that community energy projects may be more successful at bringing the benefits of low-carbon technologies into more deprived, lower income areas than at the household-level. Qualitative research has found that community groups act as intermediaries in the establishment of local energy projects, absorbing the financial, political, informational and legal responsibilities associated with accessing policies like the feed-in tariff or other grant, loan and funding schemes (Bauwens and Devine-Wright 2018; Goedkoop and Devine-Wright 2016; Max Lacey-Barnacle 2020; M. Lacey-Barnacle and Bird 2018). Highly motivated groups of volunteers from within local areas (and beyond) can coordinate expertise, leverage local connections, and source finance otherwise unavailable to individual households to fund local energy projects. In Scotland, for example, community groups can apply for support from the Community and Renewable Energy Scheme (CARES), the Low Carbon Infrastructure Transition Project (LCTIP) and the Scottish Government's £20m Green Economy Fund to assist with the up-front financial costs of installations, while Local Energy Scotland and cooperative groups such as Energy4All are widely employed to assist in navigating legal and political processes associated with bringing community projects into fruition (Local Energy Scotland 2020).

Community groups thus work with several organizations to effectively take on responsibility for overcoming some of the main barriers to low-carbon technology uptake in low-income areas and households. As a result, it may be that the benefits of low-carbon technology subsidies are less skewed towards higher income groups in the case of community energy, since community groups can utilise government-backed funding and absorb the financial, informational, and participatory costs of project establishment. Although benefits may be less immediate for community members themselves, community groups thus create scope for the benefits to flow to higher deprivation groups and areas.

From this theoretical basis, the core hypothesis of this chapter is thus:

Hypothesis 1: *Community energy projects are more likely to benefit areas of higher deprivation than low-carbon technologies at the household-level.*

In both household and community cases, there may also be some technological disparity in terms of who gets to benefit from those systems. Where much research has been dedicated to understanding the distribution of wind and solar PV installations independently

(Castaneda et al. 2020; Cherrington et al. 2013; Hitaj and Löschel 2019; Nordensvärd and Urban 2015; Richter 2014; Walters and Walsh 2011), this has tended to be somewhat disparate and again predominantly focussed on household-level systems. There are some potential differences in the distribution of solar and wind technologies across socioeconomic groups, however. Wind installations are generally more expensive than solar and require more substantial infrastructure in both household and community settings. As such, there is reason to expect that wind is more open to more affluent, lower deprivation groups in both household and community cases.

Solar PV, on the other hand, is less expensive both financially and in terms of physical infrastructure, and can be installed increasingly in built-up areas, making it less beholden to geographic factors than wind technology at present. For community installations in particular there is also scope for utilising public grounds and roofs to place installations in more deprived and urban areas (Noll, Dawes, and Rai 2014; O'Shaughnessy et al. 2020; Peters et al. 2018). With these differences then, it would be reasonable to expect that solar PV (particularly in the case of communities) is more accessible for areas of higher deprivation than wind installations more generally. This leads to the second and final hypothesis of the chapter:

Hypothesis 2: *Solar PV installations are more likely to benefit areas of higher deprivation than wind installations, particularly in the case of community energy.*

3.3 The UK Feed-in Tariff

Of policies designed to stimulate the uptake of low-carbon technologies among households and communities, the feed-in tariff is perhaps the most pertinent recent example. Feed-in tariffs have been a powerful policy option for governments concerned with promoting citizen-led uptake of small-scale renewable energy generation in a number of places and with great success in doing so in pure generation terms (Allan and McIntyre 2017; Balta-Ozkan, R. Davidson, et al. 2013; Bayer and Urpelainen 2016; Cherrington et al. 2013; Hitaj and Löschel 2019; Sommerfeld, Buys, and Vine 2017; Winter and Schlesewsky 2019). Now replaced by the Smart Export Guarantee (Ofgem 2020b), the UK feed-in tariff was first proposed to help the

UK meet renewable targets in line with EU Electricity Directive 2009/72/EC (Grover 2013). Under the policy, energy utility companies pay those who install low carbon technologies such as household solar PV or wind for the clean energy they generate. Users are given two tariff rates: an export tariff and a generation tariff. The export tariff pays users for the energy they generate and then export to the national grid, which has been steadily worth approximately 4 pence per kilowatt hour (4p/kWh) for the last decade. The generation tariff, on the other hand, pays users a rate for the electricity they generate overall. This rate varies across technologies and years, starting at almost 50p/kWh in the first year of the tariff for solar technologies and 35p for wind, before being phased down to less than 5p/kWh for each by 2019. Once an installation is registered under the feed-in-tariff, the user is locked into their tariff rate for a period of 20 years.

Exploration of the distributional impacts of the feed-in tariff in the UK has demonstrated that, per wider research, inequalities exist in who benefits from the feed-in tariff. The most comprehensive of these so far, conducted by Grover and Daniels 2017 in England and Wales, finds that payments for household-level solar PV installations have flowed consistently into wealthier groups and areas, with lower income areas and areas of higher deprivation lagging behind, revealing a substantial and persistent inequality. For this important insight, however, work thus far into understanding the distributional impacts of the feed-in-tariff in the UK has omitted investigation of Scotland, which itself is a pertinent and interesting case.

With the 26th Conference of the Parties (COP26) having taken place in Glasgow later in 2021, the Scottish Government has redoubled its explicit commitment to ensuring a "just" transition away from fossil fuels, after long positioning itself as a global renewable energy leader (Scottish Government 2019). With support from the Community and Renewable Energy Scheme (CARES) and Home Energy Scotland, the Scottish Government has also made a concerted effort in the last decade to actively promote the uptake of small-scale low-carbon energy technologies. Targets were initially set to achieve 500 MW installed small-scale capacity by 2020: this target was extended to 1000 MW after the 500 MW landmark was reached 5 years early (Energy Saving Trust 2015). Small-scale renewable generation in Scotland today now stands at 896MW[1] of operational capacity across domestic, community, industrial, and

---

[1] At the time of writing the published version of this paper in 2021, this figure was 732MW as reflected in the analysis below. Installations since then have not been registered under the feed-in tariff, and so data

business installations, which equates to approximately 6 % of total installed renewable capacity (Scottish Renewables 2020). This has been partly achieved through supporting the Local Energy Scotland consortium, who manage the CARES programme to support and advise those aiming to develop local energy systems. With these dual commitments to small-scale renewables and ensuring a just transition, along with ambitions to support heat decarbonisation in homes through the phasing out of gas boilers and promotion of heat pump technologies, understanding the distributional implications of policies like the feed-in tariff for the Scottish context can help both the Scottish and UK Governments shape fair and equitable clean energy policies designed to support the uptake of low-carbon technologies moving forward.

3.4 Data

Two key datasets were combined for the analysis: the Scottish Indices of Multiple Deprivation (SIMD) and OFGEM feed-in tariff registration information. These two datasets provide data at SIMD data-zone level, which is the spatial unit by which the two sets of data were merged.

3.4.1 Scottish indices of multiple deprivation

The SIMD data is collected by the Scottish government every 4 years and includes 38 indicators of deprivation across 7 categories of income, employment, health, education, crime, housing and access to services (Scottish Government 2020). This data is divided into 6,976 *data-zones* of 400-1100 people per data-zone, covering the entirety of Scotland and providing the key socioeconomic information for the analysis. By using data at this granularity, we can glean high-resolution insights into the distribution of the benefits of the feed-in tariff at a very local level, allowing for a more realistic comparison of household- versus community-level benefits than comparison aggregated across larger geographic areas.

3.4.2 Feed-in Tariff registration

Small-scale energy systems data was collected from OFGEM feed-in tariff registrations. Feed-in tariff data was scraped using Python from a Renewable Energy Foundation 2020 database

---

has not been available for systems installed since then, meaning that these could not be included in updated analysis.

Table 3.1: Number of installations and overall capacity.

Ownership	*Solar*	*Wind*	**Total**
		Number of installations	
Household	8,922	14,345	**23,267**
Community	2,332	619	**2,951**
Total	**11,254**	**14,964**	**26,218**
		Capacity (MW)	
Household	221.53	220.96	**442.49**
Community	112.05	177.73	**289.78**
Total	**333.58**	**398.69**	**732.27**

linked to the central OFGEM register, which has information on all FiT-registered small-scale renewable energy systems below 5MW in the UK . This information includes post code, size of installation, type of technology, ownership, parliamentary constituency and local super output area (LSOA), which corresponds to SIMD data zones in the case of Scotland. Because the analysis focusses on Scotland and because LSOA data does not match across all parts of the UK, non-Scotland cases were dropped, leaving a total of 56,274 installations. All commercial and industrial installations were then likewise dropped, along with hydropower to allow for a more direct solar and wind comparison, leaving a dataset of 26,218 domestic and community wind and solar installations. These installations were then aggregated to SIMD data-zone (LSOA) level and merged together by data-zone with the SIMD data. The number of installations by ownership and technology type is given in Table 3.1.

From Table 3.1, a few things are immediately apparent. First, there are substantially more household installations overall than community energy systems, which is to be expected. In total, there are 23,267 household systems versus 2,951 registered community assets. However, what is also clear is that community energy assets are typically of a much larger size: the average community installation capacity is 125.64 kW, versus 22.54 kW for household-level assets. Again, this is to be expected since household-level assets are designed generally only to serve single households, while community energy systems are generally designed to generate locally and create more significant revenue streams for community benefit.

3.4.3 Dependent variable

The main dependent variable of the descriptive analysis is the total amount of tariff payment to each data-zone in British pounds in the most recent year available (2020). This figure was then divided by data-zone population to give tariff per capita (TARIFFpc) as the main dependent variable of the regression model. Per capita was opted for as data-zone populations can vary quite significantly from 400 to 1100, and so the per capita measure allows for better standardisation and more comparative interpretation within the regression model.

3.4.4 Independent variables

The key independent variable of interest from the SIMD was deprivation decile, which is a composite overall measure of deprivation based on each of the included variables ranging from 1 (most deprived) to 10 (least deprived), with an equal number of data-zones in each decile. Two other variables were included in the main regression models: the rate of homeownership and a spillover variable to capture spatial diffusion. Previous research finds that the number of people who own their homes outright within an area increases the likelihood of them installing a household energy system. As such, this was included within the main model to control for these effects. Other variables, such as social class, education and employment, were also considered but found to be strongly collinear with homeownership and income deprivation, and so were excluded in the model. A final spillover proxy variable was included as per Grover and Daniels (2017), which takes the total amount of installed FiT capacity within a data-zone and subtracts it from the overall capacity within the next-highest geographic area (known as "intermediate zones" in the case of Scotland).

3.5 Methods

Two approaches were used to analyse the data. First, tariff by deprivation deciles is visualised in a series of maps and descriptive charts, allowing for a visual comparison of payments from each system and how they are distributed across deprivation groups.

Second, a random effects within-between (REWB) regression was used to explore potential statistically significant differences across these installation types. In the SIMD data,

Table 3.2: Variable overview

Name	Description	Unit	N	Min.	Max.	Mean	SD
Tariff	Total amount of tariff payment to a data-zone in the most recent year (2020)	£	6,796	0	542,869.40	20,843.94	1,735.40
Tariff per capita	Total amount of tariff payment per head of population to a data-zone in the most recent year (2020).	£	6,976	0	848.86	28.42	24.44
Deprivation decile	Deprivation decile as per the SIMD, where 1 = most deprived and 10 = least deprived	Decile	6,976	1	10	5	1
Spillover	Total FiT capacity within next-highest geographic area, minus data-zone capacity	kW	6,796	0	18,859.80	357.38	1,099.68
Homeowner	Proportion of people within the data-zone who own their homes	%	6,796	0	54.18	27.56	0.98

data-zones (small areas of 400–1100 people) are each situated within 32 larger local authority areas. Differences are expected to exist across these local authority areas: local authority areas in Scotland can vary drastically in their geography, population and demographic make-up, while local councils themselves can have substantive differences in bureaucratic processes, planning procedures, councillors and executives with diverse priorities relative to local energy, and different levels of available funding. As such, various fixed and mixed effects models were tested to account for these differences clustered by local authority. Using a Hausman test, it was established that the unobserved variance at local authority-level is correlated with included independent variables, and so pure random effects were deemed inappropriate.

However, while a researcher may typically choose fixed effects in this case, this is not the only option available. Fixed effects are useful in controlling for unobserved differences across clusters yet are susceptible to bias and can omit considerable amounts of information. Random effects within-between (REWB) models, on the other hand, are a specification of random effects which does the work of both fixed and mixed models, but which eliminates the issue of independent variables being correlated with the grouping variable by cluster de-meaning the independent variables and including the cluster mean of each respective variable as a control. In this case, this means removing the local authority mean from the deprivation, homeownership and spillover variables and including those means as a set of independent control variables within the model. REWB models perform more efficiently in simulation studies, reduce biases of both fixed and purely random effects models, produce cluster-robust standard errors, and allow for a greater degree of analytical flexibility (A. Bell, Fairbrother, and Jones 2019; Dieleman and Templin 2014; Fairbrother 2016; Lüdecke 2019). Given these benefits, Bell et al. (2019) recommend REWB as a starting point for any multi-level analysis.

The general specification of the model is as follows:

$$y_{ij} = \beta_0 + \beta_1(x_{ij} - \bar{x}_j) + \beta_{2between} x_2 + u_j + e_{ij} \tag{3.1}$$

Where y is the benefit per capita per data-zone i within a local authority area j; $\beta_1(x_{ij} - \bar{x}_j)$ is the coefficient β on the cluster de-meaned independent variable x; $\beta_{2between} x_2$ is the cluster-level mean variable included as a control, which effectively eliminates the correlation between the independent variables and the cluster effect; u is the random intercept on local authority area j; and e_{ij} are finally the level-1 residuals, which are assumed to be normally distributed.

Analysis was conducted using the lme4 package in R (Bates et al. 2015). REWB are easy to fit in most statistical software packages: they are done simply by specifying a random effects model and including the cluster-level mean of the explanatory variable to absorb the variance typically managed by fixed effects (A. Bell, Fairbrother, and Jones 2019). Results of other model specifications and robustness checks can be found in the Appendix. Across all models – no effects, simple random effects, random effects on multi-member wards, nested random effects on multi-member wards within local authority areas and fixed effects – the relationships hold in significance and direction, with REWB clustered by local authority area performing best on both Akaike Information Criterion (AIC) and Analysis of Variance (ANOVA) results in model testing. As such, the REWB model is opted for in the main analysis.

3.6 Results

Tariff payments in £ in the most recent year (2020) is mapped by data-zone in the figures below, with deprivation also mapped beneath for reference. Fig. 3.1 shows mapped household and community tariff payments per data-zone side-by-side: Fig. 3.2 gives deprivation levels, while Fig. 3.3 and Fig. 3.4 then show household tariff payments and community tariff payments respectively, with the denser local authority areas of Dundee, Aberdeen, Glasgow, and

Edinburgh enhanced to give fuller detail. These areas have a high number of very geographically small data-zones and so appear somewhat blurred on the map. Brighter green-yellow colours represent higher levels of tariff payment within a data-zone, while darker colours mean less benefit. In Fig. 3.2, lighter colours represent lower levels of deprivation (or higher levels of affluence) and vice versa.

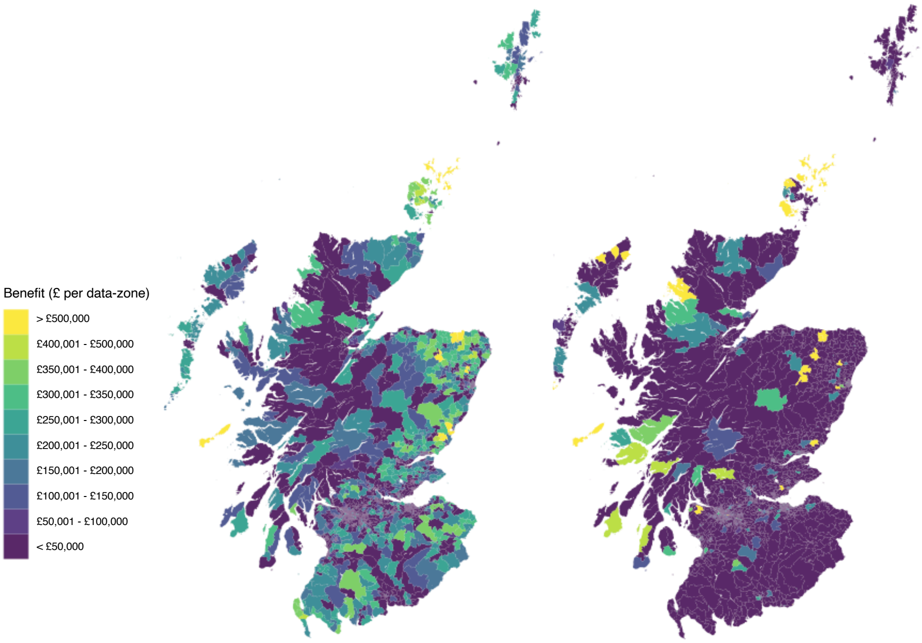


Figure 3.1: Feed-in tariff payments to each SIMD data-zone in Scotland up to 2020 (left: domestic, right: community).

As per the data overview, there is a far greater number and spread of household installations compared to community registered systems. The highest benefit household systems are consistently in the north and north-east of the country. Given that these are more open, rural areas with many wealthy villages and farms (and great natural capacity for wind), this is to be expected. Taken in comparison to the deprivation map, these areas are also areas of lower deprivation, giving some initial indication that more affluent places may be benefitting from the feed-in tariff more consistently than deprived areas. There is then likewise some concentration of household in the Western Isles and Orkney to the north, where the conditions for wind energy are ideal.

In contrast, there are simply fewer community energy systems and so the right-hand map is the darkest colour in general, representing that those areas received no community

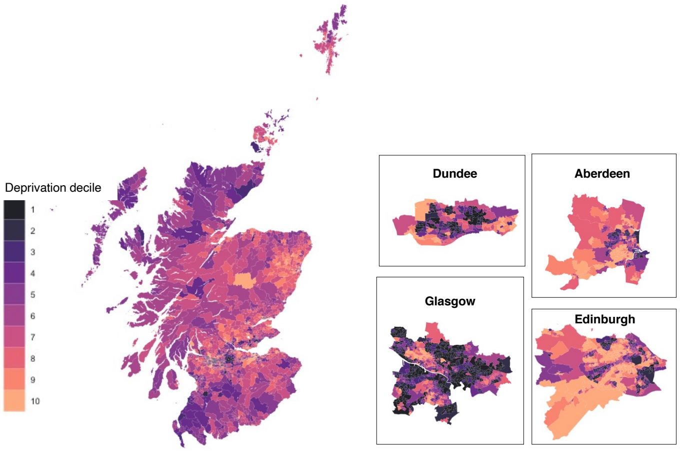


Figure 3.2: SIMD deprivation decile by data-zone (1 = most deprived, 10 = least deprived).

feed-in tariff payments whatsoever (no community energy system generates less than £5,000 per year). Yet, where there are community installations, tariff payments are mostly in the higher categories. That is, community registered energy installations are worth over £50,000 per year in tariff payments to most of the areas in which they are situated. Household feed-in tariff payments, on the other hand, has a more consistent range across the map, with more household installations spread across more data-zones overall. Since community energy systems tend to be larger as per Table 1, this is also to be expected. It is important to also note once more that these are not necessarily all community energy cooperatives or even traditional Community Benefit Funds, but rather assets registered as being under community ownership.

3.6.1 Deprivation groups

To give a clearer picture of how feed-in tariff payments have been shared across deprivation groups, feed-in tariff payments are broken down by SIMD deprivation decile in Fig. 3.5. In total, feed-in tariff payments amounted to £14,544,560 for households and communities in Scotland in 2020: of this total, payments to household systems were approximately £9,407,200

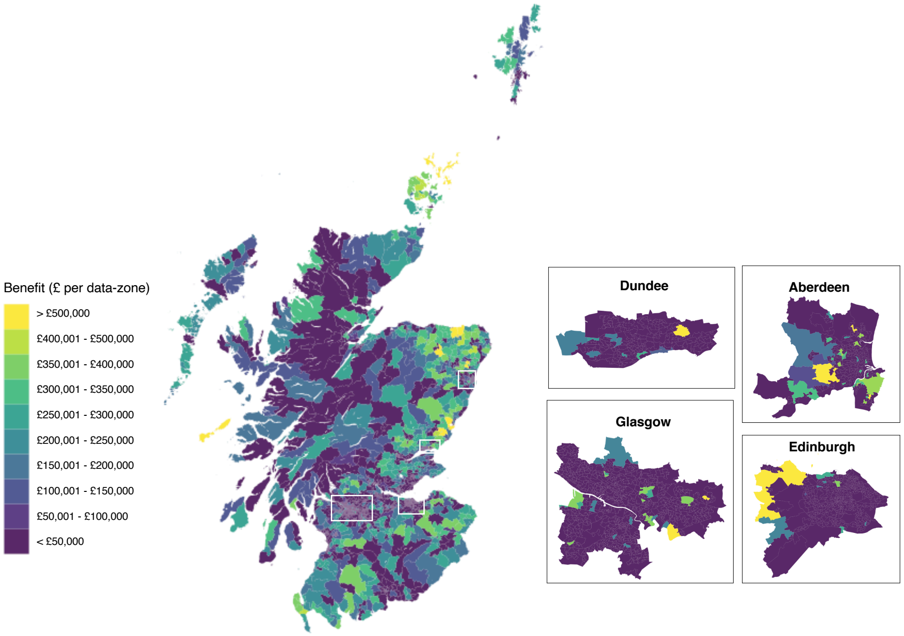


Figure 3.3: Mapped domestic feed-in-tariff benefit by data-zone).

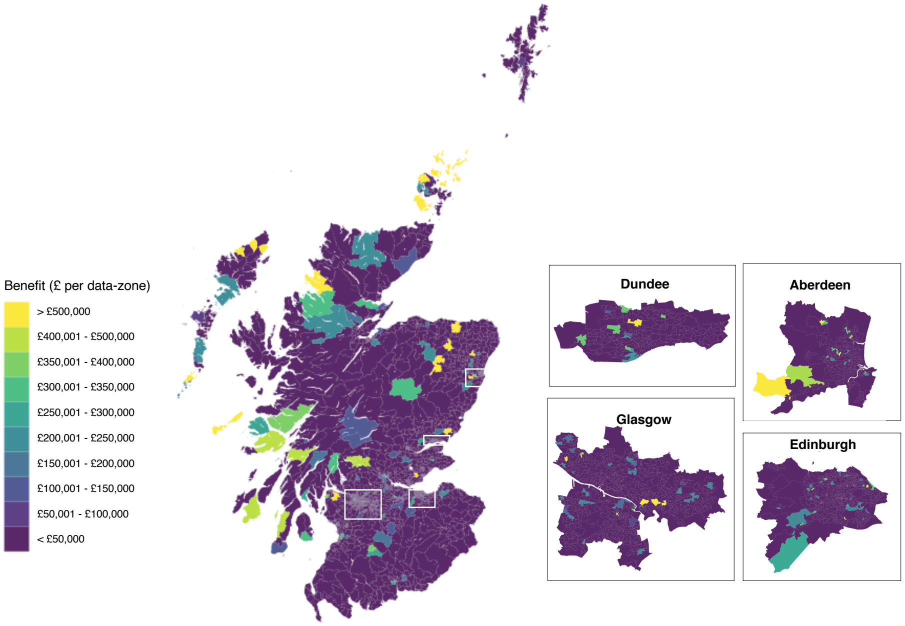


Figure 3.4: Mapped community feed-in-tariff benefit by data-zone.

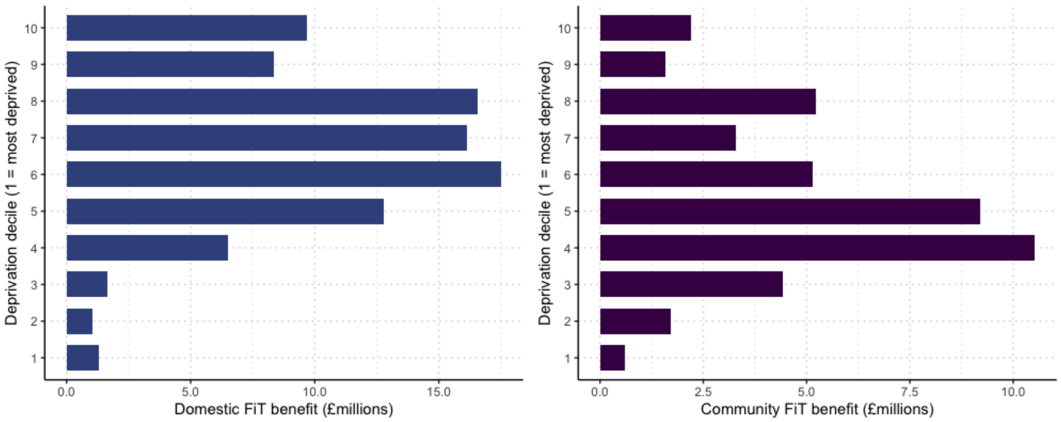


Figure 3.5: Feed-in tariff payments by deprivation decile (left: domestic, right: community).

annually, with community installations receiving £5,137,3691 in feed-in tariff payment per year.

From the blue left-hand figure, there is a clear and considerable skew towards less-deprived groups in the flow of household FiT payments as anticipated. This peaks at FiT being worth over £500,000 per year for groups 6, 7 and 8, before tailing off somewhat for the very least deprived groups, in line with other findings by Grover and Daniels 2017 in England and Wales.

The purple right-hand figure gives the equivalent breakdown of annual FiT payments by deprivation deciles for community installations, from which there is quite an immediate difference. Where the left-hand figure shows a stark and obvious skew towards least deprived groups, community feed-in tariff payments have flowed much more into deprived groups (4 and 5 in particular), providing tentative support for the main hypothesis of the paper – that community energy systems are generating revenues for more deprived groups than household-level assets. These distributions are broken down by technology type as follows.

3.6.2 Technological distribution

Fig. 3.6 shows the distribution of household FiT benefit by deprivation groups and technology. Solar PV (left) has clearly been worth less overall benefit than wind (right) due to the higher capacity for wind in Scotland and because a larger proportion of wind installations were registered on earlier, higher tariff payment rates. Payments for solar PV have flowed more

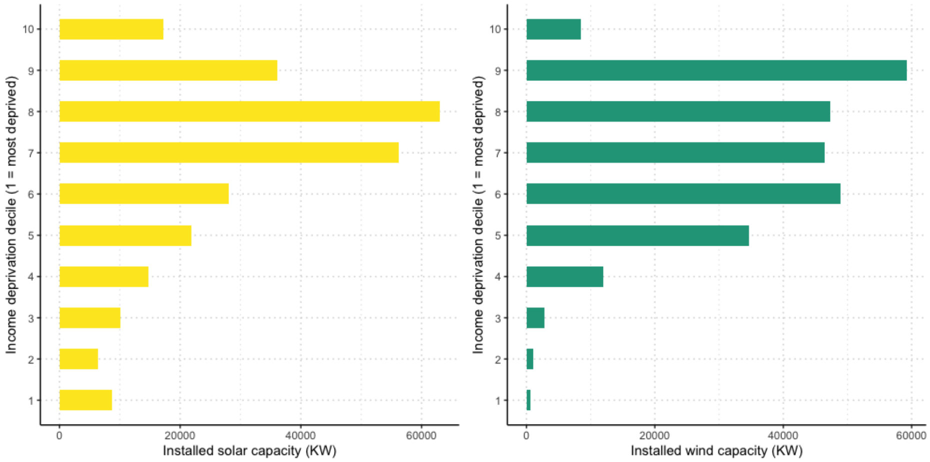


Figure 3.6: Distribution of domestic benefit by technology (left: solar, right: wind).

into more deprived areas more so than wind in general, although this distribution is still very unequal. Both still are concentrated in the lower deprivation (higher income) groups compared to all others. This is especially pronounced for wind, with a substantially higher amount of FiT flowing even more heavily into those less deprived, more affluent groups (Fig. 3.7).

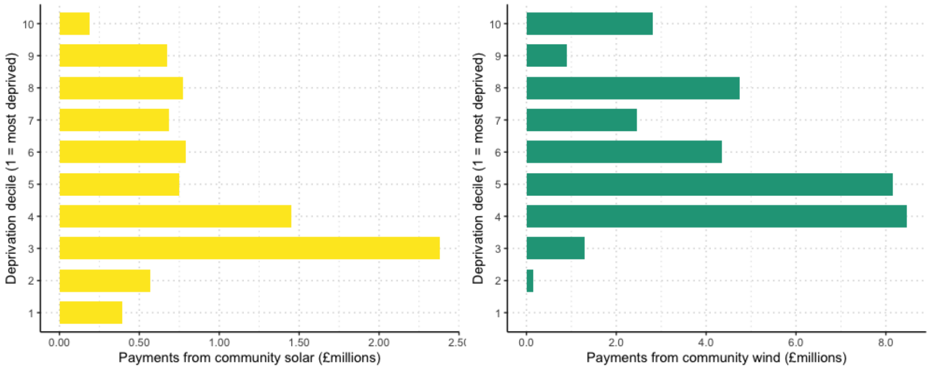


Figure 3.7: Distribution of community feed-in tariff by technology (left: solar, right: wind).

For community installations, the benefits of wind technologies seem somewhat more evenly shared with some concentration in groups 4 and 5, although with extremely little FiT payment flowing into the lowest groups (and none whatsoever in group 1). Community solar feed-in tariff payments, however, has flowed more into groups of higher deprivation, with a concentration in groups 3 and 4 and a greater share of benefit within the very lowest groups.

While still lower in scale than household or wind, this suggests that community solar projects may be having some redistributive success. These descriptive statistics thus provide some evidence for the different distributions of FiT payments by ownership and technology type (Table 3.2). Yet they are without statistical investigation at this point.

3.6.3 Regression analysis

Results from the main regression analyses are thus provided in Table 3.3, wherein the cluster de-meaned $TARIFFpc$ (tariff payments per capita per data-zone in the most recent year) is included as the key dependent variable. Six models were run in total: one for each ownership and technology type. In every case, conditional R^2 is increased by the addition of random effects, demonstrating that unobserved differences across local authority areas account for a substantial proportion of variance within the data. This increase in conditional R^2 is especially pronounced for household and community solar, suggesting that benefit from solar overall is more beholden to those unobserved local authority-level differences than wind. Tau (τ_{00}) represents the variation between the individual local authority intercepts and the average overall intercept; from this information, levels of tariff payment per capita vary most substantially across local authority areas in the cases of household wind ($\tau_{00} = 0.76$) and community solar ($\tau_{00} = 0.79$).

For the purposes of interpretation, deprivation deciles were reversed, so that 10 = most deprived and 1 = least deprived. This was done to make the interpretation of the regression more intuitive. These models broadly support the descriptive findings. In every model except the last, levels of deprivation are significant in predicting levels of FiT payment at the $p < 0.001$ level. For all household installations, higher levels of deprivation are associated with lower levels of household feed-in-tariff payments (β = -1.59 overall, representing an average reduction of £1.59 per capita per increase in deprivation decile, relative to the mean $TARIFFpc$ of £28.42 overall). These findings lend strong support to both H1 and H2 respectively. Levels of homeownership within a data-zone are also a consistently significant and positive predictor: redoubling findings from previous work, this suggests that data-zones are likely to see higher rates of feed-in-tariff payment where more individuals within the data-zone own their homes. Spatial spillover effects are finally significant for all three household

Table 3.3: Random effects within-between models.

DV: tariff payment per data-zone per capita	*Household*			*Community*		
Predictors	**TARIFFpc**	**Solar**	**Wind**	**TARIFFpc**	**Solar**	**Wind**
(Intercept)	-2.70 ***	-3.12 ***	-4.55 ***	-3.70 ***	-3.65 ***	-6.10 ***
Deprivation decile (log)	-1.59 ***	-1.60 ***	-1.74 ***	1.02 ***	1.11 ***	-1.25
Homeowner.	0.23 ***	0.17 **	0.32 ***	0.31 ***	0.32 ***	0.30 *
Spillover	1.06 ***	0.65 ***	0.41 ***	0.10 *	0.01	0.20 **
Random Effects						
$\tau 00_{Council\_area}$	0.26	0.51	0.76	0.66	0.79	0.44
$N_{Council\_area}$	32	32	32	32	32	32
Observations	6976	6976	6976	6976	6976	6976
Marginal R^2 (Conditional R^2)	0.251 (0.311)	0.10 (0.222)	0.391 (0.509)	0.054 (0.214)	0.030 (0.220)	0.276 (0.362)

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

models.

The next three models give the results of the regression on community FiT installations. For community wind systems, it appears that the effect of deprivation is more precarious than in the household case, and without significance in the data. The effect of deprivation for community solar PV and community overall, however, is completely reversed compared to household models: that is, higher levels of deprivation are associated with higher levels of tariff payments from community and community solar systems ($\beta = 1.10$ for total community tariff payments, representing an average increase of £1.10 per capita per deprivation decile, relative again to the mean $TARIFFpc$ of £28.42 overall). Coupled with the descriptive findings, this statistically significant relationship points towards more deprived, lower income areas receiving higher shares of FiT payment under community systems.

In each community model, homeownership is likewise associated with an increase in FiT benefits, significant at the $p < 0.001$ level. Spatial spillover effects from overall small-scale distribution are finally somewhat less clearly influential, with significance varying across the three models. The R^2 accounted for in the case of community installations is also smaller overall than for household installations (21.4 per cent in the case of community overall compared to 31.1 per cent household overall): this suggests that, while each independent variable is significant, more of the household tariff payment is explained within the data than community energy systems. Given there are substantially fewer data-zones with community energy installations and that the level of benefit overall is around double in the case of household systems, this is to be expected.

3.7 Discussion

Overall, then, results from the analysis demonstrate that significant, substantive differences exist in the distribution of payments under the feed-in tariff between household and community energy systems that had previously gone uncovered in the key literature. Payments to household-owned installations are highly concentrated in mid-higher socioeconomic (lower deprivation) groups in every case. This disparity is especially pronounced for household-level wind, with rooftop solar PV likewise uneven although somewhat less drastically so. In the case of community energy installations, however, payments have flowed much more into lower income, higher deprivation areas. Although the statistical relationship with community wind is insignificant, community solar PV appears to significantly favour areas of higher deprivation, suggesting that community groups pushing solar PV installations have had some success in bringing feed-in tariff benefits to lower-income communities.

Payments from the feed-in tariff have also been concentrated in all situations in Scotland in areas with high levels of homeownership. This is in line with previous empirical work. This suggests that, even in community energy projects, areas with high numbers of renters appear to benefit less compared to areas with higher numbers of homeowners (even for community solar which has the greatest capacity in theory for combatting this). One reason for this may be that people who own their homes in an area are more likely to be longstanding residents and thus more likely to participate in a community initiative, although this is not explored further here. Spatial spillover effects are lastly significant for household installations in particular, again in line with previous empirical work, suggesting that some element of peer diffusion is at play between neighbours and data-zones in close proximity to one and other.

This analysis thus adds a new insight to the literature which has repeatedly demonstrated the inequalities in the uptake of low-carbon technologies at the household-level, but which had so far overlooked the wider distributional implications of community energy systems. Although this analysis does not extend to explaining how community benefit payments are realised (be that community project funding, regeneration, new jobs etc) or for whom directly, which qualitative case studies can help to unpack, this analysis shows that community energy projects have tended to be located in more deprived areas and neighbourhoods than household-level systems.

3.7.1 Limitations

For these important findings, this chapter has some obvious limitations. First, while taking place at a very high spatial resolution, the analysis still focusses on data-zones rather than individuals or households specifically. As such, it is restricted in both the data available and in its ability to understand individual impacts and motivations, within-area inequalities, gendered or racial disparities, or wider mechanisms at play in the distribution of feed-in tariff access and benefits. What it demonstrates is that community energy projects have tended to be located in more deprived areas. Dedicated survey research and qualitative investigation with a focus on the impact and benefit of the policy for different groups and individuals would unpack these issues much more robustly and bring richer, more rounded insights to the table. Second, the paper only covers Scotland: while this is also a novelty of the research and the statistical findings are robust and generalisable to a degree, descriptive statistics and distributional analysis are only immediately applicable to the Scottish context. More comparative work between ownership types, technologies and national contexts could provide a deeper, more expansive perspective.

3.8 Conclusion and policy implications

These findings have considerable implications for policymakers in Scotland and the UK first and foremost. First, they redouble findings that show low-carbon technologies at the household-level have benefitted higher income households first and foremost. Although the rapid expansion of decentralised energy generation is undoubtedly great progress in combatting the climate emergency, the distribution of the benefits of these technologies is at odds with a just energy transition, with more deprived groups and areas at risk of being excluded in the process. Even in the case of community energy, the very lowest groups are still largely excluded. Recent Scottish Government and local authority initiatives to support the decarbonisation of electricity and heat in social housing stocks does show real promise for addressing some of this inequality, although this still poses the issue of reaching lower income socioeconomic groups in the private owned and rented sector. A more concerted effort to engage these groups directly may help to expand these benefits.

Importantly, however, the new findings from this paper suggest that bringing low-carbon technologies and their benefits to deprived areas could be aided by better supporting community energy projects, which have tended to locate in more disadvantaged areas – particularly in the case of community solar. This is a lesson not just for Scotland but for any government considering how to stimulate uptake and benefit from low-carbon technologies in future. Because community groups can absorb the more daunting financial, political and informational burdens of accessing these schemes and given their existing local ties, they are well-placed to assist to bring at least some of that benefit to areas with a high penetration of lower-income groups and begin to alleviate socioeconomic inequalities within the transition.

Dedicated financial support and priority from local and national governments to help support community energy to be more proactive in these areas could thus help to facilitate a more equitable distribution of low-carbon technology schemes. This can also be effective in promoting grant and subsidy initiatives generally, as programmes for the replacement of gas boilers and uptake of heat pumps, along with retrofit schemes, are discussed and begin to come into fruition. Ensuring that households know about the schemes available in the first place and are equipped to navigate the application process can be bolstered by systematically supporting local actors as trusted intermediaries to engage in outreach and support where feasible.

Third and finally, as the feed-in tariff is now closed in the UK, the viability of traditional community energy business models is limited. This has made it difficult to establish new larger-scale community energy generation projects. Community energy groups are thus increasingly innovating to not just develop new business models, but to ensure projects are holistic in channelling revenues into tackling fuel poverty and making homes more energy efficient.

Community energy is not the only alternative way to break the inequality trap and redistribute the benefits of low-carbon energy technologies, however. Other innovations in local energy are also making considerable in-roads into alleviating those financial, procedural and social burdens to make low-carbon technologies work for low-income households and areas. These are explored in the following, final empirical chapter of this thesis.

Chapter 4

Social innovation in local energy systems

The first empirical chapter of this thesis demonstrated that inequalities in the uptake of low-carbon energy technologies are not simply about money, but are exacerbated by social and informational forces too. These barriers mean that providing financial support alone is unlikely to redress those inequalities effectively. This is a critical issue: without supporting low-income households to transition, we will struggle to meet overall net zero targets, while potentially widening existing socioeconomic inequalities in the process.

The second empirical chapter of this thesis then explored community energy as one way of helping to overcome financial, social, informational and other barriers to bringing low-carbon technologies into low-income areas. While the value realised is typically more local and holistic, this research showed that community energy groups have had some success in bringing low-carbon technologies to lower income places. By absorbing the financial, procedural, legal and knowledge burdens, community energy has delivered value to lower income places, and could be leveraged to support the delivery of fairer net zero policies.

Extending these findings, the final empirical chapter thus explores newer innovations in local energy systems in low-income areas specifically. By again absorbing the financial, procedural, legal and knowledge burdens of installing and operating low-carbon energy technologies, innovations in local energy systems present new ways of delivering low-carbon energy more broadly and bringing those benefits into low-income areas. This chapter builds on the lessons from this thesis to unpack how these innovations are brought to life; the benefits they have already created; and how these models could be incentivised to break the inequality trap and help shape a more just low-carbon energy transition overall.

4.1 Introduction

As countries around the world accelerate the transition to a low-carbon energy system, new technologies and configurations of energy provision provide new opportunities to make sure that transition is fair and equitable (Knox et al. 2022). Technologies such as solar PV, heat pumps, electrified transport and energy efficiency will play an increasingly prominent role in the energy mix, with a plethora of propspective social and economic benefits for people using them (Ford et al. 2019; C. Walker et al. 2021; Adams et al. 2021). For users, these technologies can reduce bills; create new value and revenue streams; insulate households from external, international energy supply shocks; and allow for more citizen autonomy in the energy system overall (Akizu et al. 2018; Baer et al. 2021; Bray, Woodman, and P. Connor 2018; Adams et al. 2021).

For this massive potential and as identified earlier in this thesis, however, renewable energy technologies to date have tended to benefit more affluent people and communities: this is because these groups can usually better afford any upfront costs associated with new energy assets or installation (or new goods and services in general); own their homes meaning that there are less physical or legal barriers to making installations happen; tend to be more confident with new technologies and policy processes and so can access relevant grants and subsidies to help fund new initiatives; and are generally more open to participating in innovative new projects and initiatives (Celata and Sanna 2019; Crawley et al. 2021; Hall et al. 2020; Stewart 2022; Powells and Fell 2019). Although community energy has had some success in bring the benefits of local energy into low-income areas (Stewart 2021), new technologies have tended to benefit mid- and high-income groups, while lowest income groups remain largely excluded.

Yet it is those lowest-income communities who arguably stand to gain most from the benefits associated with an increasingly decarbonising and decentralising energy system. With the right planning and configuration, new energy technologies and innovations can help to reduce bills and tackle fuel poverty; generate new revenue for areas of high deprivation; and can lead to a number of second-order effects such as improved mental and physical health, reduced strain on health and social care, improved social capital, and local economic development (Bauwens and Devine-Wright 2018; Berka and Creamer 2018; Brummer 2018;

Max Lacey-Barnacle 2020; Lukanov and Krieger 2019; Adams et al. 2021). In a time of energy crisis that is hitting already-impoverished households by far the hardest, this is especially pertinent.

One way to redress this inequality and support typically excluded communities to participate and benefit from the energy transition is with more localised energy systems. Local energy systems - such as a neighbourhood with connected solar PV and battery storage, for instance - can connect communities together to help optimise energy use in a local area, tailor energy to local need, while reducing the need for expensive grid reinforcement upgrades for networks and government (Arvanitopoulos, Wilson, and Ferrini 2022; UKRI and Regen 2022a). This makes local energy an effective, efficient, and potentially lucrative part of the future clean energy mix. Research from innovation trials such as the Prospering from the Energy Revolution programme also show that localised energy can drive down bills, create new revenue streams and business opportunities, give communities more agency in the energy system, reduce emissions, improve transport and local economic development, and support people out of fuel poverty (UKRI and Regen 2022b).

Until this point, however, local energy in low-income areas remains a fairly novel phenomenon. This is for a few different reasons, perhaps chief of which is that lower-income communities make for less lucrative customers of new goods and services and in turn are less attractive for the design and targeting of new innovations to energy companies, policymakers, and innovation businesses. With this, there is a risk of repeating or exacerbating existing distributional issues as more affluent groups reap the benefits of cheap and clean energy, leaving already disadvantaged communities even further behind (Powells and Fell 2019; Fell 2021; Stephen Hall et al. 2021). This is a problem: to ensure a just transition and unlock the full scale of these wider social and economic benefits, bringing these communities into the fold is critical. There is also the reality that achieving net zero cannot happen without supporting those communities to decarbonise as well (UK Government 2023).

Reflecting this, some groups have taken the lead on bringing innovative local energy systems specifically into lower-income areas and communities, helping to unlock this array of benefits and promote a just energy transition. In doing so, actors have shifted priority (in the short-term at least) away from traditional return on investment onto maximising the extant social and environmental benefits thereof for communities who typically have not had a chance to benefit or participate in the net zero transition thus far. We can consider these examples of *social innovation*. In its most basic sense, social innovation refers to a policy or initiative instigated by a diverse and novel set of actors, that moves focus away from the typical maximisation of economic incentives to a more central focus on social and environmental value (Moulaert and MacCallum 2019; Logue 2019; Hiteva and B. Sovacool 2017). This paper thus takes a social innovation lens to unpack some of these projects, to dissect the key motivations, models, actors, and processes involved, and to provide lessons for how projects in these types of communities can be expanded in future. Using a combination of participatory action research, stakeholder interviews, and desk review, three local energy case studies in low-income areas are explored: a traditional community energy project in Glasgow, a smart solar and storage initiative in social housing in Aberdeenshire, and a peer-to-peer and storage trial in a block of flats in Brixton, London.

I find that each project brings together diverse actors with a relatively consistent set of motivations together to redistribute the typical risk-benefit balance of bringing low-carbon, local energy technologies to life in low-income areas. In each case, reducing emissions and bringing social and economic value into low-income communities is cited as a key motivation, while the reputational advantage that comes with being seen to lead on social and environmental as well as technological impact plays a crucial role in motivating actors like energy companies or businesses to get involved with what can be intuitively less financially lucrative developments (although some financial gain is also sometimes involved). Based on these lessons, recommendations for policymakers are made to increase the prospect of replicating or scaling these types of initiatives, with distinct implications for anyone concerned with a just energy transition moving forward.

4.2 Literature review

Who gets to access and benefit from low-carbon energy technologies in the Global North has been a key focus of energy policy research in recent years (Knox et al. 2022; Ford et al. 2019; Stewart 2021; Stephen Hall et al. 2021; Fell 2021). Driven by a growing literature on energy justice, inequalities in who benefits from more local technologies like household solar PV or smart local energy systems have been found along multiple lines: higher income groups are substantially more likely to be able to install new technologies than lower income groups (and reap the financial and environmental benefits thereof), while more innovative local energy systems have tended to involve higher income groups who are more active in their energy generation and consumption as their main participants. Survey research likewise shows that younger, higher educated groups are more likely to be willing to participate in trials of local energy systems overall (Powells and Fell 2019; Hackbarth and Löbbe 2020). Because of this, local energy systems and technologies are already exacerbating inequalities and the exclusion of lowest income groups, those experiencing fuel poverty, people with disabilities, the elderly, the various intersections of race and gender within those groups as well (Akizu et al. 2018; Dolter and Boucher 2018; K. Jenkins 2018; Knox et al. 2022; Max Lacey-Barnacle 2020; McCauley et al. 2019b; Simcock et al. 2021; B. K. Sovacool, Hess, et al. 2020a; Wolske, Gillingham, and Schultz 2020; Stephen Hall et al. 2021).

A pioneering energy justice and energy innovations literature has thus highlighted the various justice issues and vulnerabilities that exist as the energy system changes to become more digitised and decentralised (Knox et al. 2022; Ford et al. 2019; Morris et al. 2020; Powells and Fell 2019; Watson et al. 2020). Less well-covered, however, are examples of where local energy technologies and innovations are happening in lower income areas and communities, and where these systems are working *actively for* just outcomes. This is at least in part because examples of cases like this are few and far between, and because a lot of the innovations in question are extremely new and novel (Adams et al. 2021). The development of new forms of smart local energy systems has led to an abundance of research with a focus on design, business modelling, and policy implications of smart local energy innovations more generally (Ford et al. 2021; Kloppenburg and Boekelo 2019; Knox et al. 2022; Verba et al. 2021; C. Walker et al. 2021), but is lacking in real-world low-income insights.

Substantial qualitative research into community energy also exists, and provides great support for the benefits of local community energy systems environmentally, socially, and economically for local citizens and places (Akizu et al. 2018; Bauwens and Devine-Wright 2018; Becker, Kunze, and Vancea 2017; Berka, MacArthur, and Gonnelli 2020; Brummer 2018; Curtin, McInerney, and Johannsdottir 2018; Goedkoop and Devine-Wright 2016; Hewitt et al. 2019; Mirzania et al. 2019; Mundaca, Busch, and Schwer 2018; Okkonen and Lehtonen 2016). While recent research also demonstrates that, in Scotland, community energy tends to be located in lower income areas (Stewart 2021), exploration of underlying models and how other types of local and decentralised energy systems compare and are brought to life in low-income areas specifically is lacking.

4.3 Social innovation theory

For the current gaps, research into the more general impacts of local energy systems and technologies has made some critical findings. Although varying in ownership structures, design, governance processes, location, and motivation, local energy systems can have substantial social and economic value for users. Community energy has been found to generate new revenue streams and develop social capital within communities themselves (Berka, MacArthur, and Gonnelli 2020; Berka and Creamer 2018; Creamer et al. 2019); smart local energy systems and other forms of local energy supply can help optimise bills and promote energy efficiency (Ford et al. 2021; Powells and Fell 2019; Watson et al. 2020); while household-level systems like individual solar panels and heat pumps can help reduce bills and generate income for users under policy frameworks like the feed-in tariff or through providing grid flexibility where batteries are also included (Lukanov and Krieger 2019; Wolske 2020). Undoubtedly, local energy technologies and systems can have serious positive social and economic impact.

Yet, insight into how new local energy systems and these serious impacts are brought into low-income areas remains scarce. Work so far has focussed on exploring the networks and relationships and processes behind case studies which have tended to locate in middle- and higher-income areas, partly out of necessity: those groups are comprised of people who tend to own their homes and so have less legal or physical barriers to installing new technologies compared to lower-income households who are more likely to rent or live in multi-occupancy housing. Likewise, more active, highly engaged energy users who are more open to participating in new technologies and systems also tend to be from higher-income groups (Powells and Fell 2019; Stephen Hall et al. 2021). While insightful, these cases do little to help unpack how local energy can feature and the impact it can have for less affluent people and places.

That is not to say that no such initiatives exist, however. Several dedicated (and often ambitious) local energy projects with the express purpose of benefiting low-income areas have materialised in a number of places and configurations: from community energy, to energy services companies, to local authority-led energy markets, to even more cutting-edge technological trials and projects (Bray, Woodman, and P. Connor 2018; Hiteva and B. Sovacool 2017; Repowering London 2022; Hewitt et al. 2019). Understanding these cases can help to understand how new energy innovations can help mitigate against accelerating justice and equity issues as the energy system becomes smarter, decarbonised, and more decentralised going forward. Who are the key actors behind these initiatives and systems in low-income areas? What are the roles and motivations of various stakeholders, beyond simply trialling technological innovations? How are projects brought into being, who ultimately benefits, can projects like these be more widely incentivised in policy, and what does this mean for a broader just transition? These are critical questions to ask. For new ways of doing energy to succeed in avoiding widening inequalities and achieving net zero at the scale required, there needs to be buy-in from diverse actors with diverse motivations to address these more social issues in one form or another. One literature that can provide insights into this is social innovation theory.

4.3.1 Overview

Originally borne out of organisation literature, social innovation refers broadly to new ways of working among new configurations of actors to achieve a social or collective good rather than private, market-oriented, growth-based outcomes first and foremost (Hewitt et al. 2019; Hiteva and B. Sovacool 2017; Logue 2019; Moulaert and MacCallum 2019; Wittmayer et al. 2020). It can be driven by individuals, communities, organisations or social movements; can take place at and across a number of scales and levels; and tends to be collaborative among diverse actors (Logue 2019). Rather than innovating purely for economic gain (although this can still be achieved), social innovation places societal need and value at the front of the process (Selvakkumaran and Ahlgren 2021).

What constitutes a social or collective need or value is of course normatively rooted in politics and organisational, institutional, and personal preferences and can vary across actors and institutions through space and time (Adams et al. 2021; Brown, Stephen Hall, and Davis 2019), while achieving social innovation can mean overcoming distinct material, cognitive, normative, and relational barriers to change. What constitutes innovation is also complex and significantly more than the simple instrumentalist reading of social or collective co-benefit potential of technological innovations (Moulaert and MacCallum 2019). That is, social innovation is not simply a "bolt-on module" to technological innovation (Logue 2019; Wittmayer et al. 2020). It can be a challenge to classical technological and market innovation principles, and even a solution to adverse societal consequences from more profit-driven models of innovation and supply (Moulaert and MacCallum 2019). Where technological and even policy innovations can lead to adverse outcomes like growing inequalities, as demonstrated by the feed-in tariff, for instance, social innovation shifts the priority in a way that can deliberately redress imbalances or externalities that may otherwise be caused by classic, capitalist innovation practises.

4.3.2 Social innovation and local energy

Within sociotechnical transitions literature, social innovation has been employed as an intuitively useful concept. Developments in local, decentralised, and smart energy systems have uncovered new ways of working to deploy local energy innovations such as community energy, energy service companies (ESCo's), peer-to-peer energy trading, and more expansive smart local energy systems such as the Prospering from the Energy Revolution projects (UKRI 2022) for more socially positive outcomes. Given their relative technological and regulatory novelty, local energy systems in various forms are often initiated and governed by novel configurations of actors by necessity, with a focus on wider social and environmental value as well as economic viability (Tingey and Webb 2020; Selvakkumaran and Ahlgren 2021).

Community energy, for instance, has been examined as a social innovation: it requires new configurations of actors to utilise technological and policy innovations for social and collective good, with a general focus on citizen empowerment and localised social benefit rather than return on investment for funders or businesses (Hewitt et al. 2019). Energy service companies (ESCO's) have also been analysed through this lens (Hiteva and B. Sovacool 2017), with applications to energy justice specifically. Hiteva and Sovacool make a compelling case for the ability of innovative ESCo's to create social value in alleviating fuel poverty and reducing emissions in the energy system, from providing a sustainable and socially-focussed business model foundation. Baer et al. 2021 apply the concept of social innovation to positive energy districts (PEDs) in Norway, mapping the different stages of innovation required to bring three different social innovations in local energy into fruition.

4.3.3 Innovating local energy in low-income areas

The practical application of social innovation theory by Baer et al. (2021) in understanding the different engagement and co-creation processes of PEDs in Norway is especially useful here and this paper adopts a similar case study approach. However, what Baer et al. and wider existing literature has yet to do explicitly again is unpack social innovations in low-income areas, which is a highly specific context. With the knowledge that even innovative local energy approaches tend to happen predominantly among more active, more affluent citizens, how innovation is used in those types of area specifically – rather than as a co-benefit or "bolt-on" to technological innovation or business models – is less well-understood.

This is critical: delivering energy innovations among lower income, vulnerable and marginalised groups and addressing distributional issues arguably requires different motivations and processes. Actors within the energy system who are typically motivated by cost and return on investment, such as energy companies, energy networks or technology developers, may be less-inclined to develop products or services in these spaces where a traditional customer base is far less potentially lucrative. Those actors thus require either different regulatory incentives (or a change of heart) to pursue innovation in this space, or different configurations and different types of actors are required to lead the process more centrally - or some combination of each. Different actors may also be motivated by different ambitions more generally, referred to by Brown, Stephen Hall, and Davis 2019 as "competing normativities": more market-oriented actors may seek financial return or more technical outcomes around the energy system; policymakers may hope to achieve social or climate policy goals such as reduced fuel poverty or lower emissions; while community groups will typically be more mission-driven around local empowerment and citizen engagement (Brown, Stephen Hall, and Davis 2019; Adams et al. 2021). Understanding and reconciling these motivations is thus a key challenge for innovating local energy in low-income areas.

The context of more marginalised and typically less engaged citizens also presents unique challenges. People experiencing fuel poverty or poverty in general tend to be less engaged energy users, and often deal with issues of social exclusion too, which makes bringing people into innovation processes (such as citizen engagement and co-creation) a different proposition compared to the typical middle-class, active energy user. People in more marginalised communities may be less well-informed or less confident with new technologies, and less trusting of authority or substantive changes (Balta-Ozkan, R. Davidson, et al. 2013; Sarah J. Darby 2018; Guagnano, Santarelli, and Santini 2016; K. Jenkins, B. K. Sovacool, and McCauley 2018; O'Shaughnessy et al. 2020; Pitt and Nolden 2020; Stewart 2022). In turn, this can have considerable implications for social outcomes: who gets to participate in innovation processes, what people are being asked to do, and who ultimately benefits are contingent on the motivations of key stakeholders and the processes and governance structures they deploy.

To that end, this paper thus explores three new local energy projects in low-income areas in the United Kingdom, through this social innovation lens, to unpack the underlying models, the motivations of the different actors involved, the role and return for citizens within each project, and the lessons that can be learned thereby.

4.4 Project overview

Three different projects were selected as the key cases for this study. These were chosen as new projects in low-income areas specifically, each with different combinations of actors, models and procedures to understand how these innovations are brought into being, what the key motivations are, who benefits, how projects are developed and to what end. Included here are a classic community energy co-operative; a smart solar and solar initiative in social housing; and a local peer-to-peer energy system in high-rise flats with new battery storage and blockchain technology.

4.4.1 Methods

To unpack these cases, a combination of qualitative methods is used. First, participatory action research. Participatory action research is a form of investigation whereby the researcher is involved practically with the project, process, or group in question (Baum, MacDougall, and D. Smith 2006; Max Lacey-Barnacle 2020). This allows the researcher to better understand the mechanisms, barriers, and process in real-time, while gleaning close insights from participants. In an area such as local energy innovation, this is particularly useful: the researcher can understand barriers and opportunities for innovation and any changes or developments in the process as they arise in what is a rapidly moving area.

This was the case for both Glasgow Community Energy and the Aberdeenshire Smart Solar and Storage projects. In the former, the researcher has been a board member for over 3 years, supporting the direction and development of the project from its inception. In Aberdeenshire, the researcher conducted stakeholder and tenant engagement and likewise participated this way between 2019 and 2021. For the CommUNITY project, the main form of data collection was interview with two project stakeholders, and a desk review of available online progress reports, news articles and summaries. This gleaned a substantial amount of information around the key themes of the work on actors, models, motivations, and outcomes. Data collection on Glasgow Community Energy and Aberdeenshire was also supplemented with stakeholder interviews and desk review of wider information, to create a complete and comparable picture of the three projects.

4.4.2 Glasgow Community Energy

Glasgow Community Energy (GCE) is a classic community energy cooperative, generating a total of 90kW of clean electricity through solar panels across two council-owned schools in two deprived areas of Glasgow. The project was initiated in 2016 and began generating electricity in 2020. GCE sells energy back to the council via a power purchase agreement (PPA) and sells excesses to the grid under the UK feed-in-tariff. In total, the project generates approximately £5,000 per year per school in community benefit, which the membership – made up of local people who invested in the project share offer – decide how to spend.

To bring the project to life, Local Energy Scotland – a dedicated intermediary for linking local groups with expertise and funding – and Energy4All who have managed several cooperative and share offer projects in the past were employed. Using the Scottish Government's Community and Renewable Energy Scheme (CARES), a funding loan was sourced to conduct feasibility and installation on the two pilot projects. This loan was then paid back through a share offer of £30,000, invested in by members of communities local to the school who then become fully fledged members of the cooperative itself. Community members could invest in the project for as little as £50, giving them a say in project governance and how funds are then allocated.

As the panels are on public buildings, Glasgow City Council were a key project partner, granting access and permission to Glasgow Community Energy to install and supply the schools with any excess, non-export electricity. Community benefit is then generated via a combination of the feed-in-tariff export and the PPA. In this configuration, the Council receive electricity to the schools for less than the cost of the previous supply, while the local communities receive in the region of £5,000 per year via a community benefit fund to spend on new community initiatives. Investors in the share offer then receive a modest return on their investment (1-3 per cent) over the following 20-25 years and have a democratic say in how revenues are spent. This could be on anything from hiring a local youth worker to developing green space, upgrading local facilities, and other local initiatives.

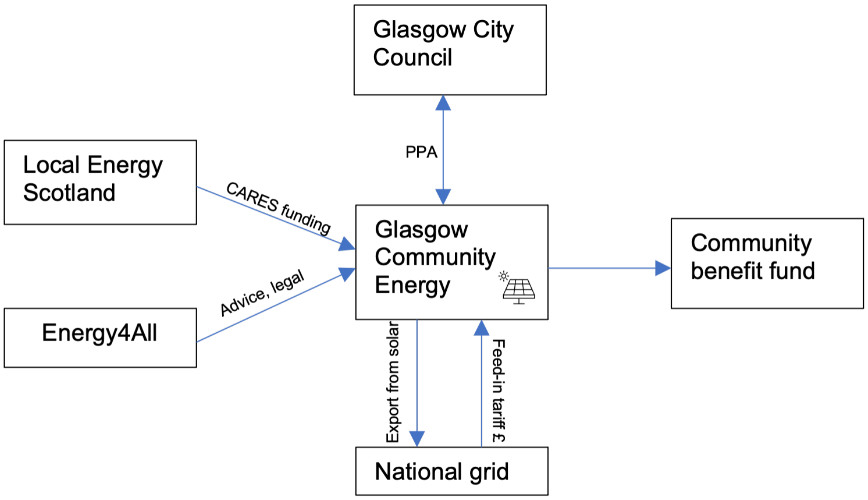


Figure 4.1: Glasgow Community Energy co-operative model.

4.4.3 Aberdeenshire Smart Solar and Storage

Led by Aberdeenshire Council and small-medium enterprise iPower and initiated in 2018, with support of community organisation Scarf, the Aberdeenshire Smart Solar and Storage (SSS) project is an initiative to bring solar panels and battery storage into 7000 social housing houses across the local authority area. Conversely to Glasgow Community Energy, the Aberdeenshire SSS project is about supplying vulnerable, low-income tenants directly with lower-cost, clean electricity and has no community ownership elements. The first phase of the project has seen the installation of solar and storage in 500 houses in total as of summer 2021, with plans to scale this number up to 7,000 over the next 3-5 years.

Originally planned to be solar PV only, grid constraints in the local area meant that battery storage was required to make the systems viable. The council and Scottish Government each fund 50 per cent of the project with the purpose of supporting people in fuel poverty and vulnerable situations. To raise this money from the Scottish Government side, an application was made jointly by iPower and Aberdeenshire Council to the Scottish Government's Low Carbon Infrastructure Transition Programme (LCITP) – a competitive pot of innovation funding for projects of this scale, in which the SSS proposal was successful to the tune of £2.1 million.

Contrary again to Glasgow Community Energy, which relies on export under the feed-in tariff, the Aberdeenshire SSS project generates revenue predominantly via grid flexibility services, which are provided by smart energy services company SMS. SMS act as aggregators between the project and the National Grid, using smart management software to bid and offer when flexibility and balancing services are most lucrative. Although typically in other cases SMS can provide up-front financing of assets and tend to generate additional revenues with a power purchase agreement, this is not the case here since the assets themselves were funded by the LCITP grant. Tenants are thus not charged in any way for the installed systems – rather, they save up to 100 per cent on their energy bills for much of the year, with the ability to draw down from the grid when generation is low to top-up supply. SMS make their money by taking a cut of the grid services revenue, which at times of high demand can be worth up to £2000 pkW/h.

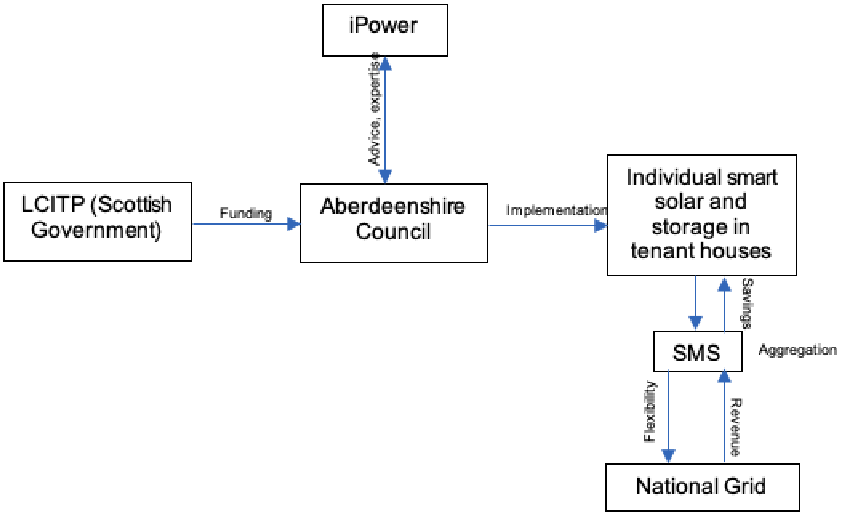


Figure 4.2: Aberdeenshire Smart Solar and Storage model.

4.4.4 CommUNITY Brixton

The final case is the CommUNITY project in Brixton, London, developed by community energy group Repowering London, energy supplier EDF, UK Power Networks, and University College London. The project started as Repowering London's first community solar project, whereby solar panels were installed in two social housing blocks in 2011. This was a straightforward community energy system, which has generated over £180,000 in community benefit since it began generating (Repowering London 2022). In 2020 as part of an OFGEM Innovation Link trial directed by EDF and supported by UK Power Networks, the first of these projects – Elmore House – received a large battery connected to the solar panels on top of the tower block. The aim was to maximise on-site use of the power generated by the PV, by charging the battery with any excesses generated by the array.

Using virtual allocation, peer-to-peer, and blockchain technology, the battery allows tenants to trade energy with each other via an app, so that they can buy and sell energy to other tenants and in theory save money on energy bills by utilising energy when it is cheapest for their need and selling when their use is low but convenient for someone else. Money saved does not pass on to the community benefit fund, which the solar panels still contribute to with their export revenue: instead, the battery is filled only with solar generation that is not exported, and this is what is then traded. As part of phase two of the trial, named the Urban

Energy Club and driven by UK Power Networks who put £193,000 into the initiative, the battery also trialled flexibility services to the distribution network, where it generates revenue by responding to supply and demand in the local area, alleviating constraints and pressure on the energy network (EDF Energy 2021).

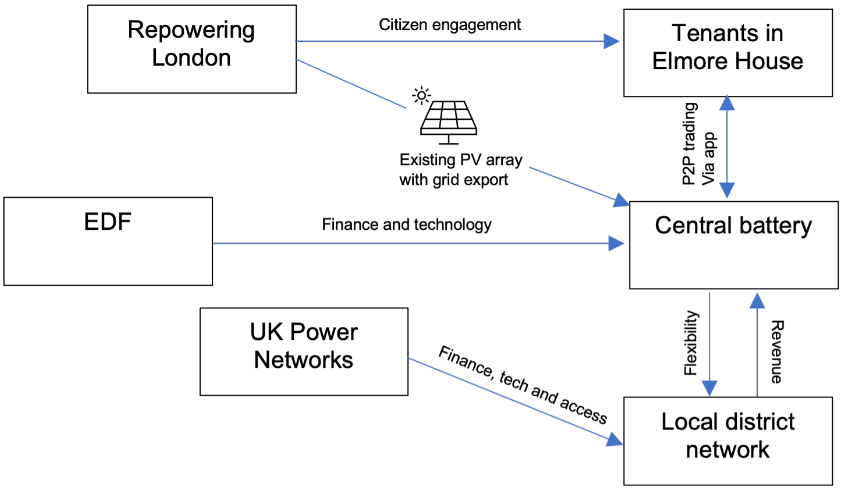


Figure 4.3: Brixton CommUNITY model.

4.5 Conceptual insights

With a social innovation lens, each of these projects meets the most foundational criteria: new ways of organising energy with a focus on social or environmental impact in low-income areas. More than simply new technologies or ways of supplying energy and interacting with the energy market, the included cases bring together new combinations of actors and technologies, with a predominant interest in bringing local energy innovations and the associated wider benefits into low-income areas, where previously those benefits had been largely captured by higher income groups (Grover and Daniels 2017; Stewart 2021; Fell 2021). An overview of these actors, processes, benefits, beneficiaries, and motivations is given in Table 4.1.

	GCE	**Aberdeen SSS**	**CommUNITY**
Actors	Glasgow Community Energy*, Glasgow City Council, Local Energy Scotland, Energy4All, local residents	Aberdeenshire Council*, SME (iPower), aggregator (SMS), installers, tenants, UoS	EDF*, UK Power Networks*, Repowering London, UCL
Process	Community group conducts planning and organisation work; engages with local community, local authority, funding bodies and agencies	Local authority, small-medium enterprise (iPower), industry collaborate to initiate action, tenants informed and engaged	EDF, Repowering and UKPN initiate action, with engagement driven by community energy group (Repowering)
Primary benefits	New income generated under FiT, community benefit, increased local capacity, reduced carbon footprint	Savings on energy bills for tenants reduced carbon footprint, reputational advantage, innovation and demonstration, flexibility and network savings	Savings on energy bills, reduced carbon footprint, reputational advantage, innovation and demonstration, flexibility and network savings
Beneficiaries	Community members, the local community more broadly	Tenants, stakeholders in meeting carbon reduction targets and reputation, energy network, aggregator through providing services	Tenants, stakeholders, energy network
Motivation	Community benefit, carbon reduction, demonstration	Reduced bills for tenants, carbon reduction, innovation and demonstration	Reduced bills for tenants, innovation and demonstration

Table 4.1: Project actors, processes, benefits, and motivations.

4.5.1 Actors and roles

While actors necessarily vary depending on the highly local contexts in which the projects are operating, there are some basic similarities. Each project draws from between 3-5 core actors across community groups, energy networks and suppliers, local authorities, and academic institutions, while there are also some common roles that actors involved have adopted throughout. In each case, here is also a distinct leading actor (Glasgow Community Energy, Aberdeenshire Council, EDF and UK Power Networks) who have initiated and largely shaped the initiative.

Local authorities

In both Aberdeenshire and Glasgow (less so in CommUNITY), the local authority played a key role, although from different perspectives. In Glasgow, because the installation utilised public buildings, the local authority was a partner that had to be legally satisfied within the process before providing revenue through a PPA. In the case of Aberdeenshire, the Council were the main driving actor, responsible for setting the core agenda, sourcing funding from the Scottish Government, identifying tenants and housing for the initiative, bringing in other partners, and guiding the entirety of the work with both legal and fiscal responsibility.

Other local energy systems have made similar findings. In the Prospering from the

Energy Revolution smart local energy system projects, for instance, the local authority has been a key convening actor. This is because local authorities can access finance from public and private sources, have considerable housing stock and can identify potential users and participants in local systems, have a democratic mandate for action in this space, can align projects with their policy goals, and have deep understanding of local energy needs, barriers and opportunities (UKRI and Regen 2022b).

Community groups

Community groups played a central role in all three projects. For Glasgow, GCE was the key initiator of action and driver of the entire initiative – they sought funding and administrative support, conducted the relevant due process, and adopted a majority of legal and fiscal responsibility by taking on a loan from the Scottish Government CARES fund. The share offer launched by GCE identifies the group's roles and responsibilities, as well as legal liability which ultimately rests with them. GCE also conducted all local and stakeholder engagement, to ensure local community needs in particular were central to the project design.

In Aberdeenshire SSS and CommUNITY, community groups play a key role that is less legal and more engagement and advocacy focussed. In Aberdeenshire, community enterprise outfit Scarf led on tenant engagement in the first instance, leveraging their longstanding local community connections to build support for the project and identify any specific tenant needs or concerns. Repowering London served a similar purpose – while the legal context is more complex since Repowering controlled the solar array already installed in Elmore House, their primary responsibility was to build support among residents where they had a close and longstanding connection, address tenant concerns and needs, and to advocate those concerns and needs throughout the planning and trial process.

This "trusted intermediary" role is one that community groups often play in new policy and energy initiatives (Max Lacey-Barnacle 2020). As groups often trusted in their local communities and known to residents, community groups can help to demystify processes for people, secure buy-in, and better advocate for a reflect people's need and perspectives in design and delivery processes. This is especially important in communities and groups that may be less engaged and more socially marginalised.

Energy suppliers, service providers, and networks

Funding came from government sources in the case of the first two projects, who had minimal involvement from energy suppliers or networks aside from negotiating export and grid services. In the case of the London trial, however, energy suppliers EDF and the district network operator UK Power Networks were driving partners. UK Power Networks funded the trial that connected the battery to the network with a total of £193,000, while EDF Research and Development provided the battery and technology itself to make the trial possible. In this case, the innovation thus began from a much more technical standpoint: although outlining a desire to bring renewables and associated value into lower-income areas, both EDF and UK Power Networks state their desire to trial the technology and configuration to understand if it is viable as a means to providing grid flexibility and reducing demand at required times (Energy Networks Association, 2021), rather than the primarily mission-driven projects in Aberdeenshire and Glasgow.

In Aberdeenshire, aggregators SMS played a critical role in designing and implementing the export and flexibility services with the district network operator on behalf of Aberdeenshire Council. More broadly and as alluded to, SMS typically provide flexibility services along with a financing option for smart solar and storage assets, although this was not the case here. Likewise, SMS make a substantial amount of their revenue through maximising on-site consumption from their funded assets through a power-purchase agreement: because the Council funded the solar and storage assets themselves, this is also not the case here. Rather, SMS utilise their interface to facilitate smart flexibility and grid services between the SSS assets and the local district network. Their role in project design and ongoing governance is minimal.

Although not always a key partner in the cases presented here, energy networks do have a core role in delivering such systems as highlighted in the case of CommUNITY with UK Power Networks. Local energy projects will typically be required to secure a grid connection so that they can export or provide services to generate revenue and savings, meaning that the district network operator (DNO) needs to be aware of the project and approve its connection at the very least. Local projects can also provide new flexibility and help avoid the need for expensive reinforcement upgrades, however, which means they do likewise have a primary interest. In addition, recent regulation around their RIIO-ED2 business plans (the things networks have to do to secure their investment from Ofgem) has outlined a need to better work with local partners on local energy projects and plans, and support people in vulnerable situations (Ofgem 2022b), with investment conditional on fulfilling these functions. As a result, in other local energy projects such as the Prospering from the Energy Revolution programme, the DNO has been a key partner and is likely to be an important actor - for innovation, collaboration and funding - in any local energy effort going forward.

Tenants and community members

While each project cited tenant savings and benefit as a critical motivation for their respective innovations, tenants and community members themselves have had a relatively small part in the innovation process. In each case, tenants and community members are consulted and engaged extensively, particularly by involved community groups as trusted intermediaries, but there is generally little expectation of any substantive personal change on their part. In Aberdeenshire SSS, tenants have a small solar PV array and battery installed within their individual homes, causing some disruption for a matter of days, but beyond this there is no intensive interaction with the system. Because the tenants live in social housing, there has been no real objection, although they were allowed to opt-out of the scheme if they wished (only two of the initial 500 chose to do so).

For the CommUNITY trial, tenants are encouraged to monitor their energy use and import and export with the app that coordinates the peer-to-peer transactions, and so they are encouraged to be more actively engaged energy users. Of the three initiatives, this is the only one that requires any real behavioural change as part of the technological configuration. Repowering London cited that getting tenants to participate was at times problematic, given the complexity of the system and the expectation of active engagement with that complex system, although tenants who did participate report a positive experience (EDF Energy 2021).

Yet this is not the only type of role tenants or community members can play: because GCE operates as a cooperative made-up of people from the local community, community members have a role in deciding how the money generated by the solar panels is spent in the local area, decided at community meetings throughout the year. The expectation on local community members – who are a mix of social backgrounds and not just necessarily form lower-income or vulnerable and marginalised groups – is thus much more procedural, to do with spending, autonomy and local issues rather than any technological behavioural participation. They also have to pay some money into the share offer to participate: this creates barriers for some people to be included in that governance process, although this particular project did allow for exceptions so that those without the upfront capital could still become members.

Academic institutions

One common thread in all projects is the presence of an academic partner or, at the very least, academic expertise within the core organising group. In both Aberdeenshire and CommUNITY in London, an academic partner (University of Strathclyde in the case of Aberdeenshire, University College London in the CommUNITY trial) was brought in as part of the process, to lead on evaluation and communicating results and findings. In both cases, it is suggested that academic partners can support innovation and the dissemination of results to provide lessons for others to take up similar initiatives in future. It is also suggested that academic partners have a perceived neutrality, which means they may be able to arbitrate between partners who have conflict or history either with each other or within an area, and glean more open insights from more marginalised tenants in particular, who may have issues in trusting authority such as the Council or other industrial partners. GCE did not utilise an independent academic partner, but representation from the University of Strathclyde and University of Glasgow are present on the board of directors and leveraged for a lot of community outreach and education efforts.

4.5.2 Benefits and beneficiaries

In keeping with the principles of social innovation, the key benefits of each project are expressed to be much more focussed around social value (for the most part) than private economic gain. Most fundamentally in Aberdeenshire and London, tenants save money directly on their energy bills by maximising their behind-the-meter use – in Aberdeenshire this translates to virtually free year-round electricity where grid services are included, while in London tenants have saved on average £7.50 per month so far from the P2P platform. This can assist with issues of fuel poverty and poverty in general, with second-order benefits for things like mental health, physical health, and wellbeing (Day, G. Walker, and Simcock 2016). In Glasgow, the financial benefit is much more holistic – solar generated on two schools is exported to the grid under the feed-in tariff, revenue from which is then re-invested in local community projects and initiatives.

The benefit for other actors is perhaps less obvious, and is crucially directly linked to motivations for engaging in each innovation in the first place. These are thus outlined more comprehensively in the following section.

4.5.3 Motivations

As is to be expected in social innovation, motivations were less to do with definitive financial return on investment (at least not from these individual initiatives in the short-term), and varied slightly yet distinctly between market, policy, and community actors as prior research had led to expect (Brown, Stephen Hall, and Davis 2020; Adams et al. 2021; Wilkinson et al. 2020). Even in the case of Glasgow Community Energy, where a formal share offer was launched and people invested their money, the promised return on that investment was a small 1-3 per cent over 20 years, which members could choose to waive if they simply wished to help the project get funded. Instead, primary motivations were found to be four-fold: (1) reducing emissions, (2) providing social or economic value to low-income communities, (3) reputational advantage, and (4) innovation and demonstration.

Emissions reduction

Perhaps unsurprising in any clean energy innovation or development, particularly at this scale, reducing emission from energy use is a key and primary motivation for a majority of stakeholders. This includes citizens themselves: in the CommUNITY project, one tenant involved in the trial outlined that they were happy to be "reducing their carbon footprint", while those in the Aberdeenshire SSS project cite "doing their bit for the environment" as something that made them more positive about participation in the first place. With popular (mis)conceptions that people experiencing poverty or deprivation or across diverse working-class communities in general are disinterested in environmental issues K. Bell 2020, this is encouraging.

Across policy and energy stakeholders, this is likewise critical. Local authorities see these innovations as a way to meet emissions reduction and clean energy generation targets, while mission-driven groups like Repowering London and Glasgow Community Energy place climate action and putting power "back into the hands of people" squarely at the heart of their work (Community Energy 2021). Although the amount of CO_2 saved is relatively small in some cases, the principle of saving those emissions and reducing dependency on fossil fuels is a natural by-product and primary motivator of social innovation around local energy systems anywhere, but in these lower-income areas too (without which net zero targets ultimately cannot be reached).

Social and economic value

The hallmark of social innovation is organising new models, policies, and projects with a focus on social value rather than economic gain for investors (Moulaert and MacCallum 2019). In low-income areas especially, this ethos is arguably a necessary precondition – people with lower-incomes are less obviously lucrative to companies or businesses as consumers and addressing things like fuel poverty may mean a reduction in traditional energy revenues in some capacity or other (to keep bills down, minimise energy use, etc). In each of the case studies, this willingness to forgo more traditional, substantive financial return, at least in the immediate term, in order to pursue and explore the potential for these technologies to work for perceived social value is a common motivator.

For Glasgow Community Energy, the core aim is to bring the social and economic benefits of solar power to deprived areas of the city. Although reducing emissions is a key ambition of the project, utilising the panels to create social and economic benefit in two low-income communities, and to challenge traditional energy supply in a way that empowers those communities, is the primary driving force cited by the cooperative and its board members. From Aberdeenshire Council's perspective, the main motivation for the project is to meet the Scottish Government's energy efficiency in social housing (EESH) targets in a way that reduces emissions and contributes crucially to the reduction of fuel poverty. Tenants receive virtually free electricity supply for a majority of the time at no financial return to the Council themselves. Because Aberdeenshire is grid constrained and often has issues with supply during adverse weather, creating a mostly self-reliant, islanded system meant that energy efficiency and fuel poverty could be addressed while also alleviating some of these resilience issues.

Likewise, both Glasgow Community Energy and the CommUNITY projects aimed to bring the benefit of renewables to people in low-income areas. Aberdeenshire SSS provides completely free electricity; GCE provides thousands of pounds in community benefit each year; EDF estimates that the P2P element of this trial has saved tenants an average of £7.50 per month on their energy bills, providing 42 per cent of tenant energy via the solar generated on the roof. Despite involvement from even more corporate actors like EDF, unlocking the benefits of local energy systems for low-income households and communities has been a key driving force for all involved.

Reputational advantage

More than others, social value for low-income communities motivated policymakers and community organisations, again as prior research had anticipated (Brown, Stephen Hall, and Davis 2020; Wilkinson et al. 2020; Hackbarth and Löbbe 2020). Beyond these more normative motivations, however, social innovation with technology at the nexus of energy, climate, and society can also carry substantial *reputational advantage* for participant organisations and groups. That is, by taking the initiative to lead on what can be seen as forward-thinking and ambitious projects with positive social and environmental impact, the actors involved *can also be seen to be* socially conscientious innovators and leaders themselves. This reputational gain is something that many involved, especially those more market and policy adjacent, outline as key drivers of involvement in their respective projects.

For Glasgow City Council, the aim was to support a demonstrator project for potential future expansion, to help meet their emissions reduction targets with clean energy, which has long been a priority in the city, and to show themselves to be at the forefront of energy innovation. Aberdeenshire Council likewise cite the reputational aspect as a key motivator: the ability for the SSS model to be a “transformational project”, for both Aberdeenshire social housing tenants and the wider energy landscape in Scotland both social and private, while representatives from the Council cite the reputational "kudos" for pioneering the project as a key benefit to them. EDF and UK Power Networks in the CommUNITY project in particular also mention wanting to be seen as leading on innovative models of energy provision.

Forgoing typically much larger profits that their model generates in other areas, SMS (the aggregators in the Aberdeenshire project) likewise note that they want to be seen to be at the forefront of this kind of innovation. In future, this would allow them to carve out a name for themselves as an outfit with strong social and environmental drive, which can potentially lead to more business down the line as new and bigger projects come into being. For energy networks, developing a reputation as leaders on supporting people in vulnerable situations can help them to secure greater investment under their future regulated business plans, which are increasingly focussing on enabling those in low-income communities to better benefit from the net zero transition (Ofgem 2022b).

Innovation and demonstration

Finally, developing innovative projects than used to demonstrate new ways of working for others to then learn from and replicate or scale-up is cited as something that drove every actor spoken to in this research. For firms like EDF or UK Power Networks this is to be expected, since innovation in these areas can help to reduce peak demand and alleviate technological constraints and barriers within the energy system.

Yet this was also found to be true of local authorities and community organisations. Indeed, in every case, there is an understanding that innovating a demonstrator project can pave the way for a wider rollout (of the project model and, ideally, benefits for low-income groups) with a greater focus on just outcomes in future. This is not entirely disconnected from financial benefit or business motivations, however. As alluded to, SMS make very little money on this project compared to their typical PPA solar and storage offering, but are motivated by being seen to be leaders in this type of project, which may increase their prospects of more projects in future as the need for grid flexibility increases and energy networks look increasingly towards local systems as a means to reducing expensive reinforcment costs (UKRI and Regen 2022a). SMS also have developed what appears to be a lucrative alternative business model. Again, energy networks are increasingly obliged to innovate to support people in low-income areas in order to secure investment, and so innovation and demonstration also carries some financial incentive.

With that, however, innovating and demonstrating is a dominant motivator of its own accord, for SMS, networks and others. While Repowering London are very much a mission-driven outfit in the business of wider community, social, and environmental benefit, EDF and UK Power Networks outline the opportunity to provide lessons from an innovative project bringing renewables and associated benefits into densely populated urban areas for potential scaling-up or replication by other groups as a key purpose of their involvement in the CommUNITY trial. EDF cite a desire to show how to expand renewables into similar areas while also having the opportunity to test new and innovative models of energy provision and grid services.

UK Power Networks cite a similar reasoning for the project, and for funding the project at a cost to them of £193,000 in total. “Living in these premises can often limit customers’ energy options and the uptake of low carbon technologies such as rooftop solar panels and batteries due to the nature of shared properties and limited space on individual sites. This can be a barrier for certain customers who would be unable to actively participate in the energy market, own distributed energy resources and offer flexibility services. Shared ownership and virtual allocation of the assets can open energy saving opportunities, choices and new revenue streams for customers who would otherwise not be able to participate in the flexibility market” (Energy Networks Association 2021). Aberdeenshire Council, iPower, and SMS all also mention that along with the savings and emissions reductions that tenants can benefit from the opportunity to launch an innovative demonstrator which other Councils or housing associations can learn from has been a key consideration.

4.6 Discussion

These three cases provide useful insights into social innovation of local energy in low-income areas. In every case, a novel combination of actors - rather than simply an individual household or energy company - combine around a mostly shared set of motivations to reduce emissions from energy generation and, crucially, to unlock social and economic value for people in low-income communities. Traditional return on investment is at least partly sidelined (for most actors in the short-term) as a means to innovating and realising value for local community members and citizens. With the technology featuring as a means to unlocking those benefits, rather than those benefits featuring as a "bolt-on" to the technologies or technical aspects themselves (Moulaert and MacCallum 2019; Logue 2019; Wittmayer et al. 2020), these initiatives serve as social innovations in a very rudimentary sense.

In line with expectations from the smart local energy and business models literature (Brown, Stephen Hall, and Davis 2020; Adams et al. 2021), different actors have different core motivations, and where certain actors have been the leading force, their motivations have tended to dictate where the core value manifests. In Glasgow, the project was led by the community energy organisation with an emphasis on local empowerment and benefit; in Aberdeen, the local authority led the project with a core aim to reduce fuel poverty, producing a project that in essence eliminates fuel bills for low-income households; in London, energy technology partners (market, technical) led the project with social intent in terms of saving for citizens and bringing technologies into these areas, but with a far more distinct focus on innovation, reputation and feasibility. Undoubtedly then, more than simply who is involved, who *leads* in projects of this nature is important to the outcomes likely to be produced. Although social value is a key driver in each case, policy and community actors have emphasised this centrally, reflected in how and for whom benefit is realised.

For these outcomes, a closer unpacking of the motivations of different actors reveal some especially interesting insights. Social innovation theory suggests that, for something to count as a social innovation in the purest sense, that social and environmental impact becomes central to the mission of new technologies and projects. Yet for some of the actors, especially those adjacent to policy, energy networks and markets, these social and environmental motivations were underpinned by a further desire *to be seen to hold those motivations* i.e. by the reputational advantage that those motivations possess. Whether we read cynically that these motivations are not sincerely held, which cannot be unpacked here save via an attempt at retrospective telekinesis, by supporting and leading projects in this type of area, actors can receive "kudos" for their social and environmental credentials and for their role as innovators more generally. This is much less prominent among mission-driven community groups who remain dedicated to local empowerment principles. Combined with growing regulatory pressure on energy networks to deliver wider social value and enable a more inclusive transition to clean energy technologies, this uncovers a reputational force that could be leveraged/materially incentivised as social and environmental impact become more important to policymakers and consumers alike.

To this end, academic institutions have been used to support the dissemination of findings from different projects. With this, project lessons can be learned and adapted to other contexts, paving the way for more of the same in future. With all partners, innovation and demonstration was a key motivator, with academic institutions well-placed to facilitate those knowledge-exchange and dissemination functions. Inclusion of an academic partner can thus support new innovations with learnings, but can likewise support reputational advantage and crucially help disseminate learnings from innovative projects for future replication and upscaling.

In the specific low-income context, the Aberdeenshire project demonstrates how local energy innovations can at-once provide social benefit in the form of reducing energy bills effectively to zero for low-income citizens (with minimal citizen input), while also generating revenue to pay back installations or businesses and investors. As battery technology becomes cheaper and government and the regulator reshape markets to more consistently value and reward flexibility, which is ultimately required to help the wider energy system transition to net zero, operating this model at scale can become more feasible as a revenue-generating model in future. However, this is where social innovation meets more traditional motivations, which is likewise the case for energy suppliers and networks seeking to secure future investment, develop new technical solutions and gain a reputational advantage.

This is not necessarily a conflict in thinking. In fact, this arguably presents a key opportunity to address income inequalities in the net zero transition. What this research tells us is that those social outcomes can be leveraged as a prerequisite to upscaling innovations or securing investment and returns. With more explicit requirements in energy network business plans and regulation in particular to enable social and economic value for low-income households and communities, energy system actors such as networks and developers can be incentivised to support low-income households on a more ambitious scale and help mitigate inequalities that have emerged in things like solar PV from reliance on individual purchasing and uptake of measures alone. This in turn can help to enable wider rollout of projects in low-income areas in future (while also supporting technological innovation and network needs). By shaping regulation and incentives to prioritise social and environmental outcomes, attaching greater reputational and technical as well as financial incentives to a just transition, traditional economic motivations can thus be leveraged to deliver more just outcomes such as those demonstrated in the social innovations unpacked here - and alleviate emerging socioeconomic inequalities in the process.

Interesting to the Aberdeenshire project is that, while citizens were engaged at length and have a direct means to contact the Council to rectify any issues, their involvement and behavioural change was minimal, while producing the greatest amount of direct social and economic benefit. In comparison, the benefit to tenants and community members is significantly less in the CommUNITY project, where tenants are asked to have more active engagement, and much more holistic and localised as opposed to individualised in the case of Glasgow Community Energy where householders have no physical participation outside of governance and decision-making. Speaking to previous chapters of this thesis, there is a suggestion here that where communities have been supported through processes and the main procedural and financial burden has been absorbed by other stakeholders, more substantial benefit has been able to be realised (it is also no coincidence that the Aberdeenshire project happened in council housing, meaning they could access homes directly - this will be a challenge for community energy projects and when dealing with those in the private rented sector). None of this is to say that any particular model is better than another or will work in every context, of course - each has its merits and benefits for those communities in different ways, and different things will naturally work in different communities. That is also not to say that people in low-income, vulnerable or diverse working class communities should have all agency in this transition stripped. Rather, that by redistributing the risk so that the onus is not pure on households, evidence suggests much wider and more equitable benefit can be enabled.

Which is ultimately the crucial point. In line with social innovation thinking, the risk-benefit balance is weighted so that bigger organisations with financial and political capacity to bring such projects to life, like Aberdeenshire Council or UK Power Networks, are absorbing the risk and procedural burden while those lower income communities benefit centrally from the process. Compared to the likes of household solar PV, where the onus is squarely on homeowners with greater financial capacity and policy efficacy, this means that those groups can benefit in ways they cannot under a purely homeowner or autonomous model with scope to alleviate longstanding and accelerating inequalities. Where there are even more technical motivations such as alleviating grid constraints or financial motivations in securing investment down the line, these can be reconciled by incentivising local projects in low-income communities to deliver social benefits, supporting innovation for a more expansive, inclusive, and just energy transition going forward.

4.6.1 Limitations

While this paper provides insights into social innovation and local energy models in low-income areas, it does leave some avenues open for further investigation. Innovative models are explored for their capacity to function in less affluent communities, but differences in impacts and implications *within* those communities remains largely uncovered at this point. A more dedicated investigation using a fundamental energy justice perspective would lend itself well to unpacking these critical differences and ensuring that “low-income areas” are not mistakenly treated in any policy or research process as a homogenous entity.

To this end, what is not understood in any real depth from this paper is the perspective of the users and involved citizens themselves. Although some insights were gleaned throughout, extensively so in the case of Aberdeenshire, understanding how citizens experience these innovations more rigorously would help to uncover better experiential insights to then help inform future research and policy design. Deep exploration into this was beyond the scope of this paper (whose dedicated purpose was to uncover the models of innovation specifically), and may yet follow from this paper and for these cases, but understanding how different people in these places experience these innovations would help to round these findings out for a more comprehensive understanding of the subject matter.

This work also focuses exclusively on generation and storage technologies, which is only a small section of the different net zero technological solutions required within the energy transition. Low-carbon heating such as district heat networks and heat pumps have become increasingly salient in policy discussions and indeed in local energy systems, as has energy efficiency which has particular application to low-income groups given that it tends to be lower-cost and lower-regret for householders (Schleich 2019; Xu and Chen 2019). Local approaches to heat and energy efficiency have been progressing in recent years (Regen 2022). Transport is likewise an important vector to consider - given inequalities that could emerge from electric vehicle rollout and recent insights into transport poverty (Alabi et al. 2022; Martiskainen et al. 2021), understanding these different technologies will require its own dedicated research and thinking.

A final point is that this chapter does not include an example of a project in the private rented sector, which comprises a large proportion of low-income communities and which presents a particularly challenging context. Because people in a community may not own their properties, have poor relationships with landlords or live in multi-occupancy, multi-tenure buildings, local projects can become much more complex. Some research has unpacked some of these issues, but far more robust feasibility and evidence-gathering is ultimately required (Pitt and Nolden 2020).

4.7 Conclusion and policy implications

Social innovation is thus a useful lens for understanding how the benefits of local energy systems may be brought into lower-income areas as a tool to rectify inequalities in the uptake of low carbon technologies. In the cases included here, different combinations of differently motivated actors have shifted priorities away from pure economic or financial gain to utilising new modes of energy for more social and environmental purposes. This has not been completely devoid of personal interest, of course – the reputational advantage and chance to use these findings to hone business models, save money, or advertise for business in future is a core proposition for the more business-minded actors in the process. Yet each project nonetheless demonstrates how local energy can be used in low-income areas and shows a willingness to explore and innovate at this nexus. From this, there are four key policy implications.

First, social innovations in this space take place among differently motivated actors across different sectors. Creating consensus among these actors may be relatively straightforward in individual, localised, pilot projects, but doing so more widely to address the wider inequalities that have emerged in access to land benefit from low-carbon technologies will require a much greater shift in policy and regulatory incentives and support to develop these projects going forward, and to reassess fundamentally what is considered value in energy innovation (Hiteva and Sovacool, 2017). Shaping incentives to encourage social and environmental impact as a core outcome, such as regulating for this explicitly in Ofgem's energy network business plans as a precondition to investment, and aligning incentives across the various actors involved, can feasibly help encourage the working of these types of models on a bigger scale to tackle emerging inequalities from the current individual subsidy-focussed model.

Second and relatedly, in every case, funding was provided by government-backed grants and loans or grants from industrial or innovation partners. Community groups like Glasgow Community Energy still have viable funding opportunities through ongoing support provided by CARES and the like, but the other two initiatives required significant up-front expenditure to install the assets involved. This is not entirely sustainable nor suited to making projects like this work at the kind of scale required to address socioeconomic inequalities more widely. However, different options do exist. In Aberdeenshire, aggregators SMS provide long-term financing for solar and storage assets with grid connection; partnering with larger companies like EDF or the like can also help overcome this. The problem here is that those partners may then come to dominate the process and shift priorities away from the social and environmental elements. Upfront financing and development finance to help innovations transition to business-as-usual is thus something that will need a much more dedicated policy exploration.

Third and following from this, in the absence of a more generous feed-in tariff and as identified in the previous chapter, for community energy models to succeed like Glasgow Community Energy and Repowering London have so far, there is a need for innovation in community energy business models overall. Knowing that community energy organisations tend to prioritise the social and environmental aspects of energy provision and that many have located deliberately in low-income areas to this end (Stewart, 2021), helping make innovations in community energy propositions and revenue generation more viable could serve as an organic means to doing these types of project more frequently to ultimately tackle socioeconomic inequalities in low-carbon technology uptake and benefit at the local-level. Drawing on the CommUNITY and in particular the Aberdeenshire project, implementing storage and grid flexibility services where feasible may be a lucrative avenue for future projects.

Fourth, these projects provide innovative models for potentially reducing costs, alleviating socioeconomic inequalities and even putting money back into lower income communities through the net zero transition, particularly in the Aberdeenshire cases where bills are virtually wiped altogether while providing flexibility and avoided reinforcement costs for the network. Of course, these are still in early phases with questions over scale, but over time as the energy system becomes more decentralised and decarbonised, leveraging lessons from social innovation to bring the benefits of that decentralisation and decarbonisation into fuel poor households could contribute to a more resilient, "just" energy system overall.

Chapter 5

Conclusion

5.1 Summary of findings

This thesis set out to understand inequalities in the uptake of low-carbon energy technologies, and how local approaches could help to overcome those to help bring the benefit of the net zero transition into low-income areas. The first empirical contribution demonstrated that inequalities in the uptake of low carbon technologies are not simply about income or individual factors, but that there are some key social drivers - such as peer diffusion and political efficacy - that have combined to widen and lock-in those inequalities over time. Because of this, addressing those inequalities to help lower income people and places benefit from those technologies, to help alleviate financial and social pressures, will require more than grants and subsidies alone. Breaking out of that inequality "trap" will instead require new thinking so that people are not just enabled with available financial support, but that they are fully equipped to access that support and navigate often-complex processes.

To that end, the second empirical contribution shows that community energy organisations so far have helped to bring the benefit of low carbon technologies into low-income areas, although admittedly these benefits have been more localised and holistic and on a relatively small-scale, rather than the direct benefit that having those technologies in the home en masse can bring. Despite this, what this research tells us is that community energy organisations are motivated by social justice as well as climate considerations, which - with the right support for community groups to professionalise at scale - can be leveraged to help deliver value for people and communities which may typically lack the resource and expertise required to access technologies, grants and subsidies.

Beyond community energy, the third and final contribution illustrates new models of local energy, whereby different configurations of actors at the local-level have banded together to deliver projects in low-income areas as a priority. While in some cases these projects can generate financial return for partners, the cases explored herein show how localising energy can allow for value to be realised among communities who otherwise face exclusion when left only to access grants and subsidies themselves. This can be locally, as with Glasgow Community Energy, but can benefit people directly in their homes as well as illustrated by the Aberdeenshire Smart Solar and Storage project. With these benefits and the ability to tailor projects more specifically to local need, leveraging trusted intermediaries such as community groups and local authority knowledge, local energy is diverse and can help low-income communities transition to low-carbon technologies in their homes and places, presenting a new avenue to tackling emerging socioeconomic inequalities in the low-carbon technology transition.

5.2 Lessons for the wider net zero transition

The focus of this thesis has been on the uptake of low carbon technologies that provide clear social and economic value to households. This is different to low-carbon policies more generally, such as low emission zones in cities, for instance. While low emission zones undoubtedly have socioeconomic sensitivities, the aims and benefits of such policies are mostly collective in e.g. cleaner air, increased use of public transport, improved public health etc. Low-carbon technologies like solar PV and heat pumps, on the other hand, tend to come with more substantial individual returns (as well as the collective benefits of decarbonisation overall), which are more likely to directly widen socioeconomic inequalities on one hand, or could feasibly be leveraged to tackle poverty and inequality issues on the other.

Generation and storage technologies were used as the main empirical examples in Chapters 2 and 3 of this thesis as low-carbon technologies that have been heavily subsidised by governments in the UK and elsewhere, and have provided considerable financial return for households and communities to date. Yet lessons apply strongly to heat pumps and low carbon heating systems too, along with household retrofit including energy efficiency measures, since these rely on similar forces to the uptake of generation technologies (financial capacity, peer diffusion, individual efficacy, homeownership etc) and involve direct changes in homes and communities. These technologies are receiving increasing government subsidy, can provide savings and benefits for households at a time of net zero transition and soaring fuel poverty, and have become the predominant focus of UK decarbonisation policy at the time of writing. Peer diffusion has been shown to be an especially strong influencer of heat pump uptake and retrofit (Ruokamo et al., 2023; Cairns et al., 2023) - given the cost of heat pumps, there is clear scope for a new inequality trap to emerge. Conversely, new local and community approaches to heat pumps and retrofit are also emerging (Putnam and Brown, 2021), suggesting the social innovation findings from chapter 4 can also be strongly relevant.

Lessons are less intuitive for the uptake of electric vehicles, however. Inequalities clearly exist in the uptake of electric vehicles, while recent research also shows that electric vehicles are cheaper to run than combustion engine cars, signalling some advantage for those who can afford them. However, electric vehicles are not subsidised at any scale in the UK as it stands, with the overall costs at the time of writing still well beyond that of a heat pump or solar PV, meaning individual value or the capacity for an electric vehicle to benefit people in low-income situations is less clear. Low-income households also disproportionately rely on public transport rather than individual modes such as cars for getting around, making for a less straightforward comparison overall.

5.3 Limitations and future research

For these findings, this thesis has some obvious limitations - many of which are a result of deliberate choices to help focus the work.

5.3.1 Citizen engagement and experience

Throughout this thesis, there is a lack of exploration of how best to engage citizens, particularly from the groups with which this work is concerned, in the design and shaping of low-carbon technology and wider net zero policies. This was a deliberate choice. Meaningful citizen engagement is crucial to securing a more just net zero transition, but understanding engagement requires dedicated research with those communities to better understand. This thesis instead focused on known barriers and new ways to overcome them, with a view to providing practical lessons for policymakers at a higher level. To effectively implement those findings, policymakers and researchers need to understand effective engagement with particular communities, and should engage well in the policy design process.

Likewise, how those citizens and communities experience new technologies and initiatives is a very specialised thing that many others have dedicated serious time to understanding (Ambrose 2020). To give useful, novel insights into lived experience of those communities requires far greater and specific attention. The author has published some research on this (Knox et al. 2022) but this could feasibly be a thesis on its own. In hindsight the experience of diverse working class and marginalised communities remains relatively understudied (and may have been the focus of this research had I had my time again).

5.3.2 Energy justice and other theoretical perspectives

Anyone familiar with literature on energy justice and just transitions will have noted that this feels like an omission from the overall conceptual and analytical perspective of this work. Again, this was on purpose. Accepting that all aspects of energy justice are critical to delivering a fairer transition to net zero, the hope of this thesis was to provide focussed, practical, instrumental insights. Of course, some theory is developed and applied and complex statistical techniques are deployed, but the focus on delivering benefits to low-income communities - what energy justice scholars might call *distributional justice* - was opted for as a means to providing concise and novel findings.

None of this is to undermine the value of more theory-heavy contributions such as energy justice. Justice literature is formative in the ideas and empirical findings given here. Simply, this thesis is preeminently preoccupied with providing statistical evidence on inequalities in low-carbon technology uptake and how to enable low-carbon technologies to be used against poverty and inequality broadly defined. Applying a comprehensive justice lens to this work - and marrying the theoretical together with the quantitative - could add value to this literature and the wider discussion.

5.4 Final personal thoughts

To close, this thesis has sought to add new insights to the conversation on inequalities in low-carbon technology uptake, grant and subsidy design, and local energy as a novel way to address issues of exclusion and enable a wider, just energy transition. It has provided deep quantitative and qualitative insights into this issue at a time where those inequalities are in sharper focus than ever before. It was motivated by a desire to understand how inequalities arise and how more local approaches can help to enable a transition that unlocks value to actively address not just net zero, but poverty and inequality, too.

All of this is informed by experience, as someone from this type of community who wants to see net zero happen in a way that ultimately benefits everyone - as we by now know that it can and must. Its academic contributions in demonstrating new statistical methods and conceptual insights are useful. However, this work has also begun to shape policy discussions among key stakeholders such as Scottish Government, UK Government and local authorities. If it can thus lead to change that supports even a handful of people and places like the one I'm from to benefit from net zero energy where they haven't before, I will consider it a success.

Bibliography

Adams, Sophie et al. (Dec. 2021). “Social and Economic Value in Emerging Decentralized Energy Business Models: A Critical Review”. In: *Energies* 14.23. ISSN: 1996-1073. DOI: `10.3390/EN14237864`. URL: `https://repository.tudelft.nl/islandora/object/uuid%3A6732ac44-5ec5-491a-8a4b-f232e7e59871`.

Akizu, Ortzi et al. (2018). “Contributions of bottom-up energy transitions in Germany: A case study analysis”. In: *Energies* 11.4, pp. 1–21. ISSN: 19961073. DOI: `10.3390/en11040849`.

Alabi, Oluwafisayo et al. (June 2022). “Can network spending to support the shift to electric vehicles deliver wider economy gains? The role of domestic supply chain, price, and real wage effects”. In: *Energy Economics* 110, p. 106001. ISSN: 0140-9883. DOI: `10.1016/J.ENECO.2022.106001`.

Alipour, M. et al. (May 2020). “Predictors, taxonomy of predictors, and correlations of predictors with the decision behaviour of residential solar photovoltaics adoption: A review”. In: *Renewable and Sustainable Energy Reviews* 123, p. 109749. ISSN: 1364-0321. DOI: `10.1016/J.RSER.2020.109749`. URL: `https://www.sciencedirect.com/science/article/pii/S1364032120300459`.

Allan, Grant J. and Stuart G. McIntyre (Mar. 2017). “Green in the heart or greens in the wallet? The spatial uptake of small-scale renewable technologies”. In: *Energy Policy* 102, pp. 108–115. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2016.12.005`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421516306607`.

Ambrose, Aimee (Mar. 2020). “Walking with Energy: Challenging energy invisibility and connecting citizens with energy futures through participatory research”. In: *Futures* 117, p. 102528. ISSN: 00163287. DOI: `10.1016/j.futures.2020.102528`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0016328720300185`.

Arvanitopoulos, Theodoros, Charlie Wilson, and Silvia Ferrini (2022). “Local conditions for the decentralization of energy systems”. In: DOI: `10.1080/00343404.2022.2131756`. URL: `https://www.tandfonline.com/action/journalInformation?journalCode=cres20`.

Aunedi, M and T C Green (2020). “EnergyREV WP5.3: Next Wave of Local Energy Systems in a Whole Systems Context Early Insights into System Impacts of Smart Local Energy Systems”. In: URL: `https://arxiv.org/pdf/2003.08388.pdf`.

Bach, Linda, Debbie Hopkins, and Janet Stephenson (May 2020). “Solar electricity cultures: Household adoption dynamics and energy policy in Switzerland”. In: *Energy Research &*

Social Science 63, p. 101395. ISSN: 22146296. DOI: `10.1016/j.erss.2019.101395`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S221462961930427X`.

Baer, Daniela et al. (June 2021). “Approaches to Social Innovation in Positive Energy Districts (PEDs)—A Comparison of Norwegian Projects”. In: *Sustainability 2021, Vol. 13, Page 7362* 13.13, p. 7362. ISSN: 20711050. DOI: `10.3390/SU13137362`. URL: `https://www.mdpi.com/2071-1050/13/13/7362/htm%20https://www.mdpi.com/2071-1050/13/13/7362`.

Balta-Ozkan, Nazmiye, Rosemary Davidson, et al. (Dec. 2013). “Social barriers to the adoption of smart homes”. In: *Energy Policy* 63, pp. 363–374. ISSN: 03014215. DOI: `10.1016/j.enpol.2013.08.043`.

Balta-Ozkan, Nazmiye, Julide Yildirim, and Peter M. Connor (Sept. 2015). “Regional distribution of photovoltaic deployment in the UK and its determinants: A spatial econometric approach”. In: *Energy Economics* 51, pp. 417–429. ISSN: 0140-9883. DOI: `10.1016/J.ENECO.2015.08.003`. URL: `https://www.sciencedirect.com/science/article/pii/S0140988315002248`.

Balta-Ozkan, Nazmiye, Julide Yildirim, Peter M. Connor, et al. (Jan. 2021). “Energy transition at local level: Analyzing the role of peer effects and socio-economic factors on UK solar photovoltaic deployment”. In: *Energy Policy* 148, p. 112004. ISSN: 03014215. DOI: `10.1016/j.enpol.2020.112004`.

Banks, Nicholas W and Sarah J Darby (n.d.). “A capability approach to smart local energy systems: aiming for ’smart and fair’”. In: (), pp. 5–105.

Bates, Douglas et al. (2015). “Fitting Linear Mixed-Effects Models Using lme4”. In: DOI: `10.18637/jss.v067.i01`. URL: `https://www.jstatsoft.org/`.

— (n.d.). “Fitting Linear Mixed-Effects Models Using lme4”. In: (). DOI: `10.18637/jss.v067.i01`. URL: `https://www.jstatsoft.org/`.

Baum, Fran, Colin MacDougall, and Danielle Smith (Oct. 2006). “Participatory action research”. In: *Journal of Epidemiology and Community Health* 60.10, p. 854. ISSN: 0143005X. DOI: `10.1136/JECH.2004.028662`. URL: `/pmc/articles/PMC2566051/%20/pmc/articles/PMC2566051/?report=abstract%20https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2566051/`.

Bauwens, Thomas and Patrick Devine-Wright (July 2018). “Positive energies? An empirical study of community energy participation and attitudes to renewable energy”. In: *Energy Policy* 118, pp. 612–625. ISSN: 03014215. DOI: `10.1016/j.enpol.2018.03.062`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0301421518301976`.

Bayer, Patrick and Johannes Urpelainen (Apr. 2016). “It Is All about Political Incentives: Democracy and the Renewable Feed-in Tariff”. In: *The Journal of Politics* 78.2, pp. 603–619. ISSN: 0022-3816. DOI: `10.1086/684791`. URL: `https://www.journals.uchicago.edu/doi/10.1086/684791`.

Becker, Sören, Conrad Kunze, and Mihaela Vancea (2017). “Community energy and social entrepreneurship: Addressing purpose, organisation and embeddedness of renewable energy projects”. In: *Journal of Cleaner Production* 147, pp. 25–36. ISSN: 09596526. DOI: `10.1016/j.jclepro.2017.01.048`.

Bell, Andrew, Malcolm Fairbrother, and Kelvyn Jones (Mar. 2019). “Fixed and random effects models: making an informed choice”. In: *Quality and Quantity* 53.2, pp. 1051–1074. ISSN: 15737845. DOI: `10.1007/s11135-018-0802-x`.

Bell, Karen (2020). *Working-Class Environmentalism.* Palgrave MacMillan. DOI: `10.1007/978-3-030-29519-6`.

Berka, Anna L. and Emily Creamer (Feb. 2018). “Taking stock of the local impacts of community owned renewable energy: A review and research agenda”. In: *Renewable and Sustainable Energy Reviews* 82, pp. 3400–3419. ISSN: 13640321. DOI: `10.1016/j.rser.2017.10.050`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S1364032117314247`.

Berka, Anna L., Julie L. MacArthur, and Claudia Gonnelli (Mar. 2020). “Explaining inclusivity in energy transitions: Local and community energy in Aotearoa New Zealand”. In: *Environmental Innovation and Societal Transitions* 34, pp. 165–182. ISSN: 2210-4224. DOI: `10.1016/J.EIST.2020.01.006`. URL: `https://www.sciencedirect.com/science/article/pii/S2210422420300162`.

Bollen, Kenneth A and Judea Pearl (2013). “Handbook of Causal Analysis for Social Research”. In: 15, pp. 301–328. DOI: `10.1007/978-94-007-6094-3`. URL: `https://ftp.cs.ucla.edu/pub/stat_ser/r393-reprint.pdf`.

Bollinger, Bryan et al. (2012). *Peer Effects in the Diffusion of Solar Photovoltaic Panels **. Tech. rep. URL: `https://environment.yale.edu/gillingham/BollingerGillingham_PeerEffectsSolar.pdf`.

Bray, R., B. Woodman, and P. Connor (2018). “Policy and regulatory barriers to local energy markets in Great Britain”. In: *undefined*.

Brown, Donal, Stephen Hall, and Mark E. Davis (Dec. 2019). “Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK”. In: *Energy Policy* 135, p. 110984. ISSN: 03014215. DOI: `10.1016/j.enpol.2019.110984`.

— (Aug. 2020). “What is prosumerism for? Exploring the normative dimensions of decentralised energy transitions”. In: *Energy Research and Social Science* 66, p. 101475. ISSN: 22146296. DOI: `10.1016/j.erss.2020.101475`.

Brummer, Vasco (2018). *Community energy – benefits and barriers: A comparative literature review of Community Energy in the UK, Germany and the USA, the benefits it provides for society and the barriers it faces.* DOI: `10.1016/j.rser.2018.06.013`.

Busic-Sontic, Ante and Franz Fuerst (Jan. 2018). “Does your personality shape your reaction to your neighbours’ behaviour? A spatial study of the diffusion of solar panels”. In: *Energy and Buildings* 158, pp. 1275–1285. ISSN: 0378-7788. DOI: `10.1016/J.ENBUILD.`

2017.11.009. URL: `https://www.sciencedirect.com/science/article/pii/S0378778817329092`.

Carattini, Stefano, Martin Péclat, and Andrea Baranzini (2018). “Social interactions and the adoption of solar PV: evidence from cultural borders”. In: ISSN: 2515-5717. URL: `www.cccep.ac.uk`.

Castaneda, Monica et al. (Aug. 2020). “The long-term effects of cautious feed-in tariff reductions on photovoltaic generation in the UK residential sector”. In: *Renewable Energy* 155, pp. 1432–1443. ISSN: 0960-1481. DOI: `10.1016/J.RENENE.2020.04.051`. URL: `https://www.sciencedirect.com/science/article/pii/S0960148120305838`.

Celata, Filippo and Venere Stefania Sanna (2019). “A multi-dimensional assessment of the environmental and socioeconomic performance of community-based sustainability initiatives in Europe”. In: *Regional Environmental Change* 19.4, pp. 939–952. ISSN: 1436378X. DOI: `10.1007/s10113-019-01493-9`.

Cherrington, R. et al. (Feb. 2013). “The feed-in tariff in the UK: A case study focus on domestic photovoltaic systems”. In: *Renewable Energy* 50, pp. 421–426. ISSN: 0960-1481. DOI: `10.1016/J.RENENE.2012.06.055`. URL: `https://www.sciencedirect.com/science/article/pii/S0960148112004065`.

Citizen’s Advice (2022). *October price cap rise will leave 13 million in the red - Citizens Advice*. URL: `https://www.citizensadvice.org.uk/about-us/about-us1/media/press-releases/october-price-cap-rise-will-leave-13-million-in-the-red/`.

Coffman, Makena et al. (Jan. 2016). “A policy analysis of Hawaii’s solar tax credit”. In: *Renewable Energy* 85, pp. 1036–1043. ISSN: 09601481. DOI: `10.1016/j.renene.2015.07.061`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0960148115301567`.

Colli, Francesca (2020). *The EU’s Just Transition: three challenges and how to overcome them*. Tech. rep. URL: `https://about.jstor.org/terms`.

Community Energy, Glasgow (2021). “Community Share Offer”. In.

Cornwall Insight (2022). *Cornwall Insight forecasts a fall in the April 2023 Price Cap but prices remain significantly above the Energy Price Guarantee - Cornwall Insight*. URL: `https://www.cornwall-insight.com/press/cornwall-insight-forecasts-a-fall-in-the-april-2023-price-cap-but-prices-remain-significantly-above-the-energy-price-guarantee/`.

Crawley, Jenny et al. (May 2021). “Demand response beyond the numbers: A critical reappraisal of flexibility in two United Kingdom field trials”. In: *Energy Research & Social Science* 75, p. 102032. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2021.102032`.

Creamer, Emily et al. (Nov. 2019). “Community renewable energy: What does it do? Walker and Devine-Wright (2008) ten years on”. In: *Energy Research & Social Science* 57, p. 101223. ISSN: 22146296. DOI: `10.1016/j.erss.2019.101223`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S2214629619300106`.

Curtin, Joseph, Celine McInerney, and Lara Johannsdottir (2018). “How can financial incentives promote local ownership of onshore wind and solar projects? Case study evidence from Germany, Denmark, the UK and Ontario”. In: *Local Economy* 33.1, pp. 40–62. ISSN: 14709325. DOI: `10.1177/0269094217751868`.

Darby, Sarah J. (Jan. 2018). *Smart technology in the home: time for more clarity.* DOI: `10.1080/09613218.2017.1301707`.

Day, Rosie, Gordon Walker, and Neil Simcock (2016). “Conceptualising energy use and energy poverty using a capabilities framework”. In: *Energy Policy.* ISSN: 03014215. DOI: `10.1016/j.enpol.2016.03.019`.

Dieleman, Joseph L. and Tara Templin (Oct. 2014). “Random-effects, fixed-effects and the within-between specification for clustered data in observational health studies: A simulation study”. In: *PLoS ONE* 9.10, e110257. ISSN: 19326203. DOI: `10.1371/journal.pone.0110257`. URL: `www.plosone.org`.

Dolter, Brett D. and Martin Boucher (Sept. 2018). “Solar energy justice: A case-study analysis of Saskatchewan, Canada”. In: *Applied Energy* 225, pp. 221–232. ISSN: 03062619. DOI: `10.1016/j.apenergy.2018.04.088`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0306261918306482`.

EDF Energy (2021). *‘Urban Energy Club’ reaches milestone with new battery at Elmore House | EDF.* URL: `https://www.edfenergy.com/media-centre/news-releases/urban-energy-club-reaches-milestone-new-battery-elmore-house`.

Energy Networks Association (2021). *Urban Energy Club | ENA Innovation Portal.* URL: `https://smarter.energynetworks.org/projects/nia_ukpn0050/`.

Energy Saving Trust (2015). *Community and locally owned renewable energy in Scotland at September 2015 A report by the Energy Saving Trust for the Scottish Government About the Energy Saving Trust.* Tech. rep. URL: `https://energysavingtrust.org.uk/sites/default/files/reports/Community%20and%20locally%20owned%202015%20report_final%20version%20171115.pdf`.

— (2020). *Community and locally owned renewable energy in Scotland at June 2019 A report by the Energy Saving Trust for the Scottish Government About the Energy Saving Trust.* Tech. rep. URL: `https://energysavingtrust.org.uk/sites/default/files/Community%20and%20locally%20owned%20renewable%20energy%20in%20Scotland.%202019%20Report.pdf`.

European Commission (2020). *Just Transition Mechanism.* URL: `https://ec.europa.eu/commission/presscorner/detail/en/ip_20_930`.

Fairbrother, Malcolm (2016). “Trust and Public Support for Environmental Protection in Diverse National Contexts”. In: *Sociological Science* 3, pp. 359–382. DOI: `10.15195/v3.a17`. URL: `www.sociologicalscience.com`.

Fell, Michael J. (June 2021). “Anticipating distributional impacts of peer-to-peer energy trading: Inference from a realist review of evidence on Airbnb”. In: *Cleaner and Responsible Consumption* 2, p. 100013. ISSN: 2666-7843. DOI: `10.1016/J.CLRC.2021.100013`.

Fikru, Mahelet G. (Apr. 2020). “Determinants of electricity bill savings for residential solar panel adopters in the U.S.: A multilevel modeling approach”. In: *Energy Policy* 139, p. 111351. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2020.111351`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421520301087`.

Ford, Rebecca et al. (2019). “Smart Local Energy Systems (SLES): A conceptual review and exploration”. In: DOI: `10.31235/OSF.IO/J4D57`. URL: `https://osf.io/preprints/socarxiv/j4d57/`.

— (May 2021). “Smart local energy systems (SLES): A framework for exploring transition, context, and impacts”. In: *Technological Forecasting and Social Change* 166, p. 120612. ISSN: 0040-1625. DOI: `10.1016/J.TECHFORE.2021.120612`.

Goedkoop, Fleur and Patrick Devine-Wright (July 2016). “Partnership or placation? the role of trust and justice in the shared ownership of renewable energy projects”. In: *Energy Research and Social Science* 17, pp. 135–146. ISSN: 22146296. DOI: `10.1016/j.erss.2016.04.021`.

Grace, James B. (Jan. 2008). “Structural Equation Modeling for Observational Studies”. In: *Journal of Wildlife Management* 72.1, pp. 14–22. ISSN: 0022-541X. DOI: `10.2193/2007-307`. URL: `http://www.bioone.org/doi/abs/10.2193/2007-307`.

Grover, David (2013). *The British Feed-in Tariff for small renewable energy systems: Can it be made fairer? Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and the Environment.* Tech. rep. URL: `http://www.lse.ac.uk/grantham/`.

Grover, David and Benjamin Daniels (July 2017). “Social equity issues in the distribution of feed-in tariff policy benefits: A cross sectional analysis from England and Wales using spatial census and policy data”. In: *Energy Policy* 106, pp. 255–265. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2017.03.043`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421517301878`.

Guagnano, Giuseppina, Elisabetta Santarelli, and Isabella Santini (Sept. 2016). “Can Social Capital Affect Subjective Poverty in Europe? An Empirical Analysis Based on a Generalized Ordered Logit Model”. In: *Social Indicators Research* 128.2, pp. 881–907. ISSN: 0303-8300. DOI: `10.1007/s11205-015-1061-z`. URL: `http://link.springer.com/10.1007/s11205-015-1061-z`.

Hackbarth, André and Sabine Löbbe (Mar. 2020). “Attitudes, preferences, and intentions of German households concerning participation in peer-to-peer electricity trading”. In: *Energy Policy* 138, p. 111238. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2020.111238`.

Haggett, Claire et al. (2013). *Community Energy in Scotland: the Social Factors for Success.* Tech. rep. URL: `https://www.climatexchange.org.uk/media/1585/cxc_report_-_success_factors_for_community_energy.pdf`.

Hall, S et al. (2020). *Prosumers for the Energy Union Dissemination level Public (PU) Summary of PROSEU.* Tech. rep.

Hall, Stephen et al. (Apr. 2021). "Innovative energy business models appeal to specific consumer groups but may exacerbate existing inequalities for the disengaged". In: *Nature Energy 2021 6:4* 6.4, pp. 337–338. ISSN: 2058-7546. DOI: `10.1038/s41560-021-00821-w`. URL: `https://www.nature.com/articles/s41560-021-00821-w`.

Heffron, Raphael J. and Darren McCauley (Jan. 2018). "What is the 'Just Transition'?" In: *Geoforum* 88, pp. 74–77. ISSN: 0016-7185. DOI: `10.1016/J.GEOFORUM.2017.11.016`. URL: `https://www.sciencedirect.com/science/article/pii/S0016718517303287`.

Heffron, Raphael J., Darren McCauley, and Gerardo Zarazua de Rubens (2018). "Balancing the energy trilemma through the Energy Justice Metric". In: *Applied Energy* 229, pp. 1191–1201. ISSN: 03062619. DOI: `10.1016/j.apenergy.2018.08.073`.

Hewitt, Richard J. et al. (Apr. 2019). "Social Innovation in Community Energy in Europe: A Review of the Evidence". In: *Frontiers in Energy Research* 7, p. 31. ISSN: 2296-598X. DOI: `10.3389/fenrg.2019.00031`. URL: `https://www.frontiersin.org/article/10.3389/fenrg.2019.00031/full`.

Hitaj, Claudia and Andreas Löschel (Aug. 2019). "The impact of a feed-in tariff on wind power development in Germany". In: *Resource and Energy Economics* 57, pp. 18–35. ISSN: 09287655. DOI: `10.1016/j.reseneeco.2018.12.001`.

Hiteva, Ralitsa and Benjamin Sovacool (Aug. 2017). "Harnessing social innovation for energy justice: A business model perspective". In: *Energy Policy* 107, pp. 631–639. ISSN: 03014215. DOI: `10.1016/j.enpol.2017.03.056`.

Jenkins, Kirsten (May 2018). "Setting energy justice apart from the crowd: Lessons from environmental and climate justice". In: *Energy Research & Social Science* 39, pp. 117–121. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2017.11.015`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629617304309`.

Jenkins, Kirsten, Benjamin K. Sovacool, and Darren McCauley (2018). "Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change". In: *Energy Policy* 117, pp. 66–74. ISSN: 03014215. DOI: `10.1016/j.enpol.2018.02.036`.

Jenkins, Kirsten E.H. et al. (Sept. 2020). "Towards impactful energy justice research: Transforming the power of academic engagement". In: *Energy Research & Social Science* 67, p. 101510. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2020.101510`.

Kloppenburg, Sanneke and Marten Boekelo (Mar. 2019). "Digital platforms and the future of energy provisioning: Promises and perils for the next phase of the energy transition".

In: *Energy Research & Social Science* 49, pp. 68–73. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2018.10.016`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629618307461?via%3Dihub`.

Knox, Stephen et al. (Jan. 2022). "The (in)justices of smart local energy systems: A systematic review, integrated framework, and future research agenda". In: *Energy Research & Social Science* 83, p. 102333. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2021.102333`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S2214629621004254`.

Korcaj, Liridon, Ulf J.J. Hahnel, and Hans Spada (Mar. 2015). "Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers". In: *Renewable Energy* 75, pp. 407–415. ISSN: 09601481. DOI: `10.1016/j.renene.2014.10.007`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0960148114006326`.

Kosugi, Takanobu, Yoshiyuki Shimoda, and Takayuki Tashiro (Oct. 2019). "Neighborhood influences on the diffusion of residential photovoltaic systems in Kyoto City, Japan". In: *Environmental Economics and Policy Studies* 21.4, pp. 477–505. ISSN: 1432-847X. DOI: `10.1007/s10018-019-00239-5`. URL: `http://link.springer.com/10.1007/s10018-019-00239-5`.

Kucher, Oleg, Donald Lacombe, and Sean T. Davidson (Mar. 2020). "The Residential Solar PV in the Mid-Atlantic: A Spatial Panel Approach". In: *International Regional Science Review*, p. 016001762091406. ISSN: 0160-0176. DOI: `10.1177/0160017620914063`. URL: `http://journals.sagepub.com/doi/10.1177/0160017620914063`.

Kwan, Calvin Lee (Aug. 2012). "Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States". In: *Energy Policy* 47, pp. 332–344. ISSN: 03014215. DOI: `10.1016/j.enpol.2012.04.074`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0301421512003795`.

Lacey-Barnacle, M. and C. M. Bird (2018). "Intermediating energy justice? The role of intermediaries in the civic energy sector in a time of austerity". In: *Applied Energy*. ISSN: 03062619. DOI: `10.1016/j.apenergy.2018.05.088`.

Lacey-Barnacle, Max (Nov. 2020). "Proximities of energy justice: contesting community energy and austerity in England". In: *Energy Research & Social Science* 69, p. 101713. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2020.101713`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629620302887?dgcid=author`.

Lefcheck, Johnathan S (Dec. 2019). *piecewiseSEM: Piecewise Structural Equation Modeling in R*. URL: `https://cran.r-project.org/web/packages/piecewiseSEM/vignettes/piecewiseSEM.html`.

Lefcheck, Jonathan S. (May 2016a). "piecewiseSEM : Piecewise structural equation modelling in r for ecology, evolution, and systematics". In: *Methods in Ecology and Evolution* 7.5. Ed. by Robert Freckleton, pp. 573–579. ISSN: 2041-210X. DOI: `10.1111/2041-210X.12512`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.12512`.

Lefcheck, Jonathan S. (May 2016b). "piecewiseSEM : Piecewise structural equation modelling in r for ecology, evolution, and systematics". In: *Methods in Ecology and Evolution* 7.5. Ed. by Robert Freckleton, pp. 573–579. ISSN: 2041-210X. DOI: `10.1111/2041-210X.12512`. URL: `https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.12512`.

Li, Hui and Hongtao Yi (June 2014). "Multilevel governance and deployment of solar PV panels in U.S. cities". In: *Energy Policy* 69, pp. 19–27. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2014.03.006`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421514001530`.

Local Energy Scotland (2020). *Who we work with - Local Energy Scotland*. URL: `https://www.localenergy.scot/who-we-are/who-we-work-with/`.

Logue, Danielle (July 2019). "Social innovation and its contemporary evolution". In: *Theories of Social Innovation*, pp. 6–26. DOI: `10.4337/9781786436894.00007`.

Lüdecke, Daniel (2019). *Fixed and Random Effects Models*. URL: `https://strengejacke.github.io/mixed-models-snippets/random-effects-within-between-effects-model.html`.

Lukanov, Boris R. and Elena M. Krieger (Nov. 2019). "Distributed solar and environmental justice: Exploring the demographic and socio-economic trends of residential PV adoption in California". In: *Energy Policy* 134, p. 110935. ISSN: 03014215. DOI: `10.1016/j.enpol.2019.110935`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0301421519305221`.

Martiskainen, Mari et al. (Jan. 2021). "New Dimensions of Vulnerability to Energy and Transport Poverty". In: *Joule* 5.1, pp. 3–7. ISSN: 2542-4351. DOI: `10.1016/J.JOULE.2020.11.016`.

McCauley, Darren et al. (Jan. 2019a). "Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research". In: *Applied Energy* 233-234, pp. 916–921. ISSN: 0306-2619. DOI: `10.1016/J.APENERGY.2018.10.005`. URL: `https://www.sciencedirect.com/science/article/pii/S0306261918315587`.

— (Jan. 2019b). "Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research". In: *Applied Energy* 233-234, pp. 916–921. ISSN: 03062619. DOI: `10.1016/j.apenergy.2018.10.005`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0306261918315587`.

McDonald, Ashley et al. (June 2020). "The protective roles of ethnic identity, social support, and coping on depression in low-income parents: A test of the adaptation to poverty-related stress model". In: *Journal of consulting and clinical psychology* 88.6, pp. 504–515. ISSN: 19392117. DOI: `10.1037/ccp0000477`. URL: `/record/2020-32638-001`.

Milchram, Christine (July 2021). "Keeping it in the community". In: *Nature Energy 2021 6:8* 6.8, pp. 777–778. ISSN: 2058-7546. DOI: `10.1038/s41560-021-00885-8`. URL: `https://www.nature.com/articles/s41560-021-00885-8`.

Mirzania, Pegah et al. (2019). “The impact of policy changes: The opportunities of Community Renewable Energy projects in the UK and the barriers they face”. In: *Energy Policy* 129.November 2017, pp. 1282–1296. ISSN: 03014215. DOI: `10.1016/j.enpol.2019.02.066`. URL: `https://doi.org/10.1016/j.enpol.2019.02.066`.

Morris, Madeleine et al. (2020). *Working Paper 2: Digital energy platforms.* ISBN: 9781909522640. URL: `www.energyrev.org.uk`.

Moulaert, Frank and Diana MacCallum (2019). *Advanced Introduction to Social Innovation.* Cheltenham: Edward Elgar. ISBN: 978 1 78536 038 1.

Mundaca, Luis, Henner Busch, and Sophie Schwer (2018). “‘Successful’ low-carbon energy transitions at the community level? An energy justice perspective”. In: *Applied Energy.* ISSN: 03062619. DOI: `10.1016/j.apenergy.2018.02.146`.

Noll, Daniel, Colleen Dawes, and Varun Rai (Apr. 2014). “Solar Community Organizations and active peer effects in the adoption of residential PV”. In: *Energy Policy* 67, pp. 330–343. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2013.12.050`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421513013141`.

Nordensvärd, Johan and Frauke Urban (July 2015). “The stuttering energy transition in Germany: Wind energy policy and feed-in tariff lock-in”. In: *Energy Policy* 82.1, pp. 156–165. ISSN: 03014215. DOI: `10.1016/j.enpol.2015.03.009`.

O’Shaughnessy, Eric et al. (Nov. 2020). “The impact of policies and business models on income equity in rooftop solar adoption”. In: *Nature Energy*, pp. 1–8. ISSN: 20587546. DOI: `10.1038/s41560-020-00724-2`. URL: `https://www.nature.com/articles/s41560-020-00724-2`.

Ofgem (2020a). *Changes to the FIT scheme | Ofgem.* URL: `https://www.ofgem.gov.uk/environmental-programmes/fit/about-fit-scheme/changes-fit-scheme`.

— (2020b). *Electricity Settlement Reform | Ofgem.* URL: `https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/smarter-markets-programme/electricity-settlement-reform`.

— (2022a). *Ofgem Strategic Innovation Fund announces challenge areas for second round of funding, to help accelerate the transition to net zero | Ofgem.* URL: `https://www.ofgem.gov.uk/publications/ofgem-strategic-innovation-fund-announces-challenge-areas-second-round-funding-help-accelerate-transition-net-zero-0`.

— (2022b). *RIIO-ED2 Draft Determinations | Ofgem.* URL: `https://www.ofgem.gov.uk/publications/riio-ed2-draft-determinations`.

Okkonen, Lasse and Olli Lehtonen (Jan. 2016). “Socio-economic impacts of community wind power projects in Northern Scotland”. In: *Renewable Energy* 85, pp. 826–833. ISSN: 18790682. DOI: `10.1016/j.renene.2015.07.047`.

Peters, Michael et al. (2018). “Community solar initiatives in the United States of America: Comparisons with – and lessons for – the UK and other European countries”. In: *Energy Policy* 121.June, pp. 355–364. ISSN: 03014215. DOI: `10.1016/j.enpol.2018.06.022`.

Pitt, Joe and Colin Nolden (Sept. 2020). “Post-Subsidy Solar PV Business Models to Tackle Fuel Poverty in Multi-Occupancy Social Housing”. In: *Energies* 13.18, p. 4852. ISSN: 1996-1073. DOI: `10.3390/en13184852`. URL: `https://www.mdpi.com/1996-1073/13/18/4852`.

Poruschi, Lavinia and Christopher L. Ambrey (Feb. 2019). “Energy justice, the built environment, and solar photovoltaic (PV) energy transitions in urban Australia: A dynamic panel data analysis”. In: *Energy Research & Social Science* 48, pp. 22–32. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2018.09.008`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629618310107`.

Powells, Gareth and Michael J. Fell (Aug. 2019). “Flexibility capital and flexibility justice in smart energy systems”. In: *Energy Research & Social Science* 54, pp. 56–59. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2019.03.015`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629619301185`.

PwC (2022). *Accelerating Net Zero Delivery.* Tech. rep. URL: `https://www.ukri.org/wp-content/uploads/2022/03/IUK-090322-AcceleratingNetZeroDelivery-UnlockingBenefitsClimateAct pdf`.

Rai, Varun, D. Cale Reeves, and Robert Margolis (Apr. 2016). “Overcoming barriers and uncertainties in the adoption of residential solar PV”. In: *Renewable Energy* 89, pp. 498–505. ISSN: 0960-1481. DOI: `10.1016/J.RENENE.2015.11.080`. URL: `https://www.sciencedirect.com/science/article/pii/S0960148115304961`.

Regen (2019). *Local supply: Options for selling your energy locally 3rd Edition Sponsored by: 2 3rd Edition | Local supply: Options for selling your energy locally.* Tech. rep.

— (2022). *The Local Delivery of Clean Heat.* Tech. rep. URL: `https://www.regen.co.uk/publications/local-delivery-of-clean-heat/`.

Renewable Energy Foundation (2020). *Energy Data.* URL: `https://www.ref.org.uk/energy-data`.

Repowering London (2022). *Rooftop Solar Projects | Repowering.* URL: `https://www.repowering.org.uk/rooftop-solar/`.

Richler, Jenn (Apr. 2017). “Solar PV adoption: Incentives and behaviour”. In: *Nature Energy* 2.4, p. 17066. ISSN: 2058-7546. DOI: `10.1038/nenergy.2017.66`. URL: `http://www.nature.com/articles/nenergy201766`.

Richter, Laura-Lucia (2014). *Social Effects in the Diffusion of Solar Photovoltaic Technology in the UK Social Effects in the Diffusion of Solar Photovoltaic Technology in the UK *.* Tech. rep. URL: `www.eprg.group.cam.ac.ukhttp://www.eprg.group.cam.ac.uk/.`.

Rode, Johannes and Alexander Weber (July 2016). “Does localized imitation drive technology adoption? A case study on rooftop photovoltaic systems in Germany”. In: *Journal of*

Environmental Economics and Management 78, pp. 38–48. ISSN: 0095-0696. DOI: `10.1016/J.JEEM.2016.02.001`. URL: `https://www.sciencedirect.com/science/article/pii/S0095069616000073`.

Rosenow, Jan (2022). *Analysis: Running costs of heat pumps versus gas boilers*. Tech. rep. Regulatory Assistance Project. URL: `https://www.raponline.org/wp-content/uploads/2022/02/Heat-pump-running-costs-v271.pdf`.

Rossiter, Will and David J. Smith (2018). "Green innovation and the development of sustainable communities: The case of Blueprint Regeneration's Trent Basin development". In: *International Journal of Entrepreneurship and Innovation* 19.1, pp. 21–32. ISSN: 20436882. DOI: `10.1177/1465750317751989`.

Schleich, Joachim (Feb. 2019). "Energy efficient technology adoption in low-income households in the European Union – What is the evidence?" In: *Energy Policy* 125, pp. 196–206. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2018.10.061`.

Scottish Government (2019). "Just Transition Commission". In: pp. 1–40. URL: `https://www.gov.scot/groups/just-transition-commission/`.

— (2020). *SIMD (Scottish Index of Multiple Deprivation)*. URL: `https://simd.scot/#/simd2020/BTTTFTT/9/-4.0000/55.9000/`.

Scottish Government, The (2023). *Draft Energy Strategy and Just Transition Plan-delivering a fair and secure zero carbon energy system for Scotland*. Tech. rep. URL: `https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2023/01/draft-energy-strategy-transition-plan/documents/draft-energy-strategy-transition-plan/draft-energy-strategy-transition-plan/govscot%3Adocument/draft-energy-strategy-transition-plan.pdf`.

Scottish Power (2021). "A Just Transition. We're on it". In: URL: `https://www.scottishpower.com/userfiles/file/SP%20COP26%20Just%20Transition%20V3.pdf`.

Scottish Renewables (2020). *Renewable Energy Facts & Statistics | Scottish Renewables*. URL: `https://www.scottishrenewables.com/our-industry/statistics`.

Selvakkumaran, Sujeetha and Erik O. Ahlgren (Jan. 2021). "Understanding social innovation in local energy transitions processes: A multi-case study". In: *Global Transitions* 3, pp. 1–12. ISSN: 2589-7918. DOI: `10.1016/J.GLT.2020.12.001`.

Shipley, Bill (2016). *Cause and Correlation in Biology: A User's Guide to Path Analysis ... - Bill Shipley - Google Books*. 2nd. Cambridge: Cambridge University Press. ISBN: 987-1-107-44259-7.

Simcock, Neil (2016). "Procedural justice and the implementation of community wind energy projects: A case study from South Yorkshire, UK". In: *Land Use Policy* 59, pp. 467–477. ISSN: 02648377. DOI: `10.1016/j.landusepol.2016.08.034`. URL: `http://dx.doi.org/10.1016/j.landusepol.2016.08.034`.

Simcock, Neil et al. (Nov. 2021). “Identifying double energy vulnerability: A systematic and narrative review of groups at-risk of energy and transport poverty in the global north”. In: *Energy Research & Social Science*, p. 102351. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2021.102351`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S2214629621004424`.

Snape, J. (Mar. 2016). “Spatial and Temporal Characteristics of PV Adoption in the UK and Their Implications for the Smart Grid”. In: *Energies* 9.3, p. 210. ISSN: 1996-1073. DOI: `10.3390/en9030210`. URL: `http://www.mdpi.com/1996-1073/9/3/210`.

Sommerfeld, Jeff, Laurie Buys, and Desley Vine (June 2017). “Residential consumers’ experiences in the adoption and use of solar PV”. In: *Energy Policy* 105, pp. 10–16. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2017.02.021`. URL: `https://www.sciencedirect.com/science/article/abs/pii/S0301421517300988`.

Sovacool, Benjamin K., Max Lacey Barnacle, et al. (May 2022). “Towards improved solar energy justice: Exploring the complex inequities of household adoption of photovoltaic panels”. In: *Energy Policy* 164, p. 112868. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2022.112868`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S0301421522000933`.

Sovacool, Benjamin K., David J. Hess, et al. (Dec. 2020a). *Sociotechnical agendas: Reviewing future directions for energy and climate research.* DOI: `10.1016/j.erss.2020.101617`.

— (Dec. 2020b). *Sociotechnical agendas: Reviewing future directions for energy and climate research.* DOI: `10.1016/j.erss.2020.101617`.

Sovacool, Benjamin K., Matthew M. Lipson, and Rose Chard (May 2019). “Temporality, vulnerability, and energy justice in household low carbon innovations”. In: *Energy Policy* 128, pp. 495–504. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2019.01.010`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421519300102`.

Stenegren, Marcus et al. (May 2017). “Piecewise Structural Equation Model (SEM) Disentangles the Environmental Conditions Favoring Diatom Diazotroph Associations (DDAs) in the Western Tropical North Atlantic (WTNA)”. In: *Frontiers in Microbiology* 8, p. 810. ISSN: 1664-302X. DOI: `10.3389/fmicb.2017.00810`. URL: `http://journal.frontiersin.org/article/10.3389/fmicb.2017.00810/full`.

Stewart, Fraser (Oct. 2021). “All for sun, sun for all: Can community energy help to overcome socioeconomic inequalities in low-carbon technology subsidies?” In: *Energy Policy* 157, p. 112512. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2021.112512`.

— (Apr. 2022). “Friends with benefits: How income and peer diffusion combine to create an inequality “trap” in the uptake of low-carbon technologies”. In: *Energy Policy* 163, p. 112832. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2022.112832`. URL: `https://linkinghub.elsevier.com/retrieve/pii/S030142152200057X`.

Sunderland, Louise and Duncan Gibb (2022). *Taking the burn out of heating for low-income households.* Tech. rep. Regulatory Assistance Project. URL: `https://www.raponline.`

org/wp-content/uploads/2022/11/rap-sunderland-gibb-clean-heating-for-low-income-households-2022-dec-1.pdf.

Sunter, Deborah A., Sergio Castellanos, and Daniel M. Kammen (Jan. 2019). "Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity". In: *Nature Sustainability* 2.1, pp. 71–76. ISSN: 2398-9629. DOI: 10.1038/s41893-018-0204-z. URL: http://www.nature.com/articles/s41893-018-0204-z.

Thormeyer, Christoph, Jan-Philipp Sasse, and Evelina Trutnevyte (Jan. 2020). "Spatially-explicit models should consider real-world diffusion of renewable electricity: Solar PV example in Switzerland". In: *Renewable Energy* 145, pp. 363–374. ISSN: 0960-1481. DOI: 10.1016/J.RENENE.2019.06.017. URL: https://www.sciencedirect.com/science/article/pii/S0960148119308390.

Tingey, Margaret and Janette Webb (Mar. 2020). "Governance institutions and prospects for local energy innovation: laggards and leaders among UK local authorities". In: *Energy Policy* 138, p. 111211. ISSN: 0301-4215. DOI: 10.1016/J.ENPOL.2019.111211.

UK Government (2020). *Apply for the Green Homes Grant scheme - GOV.UK*. URL: https://www.gov.uk/guidance/apply-for-the-green-homes-grant-scheme.

— (2023). *Net Zero Review: UK could do more to reap economic benefits of green growth.*

UKRI (2022). *Prospering from the energy revolution – UKRI*. URL: https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/prospering-from-the-energy-revolution/.

UKRI and Regen (2022a). "Insights from smart local energy systems: Finance and investment". In.

— (2022b). "Insights from UKRI-funded innovation projects: Policy and regulation". In.

Verba, Nandor et al. (June 2021). "The energy revolution: cyber physical advances and opportunities for smart local energy systems". In: DOI: 10.13140/RG.2.2.12963.99368. URL: http://arxiv.org/abs/2106.16157%20http://dx.doi.org/10.13140/RG.2.2.12963.99368.

Waal, Esther C. van der (Mar. 2020). "Local impact of community renewable energy: A case study of an Orcadian community-led wind scheme". In: *Energy Policy* 138, p. 111193. ISSN: 0301-4215. DOI: 10.1016/J.ENPOL.2019.111193. URL: https://www.sciencedirect.com/science/article/pii/S0301421519307785.

Walker, Chad et al. (Oct. 2021). "What is 'local' about Smart Local Energy Systems? Emerging stakeholder geographies of decentralised energy in the United Kingdom". In: *Energy Research & Social Science* 80, p. 102182. ISSN: 2214-6296. DOI: 10.1016/J.ERSS.2021.102182.

Walters, Ryan and Philip R. Walsh (Sept. 2011). "Examining the financial performance of micro-generation wind projects and the subsidy effect of feed-in tariffs for urban locations in the United Kingdom". In: *Energy Policy* 39.9, pp. 5167–5181. ISSN: 03014215. DOI: `10.1016/j.enpol.2011.05.047`.

Watson, Nicole Elizabeth et al. (2020). "Two energy suppliers are better than one: survey experiments on consumer engagement with local energy in GB". In: DOI: `10.31235/osf.io/e9nyu`. URL: `https://osf.io/preprints/socarxiv/e9nyu/`.

Wilkinson, Sam et al. (Aug. 2020). "Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia". In: *Energy Research & Social Science* 66, p. 101500. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2020.101500`.

Winter, Simon and Lisa Schlesewsky (Sept. 2019). "The German feed-in tariff revisited - an empirical investigation on its distributional effects". In: *Energy Policy* 132, pp. 344–356. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2019.05.043`. URL: `https://www.sciencedirect.com/science/article/pii/S0301421519303477`.

Wittmayer, Julia M. et al. (Dec. 2020). "Beyond instrumentalism: Broadening the understanding of social innovation in socio-technical energy systems". In: *Energy Research & Social Science* 70, p. 101689. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2020.101689`.

Wolske, Kimberly S. (May 2020). "More alike than different: Profiles of high-income and low-income rooftop solar adopters in the United States". In: *Energy Research & Social Science* 63, p. 101399. ISSN: 2214-6296. DOI: `10.1016/J.ERSS.2019.101399`. URL: `https://www.sciencedirect.com/science/article/pii/S2214629619307327`.

Wolske, Kimberly S., Kenneth T. Gillingham, and P. Wesley Schultz (Mar. 2020). *Peer influence on household energy behaviours*. DOI: `10.1038/s41560-019-0541-9`. URL: `https://www.nature.com/articles/s41560-019-0541-9`.

Xu, Xiaojing and Chien fei Chen (May 2019). "Energy efficiency and energy justice for U.S. low-income households: An analysis of multifaceted challenges and potential". In: *Energy Policy* 128, pp. 763–774. ISSN: 0301-4215. DOI: `10.1016/J.ENPOL.2019.01.020`.

Zur, R. M., S. Aballea, and S. Sherman (2018). *Implementation of Piecewise Structural Equation Modelling (SEM) as an Alternative to Traditional Sem_ A Simulation Study*. Tech. rep. DOI: `10.1016/j.jval.2018.04.1455`.

Chapter 6

Appendix

Understanding inequalities, Appendix A. Generalized linear mixed effects regressions

	Dependent variable:		
	New installed capacity	Solar	Wind
	(1)	(2)	(3)
Income deprivation	-0.597^{***}	-0.413^{***}	-1.092^{***}
	(0.069)	(0.065)	(0.136)
KW capacity t-1	0.536^{***}		
	(0.103)		
lag.solar		0.660^{***}	
		(0.163)	
lag.wind			0.214^{**}
			(0.098)
Constant	-3.573^{***}	-4.005^{***}	-5.948^{***}
	(0.644)	(0.465)	(1.604)
Observations	20,922	20,923	20,923
Akaike Inf. Crit.	5,939.191	4,349.562	2,657.245
Bayesian Inf. Crit.	5,986.882	4,397.253	2,704.937
Note:		*p<0.1; **p<0.05; ***p<0.01	

Understanding inequalities, Appendix B. With interaction term

	Dependent variable:	
	New installed capacity	
	(1)	(2)
Income deprivation	-0.597^{***}	-0.591^{***}
	(0.069)	(0.069)
KW capacity t-1	0.536^{***}	0.648^{***}
	(0.103)	(0.184)
ID*KW		-0.192
		(0.261)
Constant	-3.573^{***}	-3.585^{***}
	(0.644)	(0.646)
Observations	20,922	20,922
Akaike Inf. Crit.	5,939.191	5,940.645
Bayesian Inf. Crit.	5,986.882	5,996.285
Note:	*p<0.1; **p<0.05; ***p<0.01	

Understanding inequalities, Appendix C. Mixed versus fixed effects

	Dependent variable:		
	New capacity added		
	logistic	*generalized linear mixed-effects*	*fixed effects*
	(1)	(2)	(3)
Income deprivation	-0.647^{***}	-0.597^{***}	-0.481^{***}
	(0.051)	(0.069)	(0.060)
KW capacity t-1	1.086^{***}	0.536^{***}	0.671^{***}
	(0.081)	(0.103)	(0.079)
Constant	-2.513^{***}	-3.573^{***}	-2.753^{***}
	(0.057)	(0.644)	(0.173)
Observations	20,922	20,922	20,922
Log Likelihood	-3,490.239	-2,963.595	-3,148.478
Akaike Inf. Crit.	6,986.478	5,939.191	6,364.957
Bayesian Inf. Crit.		5,986.882	
Note:			*p<0.1; **p<0.05; ***p<0.01

Community energy, Appendix A. No effects

	TARIFFpc	**Solar**	**Wind**	**TARIFFpc**	**Solar**	**Wind**
Predictors	*ß (S.E.)*	*ß (S.E.)*	*ß (S.E.)*	*ß (S.E.)*	*ß (S.E.)*	*ß (S.E.)*
(Intercept)	-2.55 ***	-3.01 ***	-4.29 ***	-3.59 ***	-3.54 ***	-6.00 ***
Deprivation decile. (log)	-1.40 ***	-1.60 ***	-1.74 ***	1.30 ***	1.41 ***	-1.25
Homeowner.	0.23 ***	0.17 **	0.32 ***	0.31 ***	0.32 ***	0.30 *
Spillover	1.06 ***	0.65 ***	0.41 ***	0.10 *	0.01	0.20 **
Observations	6976	6976	6976	6976	6976	6976
R^2	0.122	0.040	0.179	0.011	0.032	0.044
** p<0.05 ** p<0.01 *** p<0.001*						

Community energy, Appendix B. Comparison of FE, RE and REWB on overall household benefit models.

Predictors	**FE**	**RE**	**REWB**
(Intercept)	-2.16 ***	-2.52 ***	-2.68 ***
Deprivation decile(log)	-1.57 ***	-1.59 ***	-1.59 ***
Homeownership	0.21 ***	0.17 ***	0.17 ***
Spillover	1.06 ***	1.05 ***	1.06 ***
Income dep.b			-0.19
Homeownership.b			0.87 **
Spillover.b			0.23 **
Random Effects			
00		0.57 Council_area	0.26 Council_area
N		32 Council_area	32 Council_area
Observations	6976	6976	6976
R^2	0.190	0.151 / 0.276	0.251 / 0.311
* $p<0.05$ ** $p<0.01$ *** $p<0.001$			

Community energy, Appendix C. Full fixed effect model

	Household			**Community**		
	TARIFFpc	**Solar**	**Wind**	**TARIFFpc**	**Solar**	**Wind**
Predictors	*ß*	*ß*	*ß*	*ß*	*ß*	*ß*
(Intercept)	-2.16 ***	-2.15 ***	-5.51 ***	-3.56 ***	-3.54 ***	-10.77
Deprivation (log)	-1.61 ***	-1.62 ***	-1.78 ***	1.04 ***	1.14 ***	1.31
Homeownership	0.23 ***	0.16 **	0.36 ***	0.31 ***	0.31 ***	-0.33
Spillover	1.06 ***	0.94 ***	0.62 ***	0.12 *	0.02	0.21 **
CA [Aberdeenshire]	0.15	0.10	2.51 ***	0.30	0.13	7.42
CA [Angus]	-0.01	0.19	1.91 *	0.20	0.28	-0.32
CA [Argyll and Bute]	0.10	-0.90 *	2.84 ***	1.18 *	0.86	8.68
CA [City of Edinburgh]	-1.90 ***	-2.06 ***	-1.34	0.33	0.29	-0.02
CA [Clackmannanshire]	-0.79	-1.31	1.32	1.17 *	1.11	0.30
CA [Dumfries and Galloway]	0.35	-0.18	2.97 ***	0.86	0.81	7.00
CA [Dundee City]	-0.80 *	-0.88 *	0.04	-0.17	-0.24	0.25
CA [East Ayrshire]	-0.38	-0.91 *	2.53 **	-0.52	-0.97	7.70
CA [East Dunbartonshire]	-1.57 **	-1.58 **	-13.73	-1.35	-1.38	-0.25
CA [East Lothian]	-0.13	-0.12	1.59	-1.32	-1.30	-0.05
CA [East Renfrewshire]	-1.47 **	-2.19 **	0.77	-0.50	-1.22	17.59
CA [Falkirk]	-0.96 *	-1.36 **	0.82	-0.31	-0.36	0.25
CA [Fife]	-0.38	-0.73 **	1.82 *	-1.28 *	-1.62 *	16.47
CA [Glasgow City]	-0.93 **	-1.14 ***	0.01	-0.26	-0.35	0.56
CA [Highland]	0.37	-0.32	2.91 ***	-1.18	-2.29 *	17.36
CA [Inverclyde]	-1.26 *	-1.72 *	0.85	-0.25	-1.45	18.85
CA [Midlothian]	-0.89	-0.94	0.64	-14.90	-15.93	0.21
CA [Moray]	0.57	0.28	2.52 **	-1.31	-1.29	-0.16
CA [Na h-Eileanan an Iar]	1.49 ***	-1.85	4.52 ***	2.04 ***	0.31	10.84
CA [North Ayrshire]	-0.67	-1.33 **	1.91 *	0.86	0.79	0.24
CA [North Lanarkshire]	-1.54 ***	-2.14 ***	0.80	-0.89	-0.96	0.45
CA [Orkney Islands]	0.72	-2.54 **	3.28 ***	1.09	-16.34	19.22
CA [Perth and Kinross]	0.25	0.24	2.55 ***	0.51	0.27	17.76
CA [Renfrewshire]	-1.34 **	-1.42 **	-13.09	0.66	0.60	0.20
CA [Scottish Borders]	0.75 **	0.91 ***	1.94 *	-15.17	-16.12	-0.29
CA [Shetland Islands]	1.46 ***	-13.84	4.44 ***	0.91	0.23	18.86
CA [South Ayrshire]	-0.51	-0.88 *	1.80 *	-15.17	-16.21	-0.06
CA [South Lanarkshire]	-0.44	-1.02 ***	2.17 **	0.36	0.25	16.69
CA [Stirling]	0.14	0.25	1.80 *	1.48 **	1.40 **	18.37
CA [West Dunbartonshire]	-1.33 *	-1.15 *	-13.13	-15.12	-16.14	0.34
CA [West Lothian]	-0.54	-0.72 *	0.78	-0.11	-0.38	17.41
Observations	6976	6976	6976	6976	6976	6976
R^2	0.202	0.089	0.492	0.241	0.172	0.516

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Community energy, Appendix D. Random effects on MMW

	TARIFFpc household	**Solar**	**Wind**	**TARIFFpc community**	**Solar**	**Wind**
Predictors	*ß*	*ß*	*ß*	*ß*	*ß*	*ß*
(Intercept)	-2.70 ***	-3.11 ***	-4.33 ***	-3.83 ***	-4.03 ***	-10.58 ***
Deprivation (log)	-1.59 ***	-1.41 ***	-1.87 ***	1.04 ***	1.20 ***	-1.82
Homeownership	0.30 ***	0.17 **	0.44 ***	0.41 ***	0.36 ***	0.20
Spillover	1.06 ***	1.03 ***	0.62 ***	0.17 ***	0.02	0.43 ***
Random Effects						
00	0.65 MMWname	0.85 MMWname	2.01 MMWname	0.75 MMWname	0.82 MMWname	37.90 MMWname
N	351 MMWname	351 MMWname	351 MMWname	351 MMWname	351 MMWname	351 MMWname
Observations	6976	6976	6976	6976	6976	6976
Mar. R^2 / Con. R^2	0.176 / 0.311	0.079 / 0.269	0.268 / 0.546	0.042 / 0.220	0.032 / 0.224	0.028 / 0.922
* $p<0.05$ ** $p<0.01$ *** $p<0.001$						

Community energy, Appendix E. Nested random effects, MMW within Local Authority

	TARIFFpc household	**Solar**	**Wind**	**TARIFFpc community**	**Solar**	**Wind**
Predictors	*ß*	*ß*	*ß*	*ß*	*ß*	*ß*
(Intercept)	-2.70 ***	-3.12 ***	-4.33 ***	-3.84 ***	-4.03 ***	-10.81 ***
Deprivation (log)	-1.69 ***	-1.61 ***	-1.87 ***	1.30 ***	1.37 ***	-1.91
Homeownership	0.30 ***	0.17 **	0.44 ***	0.41 ***	0.36 ***	0.13
Spillover	1.06 ***	0.65 ***	0.41 ***	0.17 ***	0.02	0.34 *
Random Effects						
00	0.65 Council:MMW	0.85 Council:MMW	1.99 Council:MMW	0.77 Council:MMW	0.82 Council:MMW	44.62 Council:MMW
N	32 Council 351 MMW	32 Council 351 MMW	32 Council 351 MMW	32 Council 351 MMW	32 Council 351 MMW	32 Council 351 MMW
Observations	6976	6976	6976	6976	6976	6976
Mar. R^2 / Con. R^2	0.177 / 0.312	0.079 / 0.269	0.270 / 0.545	0.041 / 0.223	0.031 / 0.225	0.024 / 0.933
* $p<0.05$ ** $p<0.01$ *** $p<0.001$						

Table 6.9: Community energy, Appendix F. Analysis of variance between random effects and REWB models.

Anova	**AIC**	**BIC**	**logLik**	**deviance**	**Chisq**	**Df.**	**Pr(>Chisq)**
Random effects	3656.0	3690.2	-1832.0	3646.0			
REWB	3643.4	3698.2	-1813.7	3627.4	18.615	3	0.0003283***

Community energy, Appendix G. REWB without homeownership variable

	TARIFFpc household	**Solar**	**Wind**	**TARIFFpc community**	**Solar**	**Wind**
Predictors						
(Intercept)	-2.60 ***	-3.02 ***	-4.06 ***	-3.68 ***	-3.91 ***	-6.46 ***
Deprivation (log)	-1.43 ***	-1.40 ***	-1.84 ***	1.18 *	1.22 **	-1.43
Spillover	1.08 ***	0.64 ***	0.43 ***	0.13 **	0.03	0.21 **
Random Effects						
00	0.41 Council_area	0.51 Council_area	1.50 Council_area	0.86 Council_area	0.82 Council_area	2.36 Council_area
N	32 Council_area	32 Council_area	32 Council_area	32 Council_area	32 Council_area	32 Council_area
Observations	6976	6976	6976	6976	6976	6976
Mar. R^2 / Con. R^2	0.235 / 0.319	0.103 / 0.224	0.326 / 0.537	0.020 / 0.223	0.012 / 0.210	0.146 / 0.502
* $p<0.05$ ** $p<0.01$ *** $p<0.001$						