EnergyREV

Incorporating novel renewable energy cooperatives to scale-up smart local energy systems for UK's net zero future

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February 2022

INDUSTRIAL STRATEGY

UK Research and Innovation

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This report should be referenced as:

Li, P-H, Barazza, E. and Strachan, N. 2022. Incorporating novel renewable energy cooperatives to scale-up smart local energy systems for UK's net zero future. EnergyREV, University of Strathclyde Publishing: Glasgow, UK.

ISBN 978-1-909522-97-8

Acknowledgements

The analysis presented in this Briefing Note was undertaken in the EnergyREV project, specifically in Work Package 5.3. EnergyREV aims to drive forward research and innovation in SLES. Work Package 5.3, "Next Wave of Local Energy Systems in a Whole Systems Context", aims to understand how the development of SLES will relate to the national energy system as a whole and the extent to which the future investment in national electricity and gas grids may be altered by widespread deployment of SLES.

Contents

Summary

The scale-up of smart local energy systems (SLES) is a potential new approach to accelerate the energy transition to deep decarbonisation. Such a local systems approach will be funded through a range of investor types and enabled by a range of governance institutions (Ford, 2019). A key area for investigation is the critical role of local energy investors – cooperatives – that can leverage household finance and grow this business model into major renewable energy market players.

This Briefing Note aims to assess the role of cooperatives in the SLES transition by using an innovative agent-based energy model, the Bounded Rationality Agents INvestment model (BRAIN-Energy). The model does not assume a perfect world, optimal decision making, or complete achievement of ambitious policy goals. Instead it focuses on how individual decision making by both investors and policy agents, not necessarily optimal, can influence the uptake of SLES and hence drive the UK electricity sector's long-term decarbonisation. The key novelty in this briefing note is the inclusion of local cooperatives. These cooperatives can access household finance to benefit from economies of scale when investing in renewable energy (RE) such as onshore wind and solar PV and subsequently expand their business model to allow households to access policy mechanisms such as capacity market and contracts for difference (CfD). As cooperatives get bigger, households can even use them to contribute to the development of offshore wind. The modelling then investigates how the rest of the market reacts to these cooperatives, both competing against them and copying their business model.

Key findings are that cooperatives can have a major impact on both the scale-up of SLES and overall national efforts to decarbonise the electricity sector. The role of local cooperatives is boosted when they have access to a larger pool of cheap household capital to enable them to quickly grow their RE portfolios and become national players. And in the long-term, when cooperative financial strength is tied up in existing renewable investments, new entrants – underpinned by a continued minimum level of government support – can copy the cooperatives' business model and complete the energy transition to net zero carbon emissions.

Hence, it is essential to introduce new cooperatives that focus on scaling-up SLES and RE and provide them with flexible financial strategies that allow them to grow, supported by strong interventions from active governments. Only in this way can the power system be decarbonised effectively and reach net zero emissions even before 2050, as deemed crucial for the net zero transition of the energy system (CCC, 2020).

Introduction

To achieve the goals of the Paris Agreement (UNFCC, 2015), global energy systems should be deeply decarbonised in the coming decades to reach net-zero greenhouse gas (GHG) emissions by 2050 (IPCC, 2018). In 2019, the UK legislated ambitious net zero emissions targets by 2050 to align with the Paris Agreement (BEIS, 2019). The electricity sector accounts for about 24.2% of total GHG emissions in 2020, making it one of the largest sources in the UK (BEIS, 2021). The electricity system is generally seen as the first that should be fully decarbonised in order to then enable low carbon transport and buildings technologies. Decarbonising the electricity system will include significantly ramping up the share of RE and improving system flexibility to balance electricity supply and demand (CCC, 2015).

SLES that combine RE and smart technologies for system flexibility have been touted as a potential way to accelerate the energy transition to deep decarbonisation (Ford, 2019). In particular, the scale-up of SLES could considerably expand the pool of investors to boost the adoption of RE to decarbonise the power sector (Braunholtz-Speight et al, 2020; McInerney and Bunn, 2019). In a previous EnergyRev policy brief (Li, 2020) the potential contribution of local investors, defined as households and municipal utilities, was investigated under various system settings with the BRAIN-Energy, a novel agent-based model. The participation of local investors was found to significantly increase the share of RE by 2050. However, even with the support of incumbent utilities and the underpinning role of policy makers through carbon pricing, the share of RE across all four scenarios considered could only reach around 75% at most, which is not enough on its own to fully decarbonise the electricity system. The limits to the role of local investors are linked to their constrained financial resources and relatively conservative investment strategies. New business models should thus be introduced into the market to incentivise or enable local investors to exploit the very large RE potential in all regions across the UK to further scale-up SLES.

Community ownership schemes are new business models that allow collective ownership and management of RE plants and share the revenues from those plants among a community. Consumers who do not want to, or cannot, invest in renewable power plants on their own can do so through community ownership models. Sharing costs means lower upfront investment costs for RE projects. These business models encourage the growth of distributed generation and local RE power plants (IRENA, 2019), contributing to reaching the 2050 decarbonisation targets.

The International Renewable Energy Agency (IRENA, 2019) estimates that over 4,000 community ownership projects are active worldwide, with the majority in the US and Europe (mainly in Germany, Norway and Denmark). In Germany, community ownership schemes have been flourishing thanks to a long-standing culture of decentralisation, a strong regime of subsidies to renewables (also small-scale), and low-cost finance (Hall et al, 2016). IRENA (2019) estimated that half of the community ownership projects in Germany were financed by cooperative banks, and a third by KfW, the German state-owned development bank, at very competitive rates.

In the UK, community ownership models are less developed than Germany, with around 300 UK community ownership projects active in energy generation (Braunholtz-Speight et al, 2018). However, Braunholtz-Speight et al. (2018) estimate that these models are in a position to grow and to contribute to the scale-up of RE generation. This is thanks to the development of networks of learning within communities, grant funding, and the rise in alternative financing mechanisms like community shares which allow finance to be raised from the general public.

In this Briefing Note we introduce RE cooperatives, which are based on the community ownership just described. They can borrow money from households, offering these households the prospect of returns from their investments. It is important to stress that in our definition, successful cooperative business models would be expected to grow from local to national players and evolve their functions, including enabling households to participate in wider energy market support mechanisms such as capacity markets and CfD. Ultimately other market players would aim to copy a successful and expanding cooperative's business model.

This Briefing Note thus aims to assess how a novel business model, specifically RE cooperatives, can help scale-up SLES and the share of RE for the decarbonisation of the electricity system. In order to better represent how the electricity market works, like our previous work on non-optimal investments (Li, 2020), all market players can only make investment decisions based on their limited evidence of system characteristics in the near future (i.e. myopic decision-making), with various technology preferences and investment strategies (i.e. heterogeneity) (Barazza and Strachan, 2020). National, local investors and new cooperatives are explicitly represented in the modelling framework, along with their interactions with capacity market and CfD schemes and policy instruments such as carbon prices. Finally, this note focuses on exploring a better market setting for RE cooperatives to help the UK power sector reach net zero targets.

Modelling approach

The BRAIN-Energy Agent Based Model

The BRAIN-Energy, an agent-based model of electricity generation and investments, was further extended to investigate how more flexible business models, such as RE cooperatives, can help the growth of SLES and further expand the share of RE to reach long-term net zero targets.

The BRAIN-Energy represents market players as agents, with bounded-rationality and heterogeneous strategies in investment decisions, and multi-agent interactions. Using such an approach, the model can better reflect realistic behaviours of market participants, such as heterogeneity (i.e., differences in investors' experience, size, wealth and other characteristics) and bounded-rationality (i.e. making "good enough" decisions), which traditional equilibrium and optimisation energy models do not address (Iychettira et al, 2017; Bergek et al, 2013; Wüstenhagen and Menichetti, 2012; Barazza and Strachan, 2020; Hansen et al, 2019; Bale et al, 2015).

Two types of market players are considered in BRAIN-Energy: policy and investor agents, as listed in Table 1 and Table 2. Each of these has distinct goals in the market. Policy agents, including the national government, the national regulator and local governments, aim to ensure system security while incentivising system decarbonisation using multiple policy tools, such as carbon prices and capacity auctions. Investor agents, including national (incumbent utilities and new-entrants) and local (municipal utilities and households), participate in the electricity market based on their own heterogeneous strategies, financial endowments and risk-return considerations.

Table 1: Definition of policy agents

Policy agents	Region, number & aim	Policy instrument
National government	1 national agent Aim: to decarbonise the UK power sector, by encouraging new investments in RE plants.	CO_2 price CfD for RE technologies Local energy development loans to incentivise local investments
Regulator	1 national agent Aim: to promote the security of supply by encouraging investments in gas and nuclear power plants	Capacity market: to promote the security of supply by encouraging investments in gas, biomass and nuclear
Local government	3 local government agents (one in each region) Aim: to decarbonise the local region	Implicitly subsidises technologies through guaranteeing they receive electricity prices set at the national level Local energy development loans to incentivise local investments

Table 2: Definition of investor agents

Investor agents		Region and number	Technology preference
National	Incumbent utility	2 national agents	All: nuclear, gas, biomass, PV, onshore-and offshore wind
	New-entrant	2 national agents	RE only: biomass, PV, onshore-and offshore wind
Local	Municipal utility	1 in London region, 1 in Scotland region, 1 in the rest of UK region	• London: PV • Scotland and the rest of UK: biomass, PV, onshore and offshore wind
	Household	1 in London region, 1 in Scotland region, 1 in the rest of UK region	• London: PV • Scotland and the rest of UK: PV and onshore wind
	RE cooperative*	1 in London region, 1 in Scotland region, 1 in the rest of UK region	RE only: biomass, PV, onshore and offshore wind

* This is a newly introduced agent in this study.

Local investors were introduced in the previous policy brief (Li, 2020) to investigate how the participation of households and municipal utilities that focus on developing local RE projects can help scale-up SLES. They have relatively constrained capital and conservative investment strategies that eventually limit their capacity for further raising the share of RE in the system for deep decarbonisation.

New RE cooperative agents, which are established by local community members, have thus been developed and incorporated into the model. These agents adopt a more flexible investment strategy to compete and grow in the market, as shown in Figure 1. In the beginning, with limited capital, these cooperatives focus on developing local RE projects to scale-up SLES, leveraging their strong connections in local regions. They can recruit households to buy shares and so invest in RE without the need to manage any technical hurdles. Households might be more willing to participate in the system transition in this financial way.

However, unlike other local investors, RE cooperatives expand their business models and do not confine themselves to developments in local regions. Subsidies provided by the government incentivise them to look for investment opportunities in other regions and in even more capital-intensive power technologies, such as offshore wind, to create multiple income streams and to meet a diverse set of investment preferences of communities, including coastal communities, around the UK. To encourage the investments in SLES, national or local governments can establish a "local energy development loan" with low interest rates to reduce local investors' debt level. It should be noted that these new cooperative agents, like other local investors, invest in RE plants both to protect the environment and to hedge themselves against a potential financial burden from increasing carbon prices.

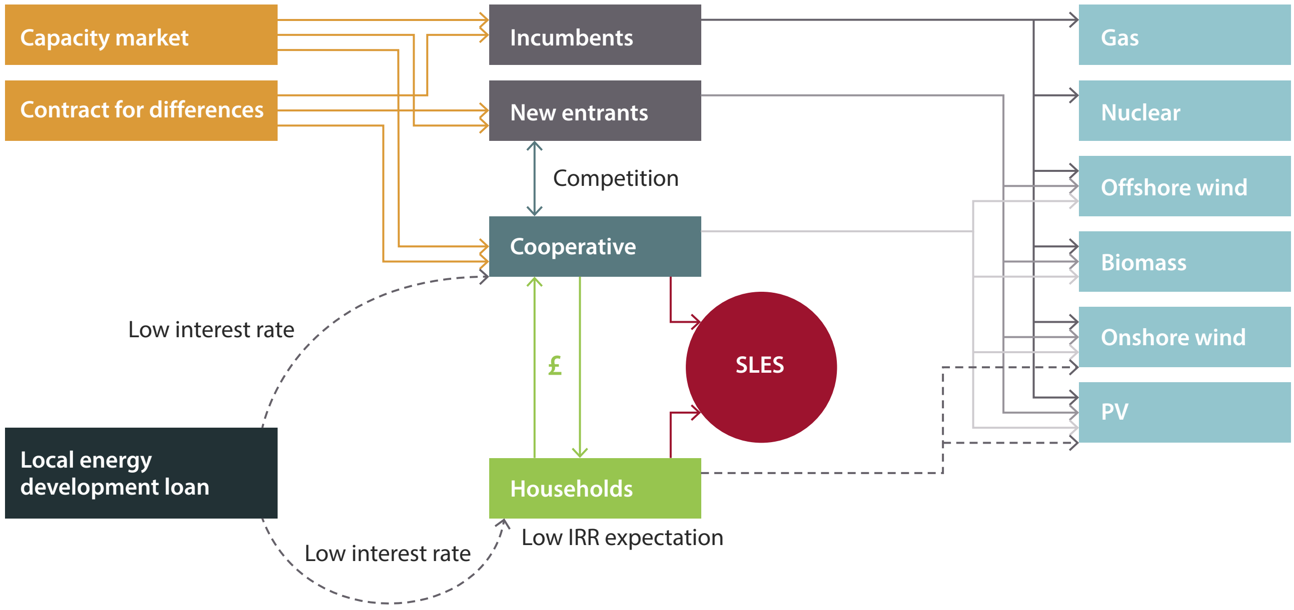

Figure 1: Investment activities of renewable energy cooperatives in the electricity market

The modelling horizon has been extended from 2050 to 2070 to allow time for current power plants to be replaced. Hence the learning and imitation strategies of market investors can fully play out to show the emergent evolution of the energy system, including which investor types are successful, as well as the response of policy agents to changes in the market structure. The underlying projection of electricity demand is based on the UK TIMES's estimation for a net zero scenario (Pye et al, 2017).

For a more detailed description of the BRAIN-Energy model, please refer to the Appendix of the previous policy brief (Li, 2020) and model documentation (Barraza et al, 2020).

Scenarios and results

System scenarios for the role of cooperatives in the market

Four scenarios, as defined in Table 3, are investigated to understand the influences of the financial capacity of cooperatives– as locally based investor-actors with the potential to leverage household finance to make SLES into a major market player across the UK – and the role of government's interventions on the transition of the UK electricity system.

No-cooperative: This is the reference scenario that does NOT contain cooperatives. Instead it includes national investors focusing on capital-intensive projects such as nuclear and local investors aiming to invest in local RE projects to scale-up SLES.

In the other three scenarios, RE cooperatives are present alongside national and local investors to further boost investments in SLES and RE.

Weak-cooperative: This describes cooperatives that have close collaborations with stakeholders in local regions and initially focus on developing regional RE projects. After accumulating sufficient capital, they will try to grow by investing in more capital-intensive power plants, such as biomass power plants, so that they have the opportunities to receive subsidies from the government through the capacity market and CfD schemes. They are limited by the amount of potential capital and the cost of financing such capital. In this case, households can invest only in RE projects that directly affect them. They cannot invest in broader activities by the cooperative.

Strong-cooperative: The financial capability of these cooperatives is strengthened by enabling households to invest in their RE projects, including both local and capital-intensive projects. This additional cash stream provides cooperatives with greater flexibility to invest in new power plants that they deem profitable even if their own capital falls short. In this scenario, it is assumed that the national government establishes a "local energy development loan" to offer cheap capital with a low interest rate of 1.5% to encourage local investments by cooperatives.

Cooperative-partnership: In addition to the settings of the strong-cooperative scenario, cooperatives in this scenario have two key allies. First, the national government plays a more active role in the electricity market by setting an electricity price floor to tackle the "missing money problem"(Winkler et al, 2016)[1] so that the value of system security can be reflected. The electricity price floor (£80/MWh before 2050 and £40/MWh afterwards) is set in a similar range of electricity prices in the early 2030s when active investments in RE take place. Therefore investors have a greater incentive and opportunity to accumulate sufficient revenues for their next investments. Second, new entrants with robust financial resources copy the cooperative's successful SLES business model and can decide to join and further amplify the SLES market.

Carbon budgets imposed in all four scenarios are defined relative to the UK's 5th carbon budget (CCC, 2015). They are set according to the carbon intensity of the power system, which has to drop to 50 gCO2/kWh by 2030, followed by full decarbonisation by 2050.[2] In an agent-based model the strategies of agents may mean that these targets can be missed. A predefined increase in the adoption of demand-side response (DSR) – demand-shifting with smart appliances in the building sector – has also been modelled in all four scenarios to enable system flexibility. However, we note that in a detailed power system model with a finer temporal resolution than BRAIN-Energy has, DSR could potentially play a larger role.

1 According to Winkler et al. (2016), the "missing money problem" refers to the underinvestment in capacity of power plants in liberalised electricity markets as electricity generators only receive revenues for selling electricity but not for providing capacities. This market failure is aggravated as the share of renewable energy increases.

2 More stringent budgets suggested by the 6th Carbon Budget (CCC, 2020) will be considered for sensitivity analysis in a future journal paper.

Table 3: Definition of scenarios

Scenario	Investor	Cooperative's financial capability	Additional market and policy support
No-cooperative	National and local investors	N/A	No
Weak-cooperative	National, local investors and renewable energy cooperatives	Expensive capital from banks (6%)	No
Strong-cooperative	National, local investors and RE cooperatives	Cheap capital from banks (1.5%); gathering capital from households	No
Cooperative-partnership	National, local investors and RE cooperatives	Cheap capital from banks (1.5%); gathering capital from households	New entrants from 2040; electricity price floor

Main results

The strategies and decisions of the newly introduced cooperatives and policy makers can lead to various deployment levels of SLES, with significant impacts on the decarbonisation of the electricity sector. Adding novel cooperative agents to the extended BRAIN-Energy model generates five key findings about the energy transition:

1. Cooperatives and new entrants can ensure the security of the UK electricity system.
2. Cooperatives can further boost investments in RE.
3. Cooperatives can accelerate emission reductions to fully decarbonise the power sector by 2050 or even earlier.
4. Cooperatives will play an increasingly dominant role in the market.
5. The overall costs of the electricity transition will fluctuate considerably with various market settings.

Cooperatives and new entrants can ensure system security

It is critically important to continually invest in a sufficient number of new power plants, both to replace plants reaching the end of their lives, and to meet increasing electricity demands for the decarbonisation of the whole energy system. These new deployments largely depend on investor decisions based on their individual financial conditions, technology preferences, and investment strategies.

Overall, all scenarios show "investment cycles" when it comes to maintaining de-rated capacity margins – the amount of installed capacity available to ensure sufficient power at peak times – over the modelling horizon up to 2070. But this investment pattern in new power plants is not a smooth process, as seen in Figure 2. All investors are actively participating in the market to ramp up their investments as long as these investments are financially feasible to them and in turn generate valuable revenues. However, investors can only speculate on a possible system status in the near future based on limited evidence, which means they have myopic or imperfect foresight. Consequently, the sharp increase in de-rated capacity margins shows that investors invest heavily in new power plants when they have healthy financial conditions.

As investments increase, their debts also accumulate as they borrow capital from banks. Eventually, investors need to pause their investment activities to restore their financial capability with incoming revenues from their existing power plants. De-rated capacity margins drop accordingly until investors are able to invest again with improved financial conditions.

All four scenarios face a major challenge in ensuring system security around 2050. There are three reasons for this:

1. A significant increase in electricity demand approaching 2050 driven by the decarbonisation of the whole energy system (including electric vehicles and electric heat pumps for home heating);
2. A huge drop in capacity of power plants due to decommissioning of capacity introduced in earlier stages;
3. Large amounts of debt means some investors are unable to invest in new capacity.

How investment cycles respond to this challenge varies widely across the four scenarios (Figure 2).

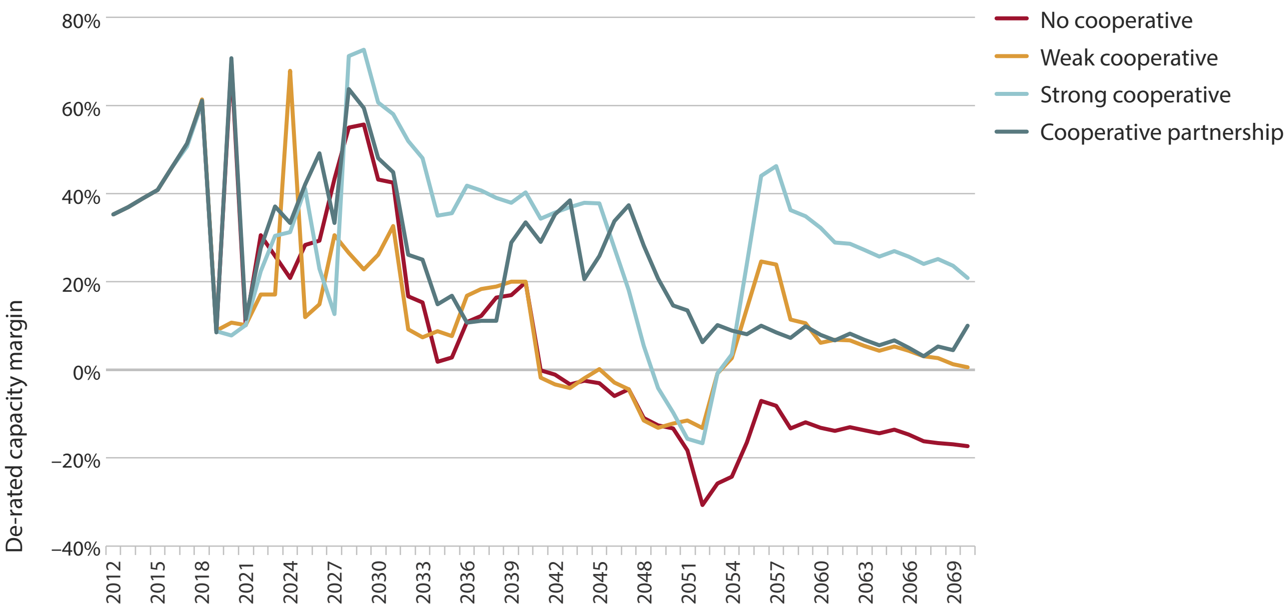

Figure 2: De-rated capacity margin over the modelling horizon for four scenarios

In the no-cooperative scenario, with only conventional investors with conservative investment strategies, limited financial resources and a significant share of non-renewable investments, the system becomes extremely unstable and is not able to fully meet electricity demands after 2040. This is despite the efforts of a regulator working via capacity auctions, who acts but not quickly or firmly enough due to its imperfect foresight. The situation worsens as the regulator fails to encourage investors; they cannot gain enough revenues to recover from previous investments because low electricity prices inhibit investing in a higher share of RE in electricity provision. This system instability would mean a prolonged period of managed demand curtailment, for example with specific industrial consumers, rather than ever higher capacity payments to reluctant investors.

In the weak-cooperative scenario, low de-rated capacity margins mean that, again, electricity demands cannot be met after 2040 because of investors overinvestments in the early stage, which deteriorates their financial capability. However, unlike the no-cooperative scenario, cooperatives play a crucial role in restoring system security by accumulating sufficient capital to enable them to invest in new RE projects such as biomass power plants again.

Weak cooperatives are able to pay back their loans sooner than other investors because they own numerous local RE plants with low levelised costs of electricity. They also have financing from government. Subsidies from participating in the capacity market and CfD help them bounce back from the poor financial conditions. Even with low electricity prices they are eventually able to make new investments.

The financial capability of strong-cooperatives is further strengthened by access to very significant amounts of investments from households, and borrowing cheap capital from local energy development loans established by central or local governments. This means they can easily further expand the scale of investments in local RE plants, as well as capital-intensive RE projects to create more revenues with government subsidies (CfD). Their significant investments lead to an early peak in de-rated capacity margin around 2030. However, like other investors, they gradually run out of capital, even with the help of households. The sharp drop in de-rated capacity margin between 2045 and 2050 is the direct result of the subsequent quiet period in investment activities. Interestingly, de-rated capacity margin bounces back strongly soon after 2050 to an extremely high level, showing how strong cooperatives can accumulate capital more quickly than the previous two cases because they can use cheap capital and have participation from households. The flip side of this is that investors might overinvest to fill the supply gap in an attempt to expand their market shares, which results in the very high peak in de-rated capacity margin around 2057.

The cooperative-partnership scenario shows a distinct and smoother investment pattern, experiencing no system instability over the modelling horizon. Both the sharp drop around 2050 and the dramatic shoot-up are absent in this case. Instead, the power system remains stable, with sufficient capacity of power plants to satisfy a huge increase in electricity demands after 2050, even though a significant number of older plants are still being gradually decommissioned approaching 2050. The drop in these installed power plants is offset by the new investments made by new entrants who join the market from 2040. Unlike incumbent utilities they are not carrying large debts, and copy the successful business models of cooperatives that operate at a national scale. These new entrants fill the investment gap during this crucial period, while other investors, including cooperatives, are limited due to their struggles with financial conditions. Consequently, system security can be maintained. The electricity price floor set by the government from 2040 also helps investors receive reasonable revenues so that they are able to invest in new power plants after 2050. Since the electricity price floor remains at a low level, investors can only accumulate capital at a relatively steady rate. This makes investors take more conservative attitudes towards new investments. The de-rated capacity margins are thus steadier after 2050.

Cooperatives can further boost investments in RE

The investments preferences of market players significantly influence the technology mix in the power system, as shown in Figure 3 and Figure 4.

As discussed in the previous policy brief (Li, 2020), participation of an existing set of local investors such as households and municipal utilities can considerably increase investments in RE at the regional level. The no-cooperative scenario with the same group of investors duplicates that finding as the share of RE reaches around 70% by 2050. However, the share of RE is far from enough to fully decarbonise the power sector by 2050, besides its struggle to meet demands. This reveals the limited investment capability of local investors (i.e. households and municipal utilities) working on their own to scale-up SLES. Local investors might tend to expect a higher return on investment and be less willing to bear too much debt by borrowing from banks with high interest rates. They are more conservative towards new investments in local RE projects.

With the presence of cooperatives in the other three scenarios, the share of RE can further increase from 70% to 95% in the weak-cooperative case, or even 100% in the strong-cooperative and cooperative-partnership cases after 2050 (Figure 3). This is initially due to cooperatives' preferences for local RE projects in the early stage when they begin to participate in the electricity market. The deployment of SLES can thus significantly scale-up in these three cases. Cooperatives have more flexible capital-raising strategies for profitable projects, which enable them to invest in more local projects at a faster pace. As cooperatives grow in scale, they can evolve from local to national players, and access subsidies from both the capacity market and CfD schemes. This can further incentivise cooperatives to invest in capital-intensive RE power plants, such as biomass and offshore wind. As a result, the share of RE is much higher in these cases.

The brief drop in RE around 2050 in the strong-cooperative scenario is explained by the fact that these cooperatives are active investors in new RE projects with cheap capital and investments from households. They expand their assets to a larger scale and run out of dispensable capital sooner than other cases. Since a sufficient number of new power plants cannot be deployed on time, existing gas plants are turned back on to fill the supply gap. The share of RE around 2050 drops accordingly.

In the cooperative-partnership case, on the other hand, the share of RE increases steadily and reaches 100% around 2050 without any short-term drops. Since the cooperatives in this case have the same financial capability as that in the strong-cooperative case, the share of RE grows in a similar pattern in both cases until 2045. New entrants see a business opportunity by spotting the diminishing investments from other investors and begin to invest in RE projects from 2040. The RE plants invested in by new entrants are deployed on time to compensate for the retired plants owned by other investors. Consequently, no existing gas plants need to be switched on to fill a supply gap around 2050.

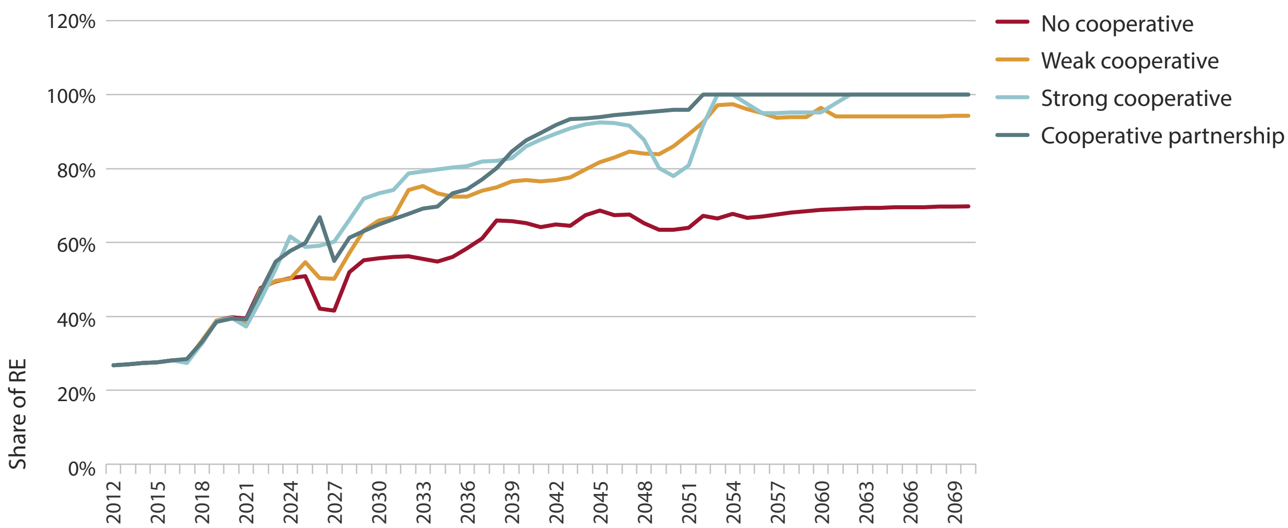

Figure 3: Share of renewable energy generation over the modelling horizon

Investors' technology preferences and investment strategies also determine the technology mix in the power system over time, as shown in Figure 4. As it takes time to introduce new power plants into the system, technology mixes are similar across all four scenarios in 2030.[3]

3 Note that to explore potential strategies to transform the power sector, this study allows a future government to relax planning criteria on power technologies, such as onshore wind. In addition, residual coal plants can be switched back on to ensure system security, considering possible under-investments.

However, by 2050, differences between scenarios become more obvious. In the no-cooperative scenario, where incumbent utilities still play a key role, their preference for nuclear power plants leads to a higher share of nuclear in the mix. With the help of local investors, the installed capacity of RE, such as biomass, onshore and offshore wind, ramps up quite significantly from 2030, the previous milestone year. However, these nuclear and RE low-carbon power plants are still not sufficient to meet all the electricity demands in 2050, and gas power plants are still in place to fill the supply shortage.

In the weak-cooperative scenario in 2050 the share of nuclear is further reduced due to the introduction of an even larger number of RE plants being introduced with the help of cooperatives and other types of local investors. As in the previous case, gas power plants still need to be used to meet electricity demands since the newly introduced low-carbon plants are still not sufficient. A similar technology portfolio can be found in the strong-cooperative case. However, as discussed above, a financially constrained quiet investment period just before 2050 gives a lower total installed capacity in 2050. Finally, in the cooperative partnership case, the share of RE, including the very aggressive deployment of almost all available biomass plant as a flexible generation plant, is further expanded to replace gas and nuclear power plants. These are almost absent in this case. This is largely due to strong investments in RE plants from 2040 by new entrants who are benefitting from copying the cooperatives' business model.

By 2070 all fossil-fuel power plants have been decommissioned and replaced by low-carbon plants, including nuclear and RE. The presence of nuclear power plants is closely linked to the competitiveness of incumbent utilities. In the no-cooperative case incumbent utilities remain an active market player, so their investments contribute to the higher share of nuclear in the power mix in 2070. In the other cases the strong competition from cooperatives and local investors who are solely interested in RE plants allows these technologies to dominate. It is noteworthy that the overinvestments in the strong-cooperative scenario in the 2050s to fill the supply gap lead to higher total capacity in 2070 than other cases.

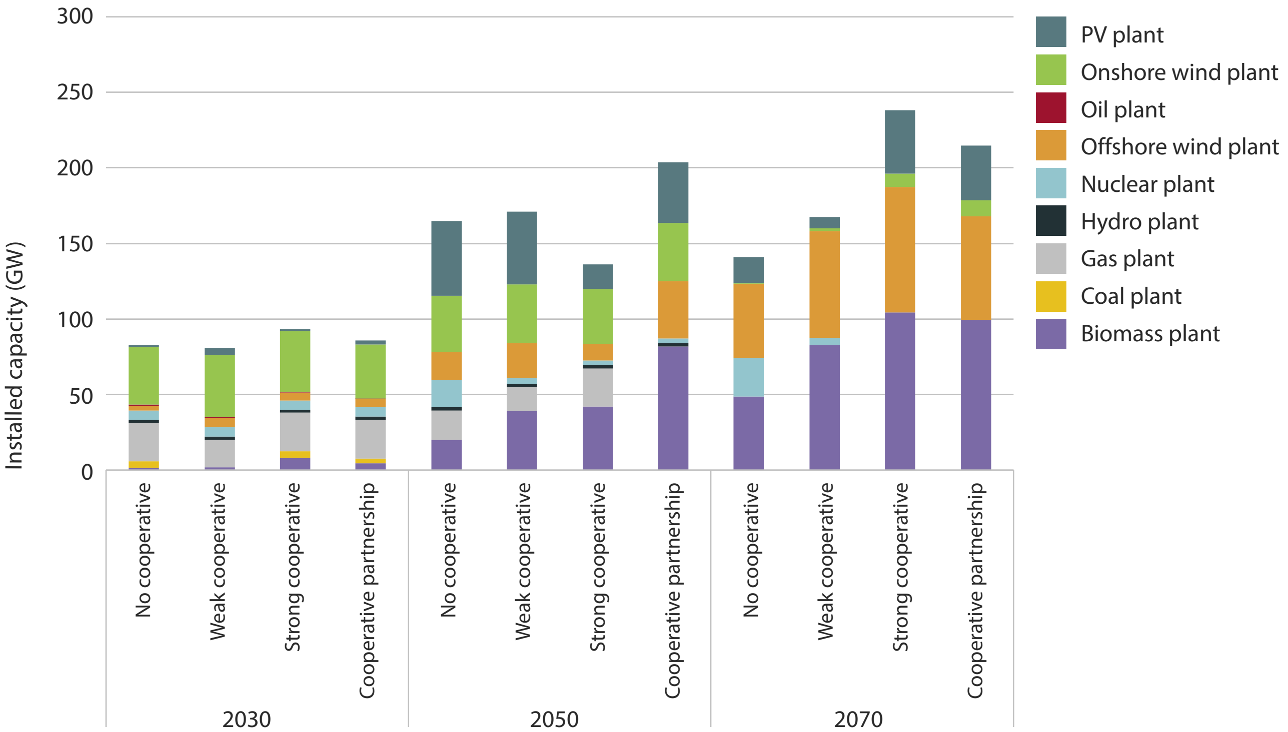

Figure 4: Installed capacity by power plant type in 2030, 2050 and 2070

Cooperatives can accelerate emission reductions to fully decarbonise the power sector by 2050 or earlier

Annual GHG emissions (Figure 5), are driven by the generation mix, and hence have a clear association with the rising profile of RE over the modelling horizon (see Figure 3). In all four scenarios carbon budgets (in carbon intensity) are imposed on the power system; this means dropping to 50 gCO2/kWh by 2035, followed by full decarbonisation by 2050 (BEIS, 2021). However, in an agent-based model the imperfect strategies of the agents may mean that these targets can be missed and indeed it is important to explore when ambitious policies fall short.

With a lower share of RE in the no-cooperative case, annual GHG emissions remain at the highest level and are at least 30% higher than the other cases, meeting net zero targets only in 2054. The active investments in RE plants by both weak and strong cooperatives do help considerably reduce GHG emissions over the complete time horizon. Nonetheless, even though the strong-cooperative can reduce GHG emissions to around 10 Mt CO2e in the 2030s and close to zero emissions by 2045, there is a large jump in GHG emissions approaching 2050 due to the shortage of new investments prior to 2050, as discussed above. The reliance on electricity provision from gas power plants to meet the demands then leads to the peak in GHG emissions. As investors recover their financial health, their heavy investments in RE in a dash for market dominance swiftly bring down GHG emissions to net zero around 2053.

Annual GHG emissions for the cooperative partnership scenario are similar to those in the cases of weak-cooperative and strong-cooperative before 2040 when these three scenarios have a similar share of RE. However, the cooperative partnership case is the only one to keep reducing its GHG emissions and reaches net zero emissions by around 2043, which is about 10 years earlier than all the other cases. This is because sufficient capacity of RE is introduced by new entrants from 2040 to avoid the reactivation of gas power plants around 2050. The remaining nuclear also aids earlier full decarbonisation before the share of RE reaches 100% around 2052. Achieving net zero electricity GHG emissions earlier is critical for the decarbonisation of the transport and buildings sectors and the overall achievement of the UK's net zero goals (CCC, 2020).

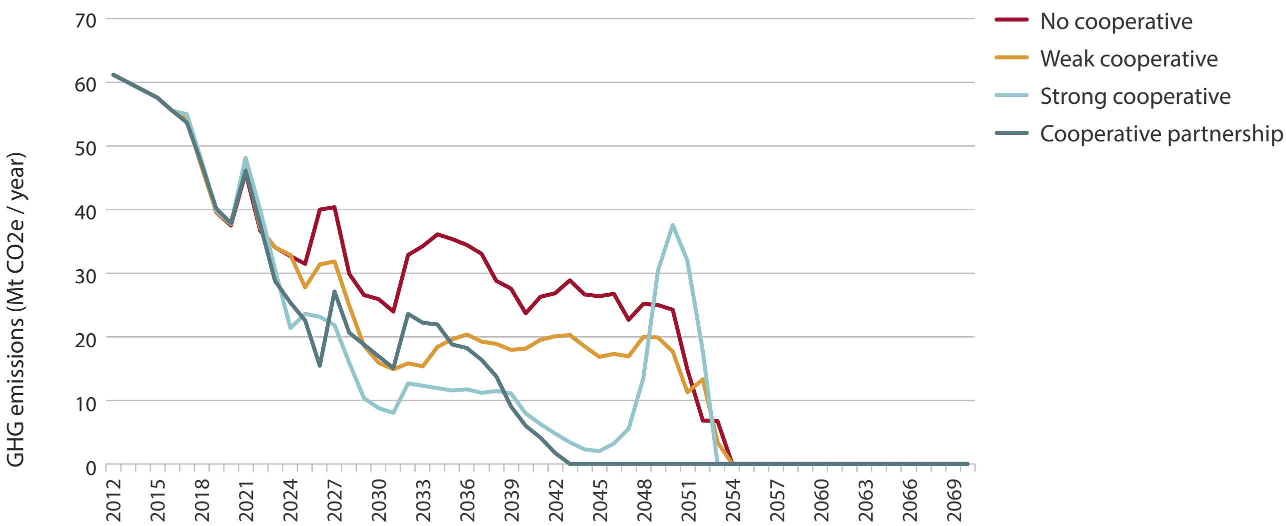

Figure 5: Annual GHG emissions

The benefits of the participation of new cooperatives and the active engagement of local and national governments become much clearer when overall GHG emissions are viewed over the modelling horizon (Figure 6). With only incumbent and existing local investors in the market, the cumulative GHG emissions can be as high as 1412 Mt CO2e over the 2020-2070 period. However, in the cases with cooperatives, the total GHG emissions reduce dramatically by 17%, 30%, and 36% for the weak-cooperative, strong-cooperative, and cooperative-partnership cases respectively.

This demonstrates that it is essential to introduce new cooperatives that focus on scaling-up SLES and RE and provide them with flexible financial strategies that allow them to grow, supported by strong interventions from active governments. In this way the power system can be decarbonised effectively and reach net zero emissions even before 2050, as deemed crucial for the net zero transition of the energy system (CCC, 2020).

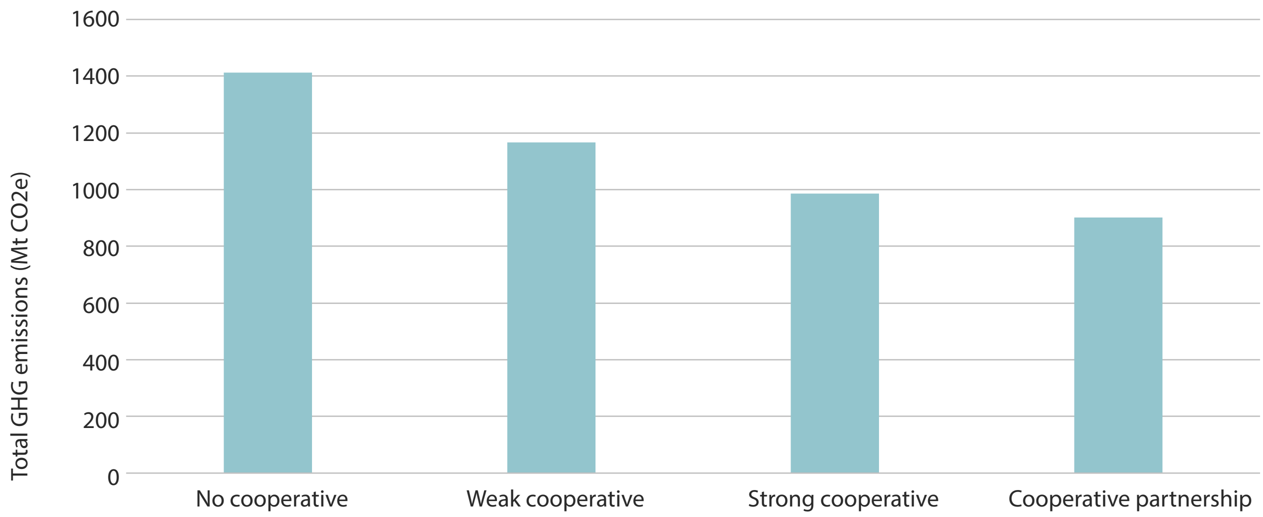

Figure 6: Cumulative GHG emissions

Growing dominance of cooperatives in the market

Market share (Figure 7, for years 2030, 2050 and 2070) is a key performance indicator for investors. With a large market share based on electricity provision, investors can attract more revenues in order to quickly accumulate capital for investments for expansion.

Figure 7: Market share of market players based on electricity provision

In the no-cooperative scenario, incumbent utilities can still dominate the market with a high share of electricity provision, which increases from 50% before 2050 to about 60% by 2070. New national entrants' investment preferences for RE, combined with increasing carbon prices that help recoup capital, enables them to grow their market share over time as well. Hence, new entrants can take up almost 40% of the power market by 2070. More interestingly, as the power sector is gradually decarbonised, the market share of existing local investors diminishes over time, almost disappearing by 2070. The significant 30% market share of local investors in 2030 is due to strong early investments in SLES, incentivised by high electricity prices while fossil-fuel power plants still contribute to electricity provision. However, local investors gradually stop investing in SLES as electricity prices drop to a low level that makes it difficult for them to recover capital costs.

The market shares in weak-cooperative and strong-cooperative scenarios are similar to one another. The presence of cooperatives diminishes the role of incumbent utilities in the market since cooperatives have more flexible investment strategies to recoup capital and receive subsidies from the government. Their investment focus on both local and national RE also helps them thrive as lower electricity production costs result in more net profits. Their market shares grow persistently from around 20% in 2030 to more than 80% by 2070 in the weak-cooperative case and to 92% in the strong-cooperative case.

The major difference between the cooperative-partnership case and the other scenarios is the role of new entrants. New entrants enter the electricity market from 2040 when other investors, including cooperatives, are struggling with financial pressures from their previous heavy investments. The timely participation of new entrants – who copy cooperative business models – not only stabilises the power system with new power plants but also gives the new entrants the opportunity to grow when competition from other investors is weak. With their new RE plants, they own 26% of the market by 2050 and grow this to 31% by 2070. It should be noted that these new entrants are still actively investing in new RE plants after 2050 to raise their market share as electricity demands are still increasing.

Overall, cooperatives are highly competitive in the electricity market, so much so that the role of incumbent utilities diminishes dramatically. In extreme cases, incumbent utilities can even eventually disappear. However, looking across all the scenarios a combination of incumbent utilities, existing local investors, new cooperatives, and new national entrants all play a key role in the transition of a stable and net zero power system.

Overall costs of the electricity transition

The cost of any decarbonisation transition of the electricity system is critical. Two cost metrics are presented. The first key cost metric is investment costs (Figure 8), which require a large amount of financing and debt. The second key cost metric is electricity prices (Figure 9), both as the income stream to recover upfront costs, and for consumers, as this impacts household bills, especially for low income or vulnerable consumers.

Cumulative (2020-2070) investments costs (Figure 8) are substantial, ranging from £391 billion to £534 billion. For the three scenarios with cooperatives, these market players account for the majority of investments (up to 82% in the strong-cooperative scenario). Their active investments are driven by cheap capital, along with investments from households. In turn, they can pay back debts more quickly than other investors to resume investments in new power plants for further expansion. The strong-cooperative scenario has the highest overall investment requirement due to cooperatives' heavy investments to fill the supply gap around 2050. This illustrates the transformation of cooperatives from local players to national players that leverage both household and wider investment streams.

The cooperative-partnership scenario, on the other hand, spend about 3% less on investments over the whole period than the strong-cooperative scenario. Since the supply shortage is avoided due to the timely investments made by new entrants, there is no need for cooperatives' urgent investments around 2050. In this case, new entrants successfully expand their market shares and hence contribute considerably to the overall investments, around 23%, by 2070.

In the no-cooperative case total investment costs are the lowest among the four scenarios. Incumbent utilities are the major investors in the market, contributing to around 48% of total investment costs. Due to low electricity prices from 2050 onwards (Figure 9), all investors have difficulties regaining their financial health to deploy new power plants to meet electricity demands and all investors end up with underinvestment in the market.

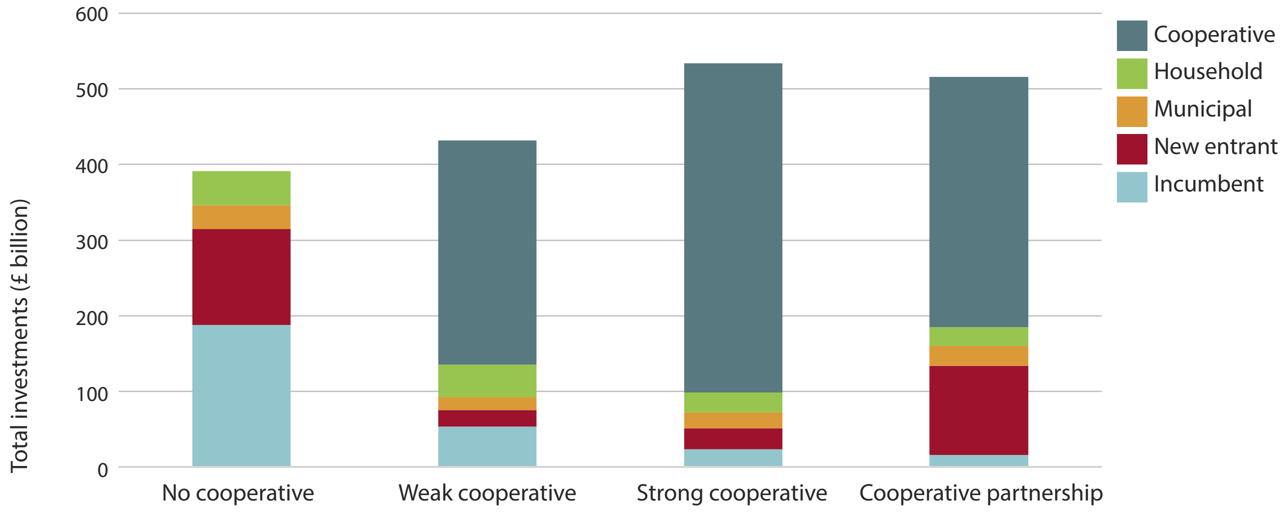

Figure 8: Cumulative investments by investor type

Modelling the decisions of market agents with limited foresight, limited capital and differing strategies does not give a smooth progression of electricity prices. Instead they fluctuate quite dramatically (Figure 9). This is exacerbated by the carbon price imposed on fossil-fuel electricity, which increases whenever emission intensities from the overall electricity portfolio exceed the predefined carbon budget (CCC, 2015). Hence, average electricity prices are especially volatile before 2043 in the cases of no-cooperative and weak-cooperative as the carbon budgets are exceeded from time to time due to the lower share of RE. It is noteworthy that electricity prices are determined by merit order, considering only the marginal costs of electricity production. It is possible to observe electricity prices being lower than the levelised costs of electricity of existing power plants; there is empirical evidence in the UK and US of very low and even negative electricity prices [24].

The strong-cooperative case, on the other hand, has relatively stable electricity prices as most of the time the power sector can provide electricity within constrained carbon budgets. However, as discussed before, underinvestment before 2050 leads to a higher share of gas power to fill the supply shortage around 2050, so electricity prices shoot up briefly in that period.

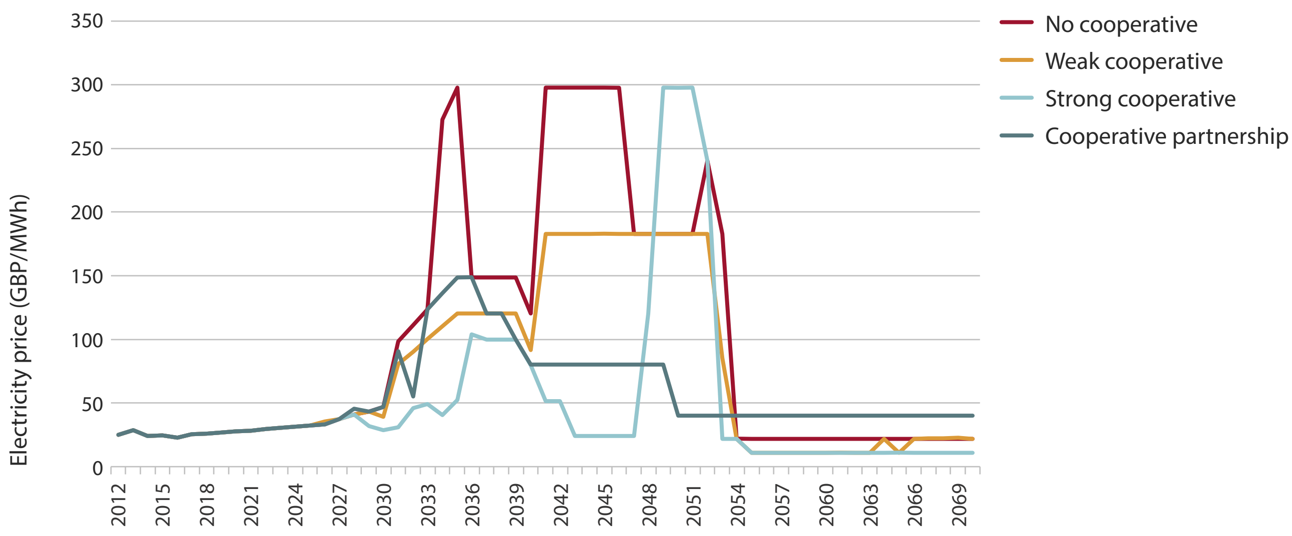

Figure 9: Average electricity price over modelling horizon

Fluctuation of electricity prices is much less pronounced in the cooperative-partnership scenario. It peaks around 2036 when carbon budgets are briefly surpassed. But heavy investments in RE by cooperatives and new entrants quickly bring the emission coefficients of electricity generation down, resulting in the drop in electricity prices. The other key difference in the cooperative-partnership scenario is that the government introduces an electricity price floor from 2040. This is to ensure the value of system security provided by RE can be better reflected so that investors can gain sufficient revenues for future investments. In this case, even though consumers cannot always enjoy the absolute lowest electricity prices, they can still benefit from a less volatile price and a low electricity price floor and have a stable electricity system that does not require any demand curtailment.

Key insights

Some of these results may be challenging for observers used to reading modelling forecasts that assume perfect investment decision making or guaranteed achievement of ambitious energy policy goals. This analysis deliberately focuses on imperfect, constrained and only partially successful decision making by both investors and policy/regulatory decision makers. This imperfect behaviour can be an emergent property of the model, for example when the regulator belatedly reacts with strong market incentives but then investors are unable/unwilling to respond.

Key insights from the modelling are:

1. The electricity decarbonisation transition will not be smooth.

The combination of a range of market investors with limited foresight, finite capital, and imperfect strategies, together with policy and regulator actors with only crude levers to influence investment will not give a smooth and orderly transition. Investment will happen in peaks and troughs, prices will be volatile and some market players will win while others will lose or vanish completely.

2. Investment cycles of investors have significant impacts on system security.

Investors' myopic foresights and heterogeneity drive them to invest heavily to build their market shares whenever they deem an investment opportunity is profitable. As debts grow, investors become overextended and slow down their investment activities to regain their financial strength for future investments. This uneven investment pattern can cause de-rated capacity margin to fluctuate dramatically and without government action, can even drop so low that some demand curtailment is required.

3. Novel business models are required to unlock the potential of local RE to scale-up SLES.

With the help of conventional local investors, the share of RE can only reach around 70% by scaling-up SLES. Local investment capacity is constrained by their strategies and the lack of expertise at managing large-scale projects. RE cooperatives can help further scale-up local RE projects, aggregating household capital and accessing low cost lending from both local and national government.

4. Cooperatives must go national to be sufficient to decarbonise the power sector.

Cooperatives evolve and grow, and in addition to supporting SLES, can invest in large-scale RE plants. Operating at a national scale allows cooperatives to access subsidies and other policy mechanisms such as capacity market and CfD, to significantly accelerate the share of RE power in the electricity system. This not only allows cooperatives to enjoy the benefits of economies of scale but also to strengthen their financial health.

5. Government's active interventions remain essential to accelerate the decarbonisation of the power sector for net zero targets.

The government must provide strong incentives such as carbon pricing, CfD and electricity price floors, to encourage new investors to deploy a large enough number of low-carbon plants and to reflect the value of system security. Without such a policy foundation, prior overinvestments leading to investors' heavy financial burdens, made worse by low electricity prices, would not create an electricity market lucrative enough for investors to fill the supply gap.

6. A spectrum of investors play key roles in transforming the power sector.

Even though cooperatives can effectively boost the investments in RE, they alone are not sufficient to ensure system security while meeting strict carbon budgets. Local investors' dedication to SLES can kick off the strong growth of RE at the early stage. Cooperatives can then further scale-up SLES and other capital-intensive RE plants to the national level with support from the government. But as cooperatives deal with future capital constraints, new entrants are crucial to exploit the cooperative business model and fill any supply shortages. Hence, with diverse market players, the electricity market is more robust and stable in the transformation towards net zero targets.

References

Bale, C.S.E., Varga, L. and Foxon, T.J. 2015. Energy and complexity: New ways forward. *Applied Energy*, 138: 150–9. doi: 10.1016/j.apenergy.2014.10.057

Barazza, E., Li, P-H. and Kothari, S. 2020. BRAIN-Energy: Bounded Rationality Agents Investments model 2020. London: UCL Energy Institute.

Barazza, E. and Strachan, N. 2020. The co-evolution of climate policy and investments in electricity markets: Simulating agent dynamics in UK, German and Italian electricity sectors. *Energy Research & Social Science*, 65: 101458. doi: 10.1016/j.erss.2020.101458

Barazza, E. and Strachan, N. 2020. The impact of heterogeneous market players with bounded-rationality on the electricity sector low-carbon transition. *Energy Policy*, 138: 111274. doi: 10.1016/j.enpol.2020.111274

BEIS, 2021. 2020 UK greenhouse gas emissions, provisional figures. London: Crown Copyright.

BEIS, 2019. UK becomes first major economy to pass net zero emissions law. London: Crown Copyright.

Bergek, A., Mignon, I. and Sundberg, G. 2013. Who invests in renewable electricity production? Empirical evidence and suggestions for further research. *Energy Policy*, 56: 568–81. doi: 10.1016/j.enpol.2013.01.038

Braunholtz-Speight, T., Mander, S., Hannon, M., Hardy, J., McLachlan, C., Manderson, E. and Sharmina, M. 2018. Evolution of community energy in the UK. London: UK Energy Research Centre.

Braunholtz-Speight ,T., Sharmina, M., Manderson, E., McLachlan, C., Hannon, M., Hardy, J. et al. 2020. Business models and financial characteristics of community energy in the UK. *Nature Energy*, 5: 169–77. doi: 10.1038/s41560-019-0546-4

CCC, 2015. The Fifth Carbon Budget. London: Climate Change Committee.

CCC, 2020. The sixth carbon budget: The UK's path to net zero. London: Climate Change Committee.

Ford, R., Maidment, C., Fell, M., Vigurs, C. and Morris, M. 2019. A framework for understanding and conceptualising smart local energy systems. EnergyREV, Strathclyde, UK. University of Strathclyde Publishing, UK. ISBN: 978-1-909522-57-2

Hall, S., Foxon, T.J. and Bolton, R. 2016. Financing the civic energy sector: How financial institutions affect ownership models in Germany and the United Kingdom. *Energy Research and Social Science*, 12: n5–15. doi: 10.1016/j.erss.2015.11.004

Hansen, P., Liu, X. and Morrison, G.M. 2019. Agent-based modelling and socio-technical energy transitions: A systematic literature review. *Energy Research and Social Science*, 49: 41–52. doi: 10.1016/j.erss.2018.10.021

IPCC, 2018. Global warming of 1.5ºC. Switzerland: Intergovernmental Panel on Climate Change.

IRENA, 2019. Business Models: Innovation landscape brief. Abu Dhabi: International Renewable Energy Agency.

Iychettira, K.K., Hakvoort, R.A., Linares, P. and de Jeu, R. 2017. Towards a comprehensive policy for electricity from renewable energy: Designing for social welfare. *Applied Energy*, 187: 228–42. doi: 10.1016/j.apenergy.2016.11.035

Li, P-H., Barazza, E. and Strachan, N. 2020. Early insights into the non optimal investment outcomes in the scale-up of smart local energy systems. EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN 978-1-909522-67-1

McInerney, C. and Bunn, D.W. 2019. Expansion of the investor base for the energy transition. *Energy Policy*, 129: 1240–4. doi: 10.1016/j.enpol.2019.03.035

Pye, S., Li, F.G.N., Price, J. and Fais, B. 2017. Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era. *Nature Energy*, 2: 17024. doi: 10.1038/nenergy.2017.24

UNFCCC, 2015. The Paris Agreement 2015. Bonn: United Nations Framework Convention on Climate Change.

Winkler, J., Gaio, A., Pfluger, B. and Ragwitz, M. 2016. Impact of renewables on electricity markets – do support schemes matter? *Energy Policy*, 93: 157–67. doi: 10.1016/j.enpol.2016.02.049

Wüstenhagen, R. and Menichetti, E. 2012. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. *Energy Policy*, 40:1–10. doi: 10.1016/j.enpol.2011.06.050

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About EnergyREV

EnergyREV was established in 2018 (December) under the UK's Industrial Strategy Challenge Fund Prospering from the Energy Revolution programme. It brings together a team of over 50 people across 22 UK universities to help drive forward research and innovation in Smart Local Energy Systems.

ISBN 978-1-909522-97-8

EnergyREV is funded by UK Research and Innovation, grant number EP/S031898/1