EnergyREV

BRIEFING NOTE

Early insights into the non optimal investment outcomes in the scale-up of smart local energy systems

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About this report

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.

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Summary

The scale-up of smart local energy systems (SLES) that combine renewable energy (RE) and smart technologies for system flexibility has been seen as a potential way to accelerate the energy transition to deep decarbonisation (Ford et al, 2019). In particular, a wider range of energy investors in local energy systems could boost the adoption of RE to decarbonise the power sector (Braunholtz-Speight et al, 2020; McInerney & Bunn, 2019). Also, consumers within the setting of SLES are more likely to engage with demand-side response (DSR) such as smart appliances and smart heating controls (Carmichael et al, 2018). To date however, there has been little investigation into how the strategies of market players will affect the role of SLES in deep decarbonisation pathways.

This Briefing Note aims to assess the role of SLES in the energy system transition. Unlike past work it does not assume a perfect world or optimal decision making. Instead it focuses on how non-optimal decision making by both investors and policy agents can influence the uptake of SLES and the UK electricity sector's long-term decarbonisation. Different types of national and local investors with different characteristics and investment strategies (e.g. myopic decision-making) are explicitly represented in the modelling framework. The interaction between the major market schemes – such as capacity market and Contracts-for-Difference (CfD) – and market players is investigated in order to explore both how SLES can be scaled-up and the potential impacts of SLES on the whole power system.

Key findings show that the strategies and decisions of investors and policy makers have significant and varied impacts on both the scale-up of SLES and overall national efforts to decarbonise the electricity sector. SLES are important for the uptake of RE, and allow a faster scale-up of the RE share. While carbon prices are important for system stability under market players' investment decisions for decarbonisation, DSR might give mixed messages to prompt alternate strategies in a non-optimal electricity market. Although SLES significantly reduce the market role of incumbents, incumbent investors are still needed to ensure enough investments to maintain system stability.

Modelling approach

The BRAIN-Energy Agent Based Model

An agent-based model of electricity generation and investments, **BRAIN-Energy (Bounded Rationality Agents INvestment model)** was used to investigate how non-optimal decision making may influence the scale-up of SLES and the impact of SLES on the UK electricity system. The advantage of BRAIN-Energy lies in its ability to represent agents with bounded-rationality and heterogeneous strategies in investment decisions, and multi-agent interactions. Using such an approach allows it to reflect realistic behaviours of market participants, such as heterogeneity 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 & Menichetti , 2012.

Two types of market players are considered in BRAIN-Energy: investor and policy agents. Investor agents can be national (incumbent utilities and new-entrants) and local (municipal utilities and households), and participate in the electricity market based on their own heterogeneous strategies, financial endowments and risk-return considerations. Policy agents comprise the national government, the national regulator and local government. For a more detailed description of the model, please refer to the Appendix.

Scenarios and results

The BRAIN-Energy model was extended to incorporate new investor agents for SLES and four scenarios were created that would explore the conditions in which SLES play a significant role in the future electricity system.

System scenarios and cases for SLES uptake

Four scenarios are investigated to understand the influences of local investors, carbon prices, and system flexibility on the transition of the UK electricity system. They are defined in Table 1.

National-only is the reference scenario. It shows how the power system transits to a low-carbon system with a traditional setting where only national agents can take part in the electricity market.

The next two SLES scenarios show the impact of local investors, with or without DSR.

Finally the SLES-NoCarbon scenario contrasts the role of local investors in a market without the presence of carbon pricing as an incentive to decarbonise.

Carbon budgets imposed in all four scenarios are defined in terms of carbon intensity of the power system, which has to drop to 50 gCO_2/kWh by 2030, followed by full decarbonisation by 2050 (CCC, 2015), noting that in an agent-based model the strategies of the agents may mean that these targets can be missed.

Table 1: Definition of scenarios

Scenario	Investor	Carbon price	Demand-side response
National-only	National investors only	With carbon price; two times higher if carbon budget not met	No
SLES-NoDSR	Both national and local investors	With carbon price; two times higher if carbon budget not met	No
SLES-DSR	Both national and local investors	With carbon price; two times higher if carbon budget not met	Yes
SLES-NoCarbon	Both national and local investors	No carbon price	Yes

Main results

The results from BRAIN-Energy show that the strategies and decisions of investors and policy makers make a critical difference to both the scale-up of SLES and then overall national efforts to decarbonise the electricity sector. The story of agent interactions is complicated. The model reveals:

1. The different ways to ensure the electricity system is stable;
2. How SLES can significantly boost investments in RE;
3. How SLES can enact faster emission reductions (in the 2030s) but not quite as low by 2050;
4. Which market players make the key investments, which market players win or lose and how incumbent national investors see their market share and profitability erode under SLES and even further with SLES plus DSR.

System stability

Ensuring supply always meet demand heavily relies on future investment activities in the market. The de-rated capacity margin, which shows how much effective extra capacity of a power system there is compared to its peak load, can give insights into how investment activities impact the overall stability of the electricity system through time. This is illustrated in Figure 1. High levels of de-rated capacity margin show the initial impact of new, low carbon, investment, while the drops of de-rated capacity margin are largely caused by decommissioning the existing power plants from the base year (2012).

As capacity margins fall because old plants retire, the regulator agent foresees possible further closures of power plants a few years ahead and holds a capacity market auction in order to stimulate construction of power plants. In the years following the base year, the incumbent investors tend to invest in gas power plants because they have a short construction period and this maintains the de-rated capacity margin at a sufficient level of 5%. However, as carbon prices increase over time in the three scenarios with carbon pricing, different dynamics play out to ensure there is sufficient capacity of power plants for generation at all times.

In the National-only reference case a few incumbent investors profitably dominate the market and are able to invest in power plants that have high capital costs, such as nuclear and biomass power plants. Due to the longer construction period of these plants, the de-rated capacity margin is lower than those for SLES-NoDSR and SLES-DSR. On the other hand, when local investors can participate in the market (e.g. SLES-NoDSR) the de-rated capacity margin rebounds faster because they invest in new RE plants, including biomass, wind, and solar plants, with a shorter construction period.

The influence of DSR, including demand-shifting and shedding, is seen by comparing SLES-NoDSR and SLES-DSR. When there is no DSR, electricity demands cannot be shifted to reduce peak loads. Policy agents thus hold capacity market auctions earlier and more frequently. As a result, new power plants are deployed earlier so that the de-rated capacity margin for SLES-NoDSR is mostly higher than that for SLES-DSR.

In the scenario with no carbon price (SLES-NoCarbon), the de-rated capacity margin is very unstable and insufficient to fulfil electricity demands after 2030. This scenario has the lowest electricity prices and investors struggle to recoup their investment capital. Although the CfD regulatory mechanism and local investors are boosting renewables, this doesn't happen fast enough, with supply-demand gaps opening up despite the best efforts of the capacity market, plus the use of DSR.

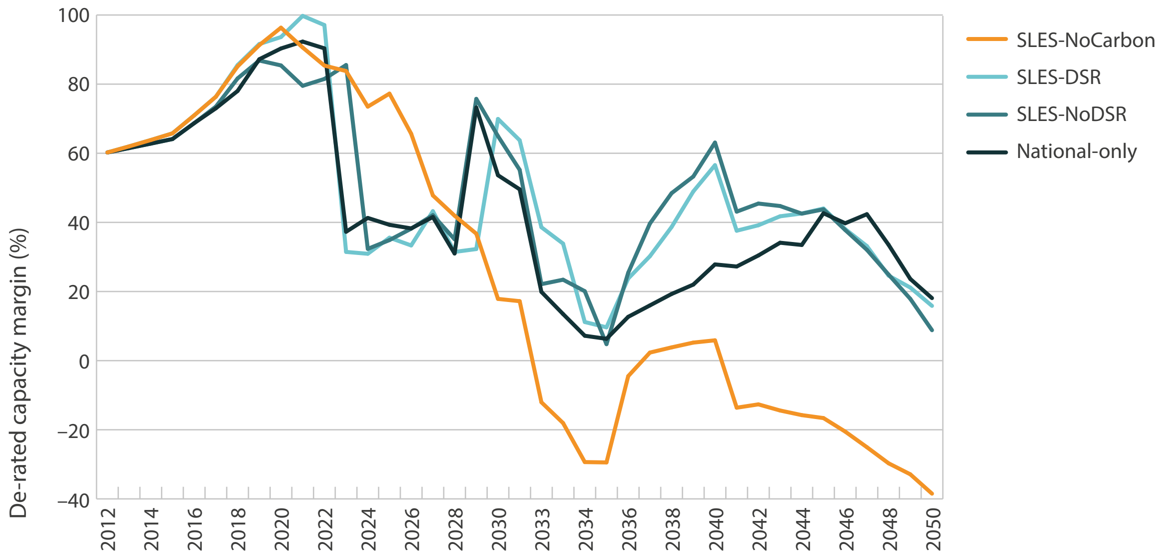

Figure 1: De-rated capacity margin over the modelling horizon for four scenarios

SLES can boost investment in RE

As shown in Figure 2, the existence of local investors changes which zero carbon technologies are invested in. The SLES scenarios dramatically increase the share of RE in the system, compared to the scenario with only national investors (National-only) where these incumbent investors with a high level of equity invest more in nuclear power plants to bring in more revenues, leaving less capital for investment in RE plants.

In contrast, in all scenarios with local investors, revenues from selling electricity to sub-national regions enable local investors to further invest in more RE plants, such as PV and even biomass power plants. Locally driven RE deployment can occur without carbon pricing but is further boosted, resulting in a higher RE share in a larger overall system, with carbon pricing.

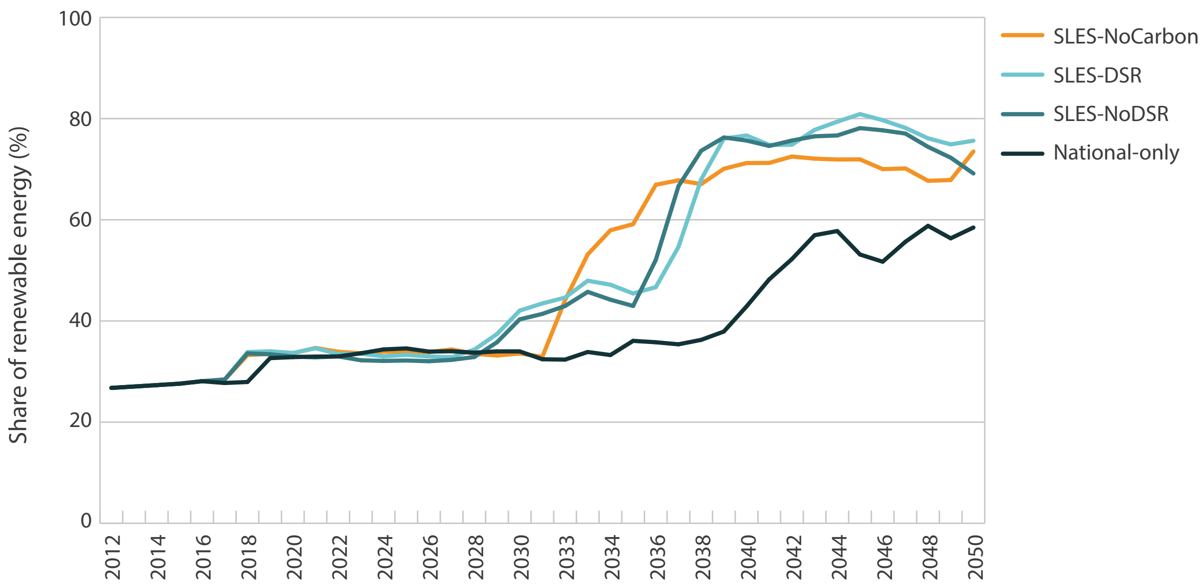

Figure 2: Share of renewable energy generation over the modelling horizon for four scenarios

The role of SLES in emissions reductions

The investments of investor agents in various technology mixes (Figure 2) have significant impacts on the greenhouse gas (GHG) emissions from the power system (Figure 3). The National-only reference case has the highest GHG emissions between 2031 and 2040, but then the lowest emissions in the last decade among the four scenarios. This is because it has the lowest share of RE in the medium term, with more gas power plants retained for generation. By the 2040s more nuclear power plants are gradually deployed into the power system to dramatically reduce GHG emissions. In fact, National-only is the only scenario that fully decarbonises the power sector by 2050, based on the stylised settings of the model.

The opposite timing occurs for local investors (SLES-NoDSR and SLES-DSR). They show much lower GHG emissions in the 2030s of 40% and 30% less respectively due to the higher investments in RE. In the 2040s, however, the uptake rate of RE doesn't match the sharp increase in electricity demand, so existing gas power plants are used to provide additional electricity. The sharp increase in electricity demand is due to the dramatic electrification of the end-use sectors for decarbonisation. Overall, the introduction of SLES has considerably reduced cumulative GHG emissions in 2040–2050 by 36% and 17% in SLES-NoDSR and SLES-DSR respectively.

Perhaps surprisingly, the SLES-DSR case has higher GHG emissions than the case without DSR – 19% and 64% higher in the 2030s and 2040s respectively. The lower emissions in SLES-NoDSR are due to the earlier adoption of more nuclear plants, as policy agents are more likely to foresee a shortage of capacity earlier with no DSR to manage peak demand. In SLES-DSR, fewer low-carbon power plants, such as nuclear and biomass plants, are introduced into the system because peak loads can be reduced with DSR and gas plants used as an additional option to fill the supply shortage. As a result, higher GHG emissions are seen in both the early and late periods in the SLES-DSR case than in the SLES-NoDSR case.

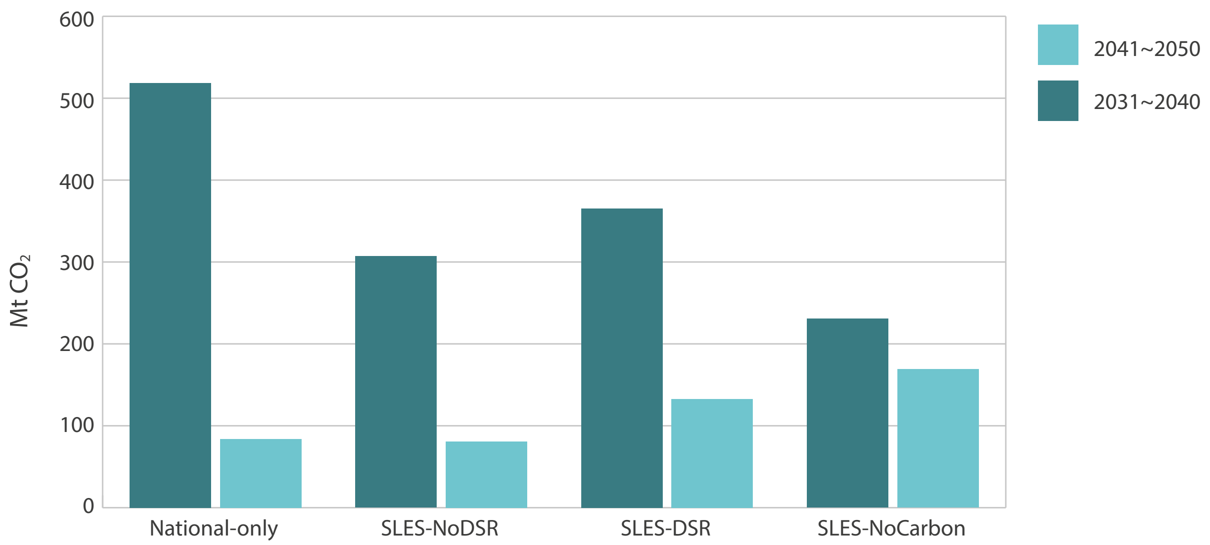

Figure 3: Cumulative GHG emissions in last two decades for four scenarios

The future of incumbent investors

The investment trends in generation technologies across the four scenarios are shown in Figure 4. In the National-only reference case, incumbent utilities provide 79% of total investments over the whole period, while 21% is provided by new entrants. Incumbent investors actively participate in the capacity market to invest in high-capital expenditure plants such as nuclear and biomass that can yield more revenue from electricity provision than other plants, as well as ensuring sufficient capacity in the power system.

In contrast, with new local investors present, the investments in RE increase significantly, rising from 21% in SLES-NoDSR to 46% in SLES-DSR. The higher RE investments are driven by preferences of local investors for RE in sub-national regions. Additionally, DSR further encourages investments in VRE, such as onshore wind and PV plants. As the demand profile can be transformed by demand-shifting to match with the supply profile of VRE, local investors can realise higher revenues and therefore invest in even more VRE. As a result, the role of incumbents is lower in SLES-NoDSR where they create only 50% of total investment compared to 79% in National-only. Investment by incumbents falls further still in SLES-DSR to only 39%, with one incumbent agent leaving the market entirely and local agents delivering 33% of total investments, the highest level across all scenarios.

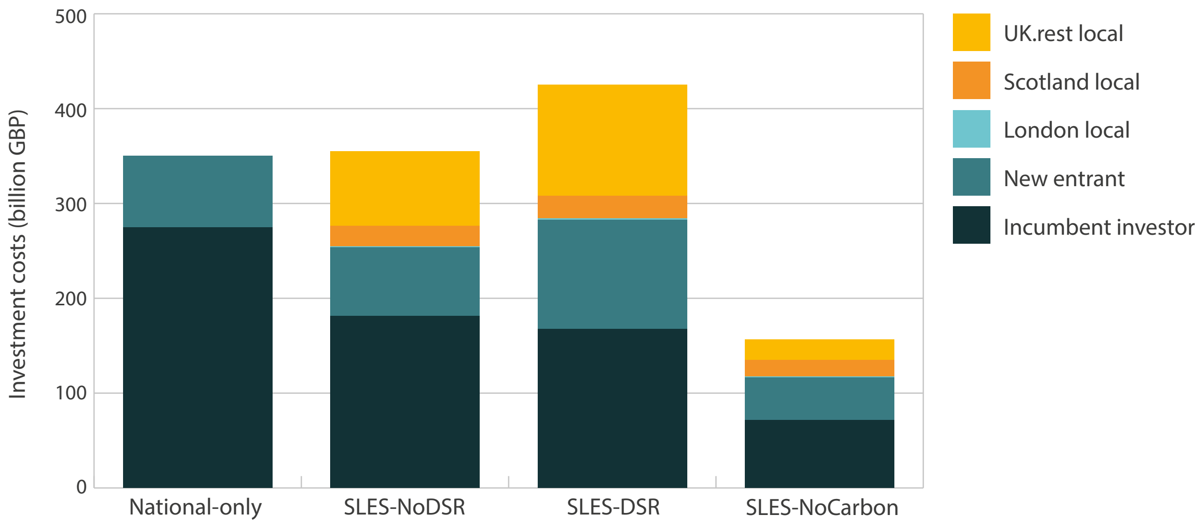

Figure 4: Cumulative investments by investor type for four scenarios

Figure 5 gives a view of investors' financial performance. Without the competition from local investors in National-only, incumbent investors dominate the market with their fleet of gas, nuclear, and biomass plants.

The scenarios with participation of local investors in the market show two major impacts:

1. the dominance of incumbent investors diminishes dramatically;
2. overall capital is much higher than the National-only reference case.

As the deployment of SLES grows over time, local investors' plants gradually become the major electricity sources, leaving a limited supply gap for incumbent investors to fill. National investors' capital thus shrinks significantly. The dominance of local investors can even force incumbent investors to leave the market as those investors' plants are not able to compete with local investors' RE plants to make sufficient profits. Moreover, local investors can benefit from RE plants' lower operation and maintenance costs to accumulate much more capital than national investors.

The capital of local investors in London remains at a similar level in both years across the three cases with local investors. This implies local investors in London exploit almost the full potential of PV in London before 2035 due to the highly competitive prices of PV plants in all three cases. On the other hand, local investors in Scotland and the rest of UK have higher capital in 2045 since additional RE plants can only be deployed in these two regions.

Although the scale-up of SLES allows local investors to thrive in the long run, local investors do need seed capital to participate in the electricity market at the beginning. Initial support, such as subsidies, loans, and grants from local or national governments, is thus crucial to deploy SLES at scale (Braunholtz-Speight et al, 2020).

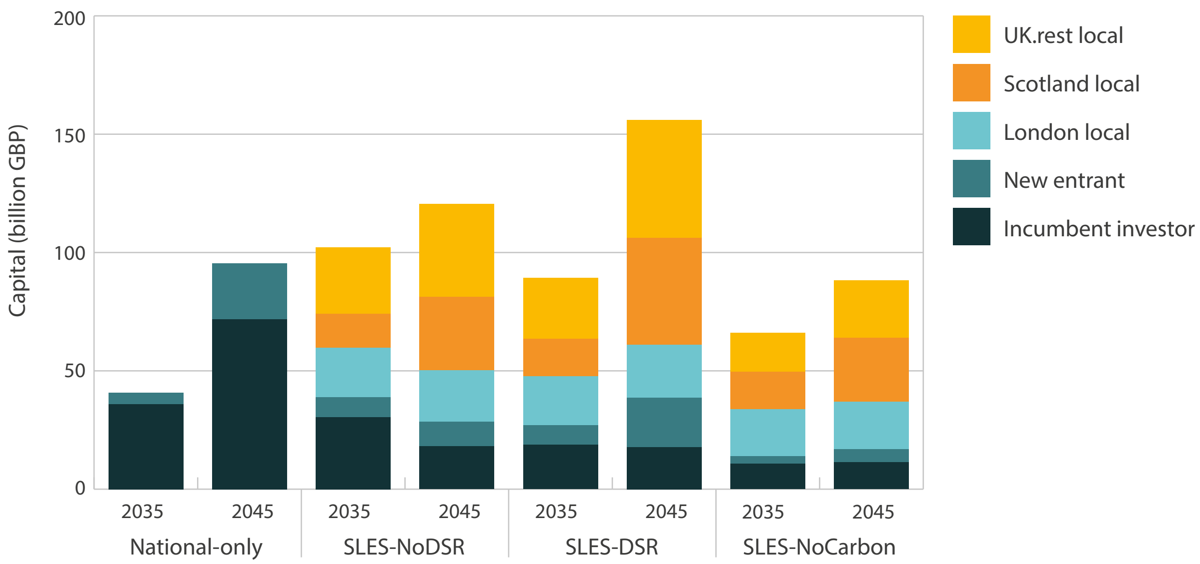

Figure 5: Capital by investor type in 2035 and 2045 for four scenarios

Key insights

The BRAIN-Energy model was extended to incorporate new investor agents for SLES and four scenarios were created that would explore the conditions in which SLES play a significant role in the future electricity system. The results generated by the model lead to the following insights into the decision-making of market players relevant to the scale-up of SLES.

1. SLES are important for the uptake of RE. The enabling of SLES by local government allows local investors such as municipal utilities and household aggregators to actively participate in, and then lead, the electricity market. The share of RE in the power system can hence be scaled-up faster and further. Renewable-based SLES systems can provide a secure supply of electricity; overall investment requirements to decarbonise the power system are higher with local agents and DSR, but the transition's resulting variable costs are lower.
2. Carbon prices are important for system stability under market players' investment decisions for decarbonisation. The imposition of carbon prices on the power system by national government ensures that supply and demand are balanced when it is combined with local government support of SLES and capacity markets run by the regulator. The agent-led dynamics (incumbents vs. new entrants, with/without DSR) are different in each scenario. But without carbon pricing, the investment security in a decarbonising system is not enough to attract non-optimising investors.
3. DSR might give mixed messages and so prompt alternate strategies in a non-optimal electricity market. Despite the indisputable benefits of DSR in balancing electricity supply and demand, it can result in policy agents (who also act imperfectly) postponing the incentives needed to persuade heterogeneous investor agents to build new low-carbon plants. Consequently, the uptake of low-carbon generation technologies could be delayed so that more dramatic investments in new plants approaching 2050 are needed.
4. The introduction of SLES significantly reduces, but does not eliminate, the market role of incumbents. Incumbent investors are still needed, and need to be incentivised, to invest in capital-intensive, dispatchable plants to ensure system stability. This is because, even though SLES gain market share and develop profitable new local producers such as municipal utilities and household aggregators, the generation from RE may not always be enough to fulfil demands in sub-national regions, and certainly cannot always meet nationwide demand.

Future work

This Briefing Note has presented early insights on the role of SLES in the energy system transition for deep-decarbonisation, with a focus on the influences of non-optimal decision making by both investors and by policy agents. In the future, BRAIN-Energy will be further applied to explore SLES in light of:

- The interactions and consistency of the various incentive schemes such as carbon prices, contracts for differences and capacity market;
- Alternate, including radical, market strategies by local and national investors;
- Strengthened learning from both successes and mistakes by investors and policy agents; and
- The impact of systemic exogenous shocks in the decarbonisation transition.

Appendix: The modelling approach explained

BRAIN-Energy Agent Based Model

BRAIN-Energy's strength and novelty lies in its sophisticated representation of agent behaviour. The model aims to study how agents with bounded-rationality, heterogeneous strategies in investment decisions and multi-agent interactions, impact the electricity sector's transition to low- or even zero-carbon in 2050. BRAIN-Energy seeks to address a limitation of traditional equilibrium and optimisation energy models which, despite their high technological, spatial and temporal detail, combine market players and then assume that these act rationally, homogeneously and in a utility-maximising way with perfect market information throughout the modelling horizon. As a result, realistic behaviours of market participants, such as heterogeneity and bounded-rationality (i.e. making "good enough" decisions), are not reflected in those models (Iychettira et al, 2017; Bergek et al, 2013; Wüstenhagen & Menichetti , 2012.

Two types of market players are considered in the model: investor and policy agents.

Investor agents can be national. These would include incumbent utilities and new-entrants. They can also be local, such as municipal utilities and households. Investor agents participate in the electricity market based on their own heterogeneous strategies, financial endowments and risk-return considerations. For example, some investor agents such as new entrants, only intend to invest in RE plants to maximise their profits. On the other hand, other investors such as incumbent utilities, can invest in all kinds of power plants – including nuclear, gas, and RE plants – to provide stable dividends to shareholders.

Policy agents comprise the national government, the national regulator and local government. The national government agent uses CfD to motivate the decarbonisation of the power system by encouraging new investments in RE plants. The national government agent can also raise carbon prices to further steer the decarbonisation of the power system. The national government sets emission reduction targets in terms of carbon intensity of electricity generation that then spur higher carbon pricing if these targets are not met.

The national regulator agent uses a capacity market to promote security of supply by encouraging investments in gas and nuclear power plants.

Local governance agents can implicitly subsidise technologies through guaranteeing they receive electricity prices set at the national level, as well as providing initial capital loans to allow new local entrants to enter the market.

For more details of the model, please refer to Barazza and Strachan (Barazza & Strachan, 2020).

Extension of BRAIN-Energy for SLES

BRAIN-Energy has been extensively extended to better represent the characteristics of SLES. Since the major strengths of the model lie in modelling the strategic behaviour of heterogeneous investor and policy agents, the spatial and temporal characteristics are relatively stylised, compared to more detailed electricity models, to lower computational loadings. The extension of the model is briefly addressed in the following sections.

Sub-national regions for niche development.

The UK is divided into three regions, both because the potential of RE varies across different regions, and because regions have their own governance structures:

- London - with a dense population, high solar photovoltaic (PV) potential and mayoral powers;
- Scotland - with high potentials for onshore and offshore wind power and an executive government)
- The rest of UK to allow further diffusion of renewable technologies

The division is to represent local electricity markets in a stylised way, not to emphasise the importance of these regions in the energy transition.

Improved temporal resolution

The model has a focus on wind and solar PV renewable energy. As both of these sources are intermittent (i.e., they cannot be guaranteed at any individual point in time) they are classified as variable renewable energy (VRE). To better represent this intermittency of VRE, the temporal resolution has been significantly refined from two time-slices of day and night to eight time-slices consisting of 4 time-slices in a typical day in two seasons. The definition of the refined time-slices is listed in the following table, which is based on the temporal representation of the UK TIMES model (Daly & Fais, 2014). On the demand-side, loads at the evening peak time-slice are scaled up by a factor to reflect possible fluctuations of electricity demand on extreme days.

Table 2: Definition of time-slices in BRAIN-Energy

Season	Intra-day period	Time represented	Notes
Winter (W) Summer (S)	Night (N)	00:00–07:00	Lowest demand
	Day (D)	07:00–17:00	Includes morning peak
	Evening peak (P)	17:00–20:00	Peak demand
	Late evening (E)	20:00–00:00	Intermediate

Local investor agents for SLES

In each region, two local investor agents - municipal utilities and household aggregators - make investment decisions on new plants based on their financial status and interests. Their development plans on new local VRE plants are prioritised over proposals by national investors, such as incumbent utilities, as local investors are more likely to have advantages of land ownership or community engagement. Local investors are guaranteed to receive the national electricity price for selling electricity to the grid to incentivise their participation.

Incorporation of demand side flexibility

System flexibility has been improved through DSR from households in SLES. In this formulation, smart appliances are assumed to be controlled collaboratively at the local level to balance the local electricity demand and electricity generation from local VRE plants. The potential of shiftable demand at each time-slice is estimated based on the participation rate of local households in the DSR scheme and the physical shiftable potential of individual smart appliances.

The participation rate is assumed to increase from 0% in the base year 2012 to 100% by 2050. Only appliances that can be controlled via direct local control schemes are considered. The future electricity consumption and its profile are estimated by UK TIMES model for a scenario where the net-zero target is achieved by 2050. The residential sector is dramatically electrified approaching 2050 to reduce GHG emissions. In turn, the DSR potential increases considerably over the modelling horizon due to the penetration of controllable appliances into UK households. For more details of the settings of the DSR modelling, please refer to Li and Pye (Li & Pye, 2018).

More details of the BRAIN-Energy model extensions can be found in Barazza et al, 2020.

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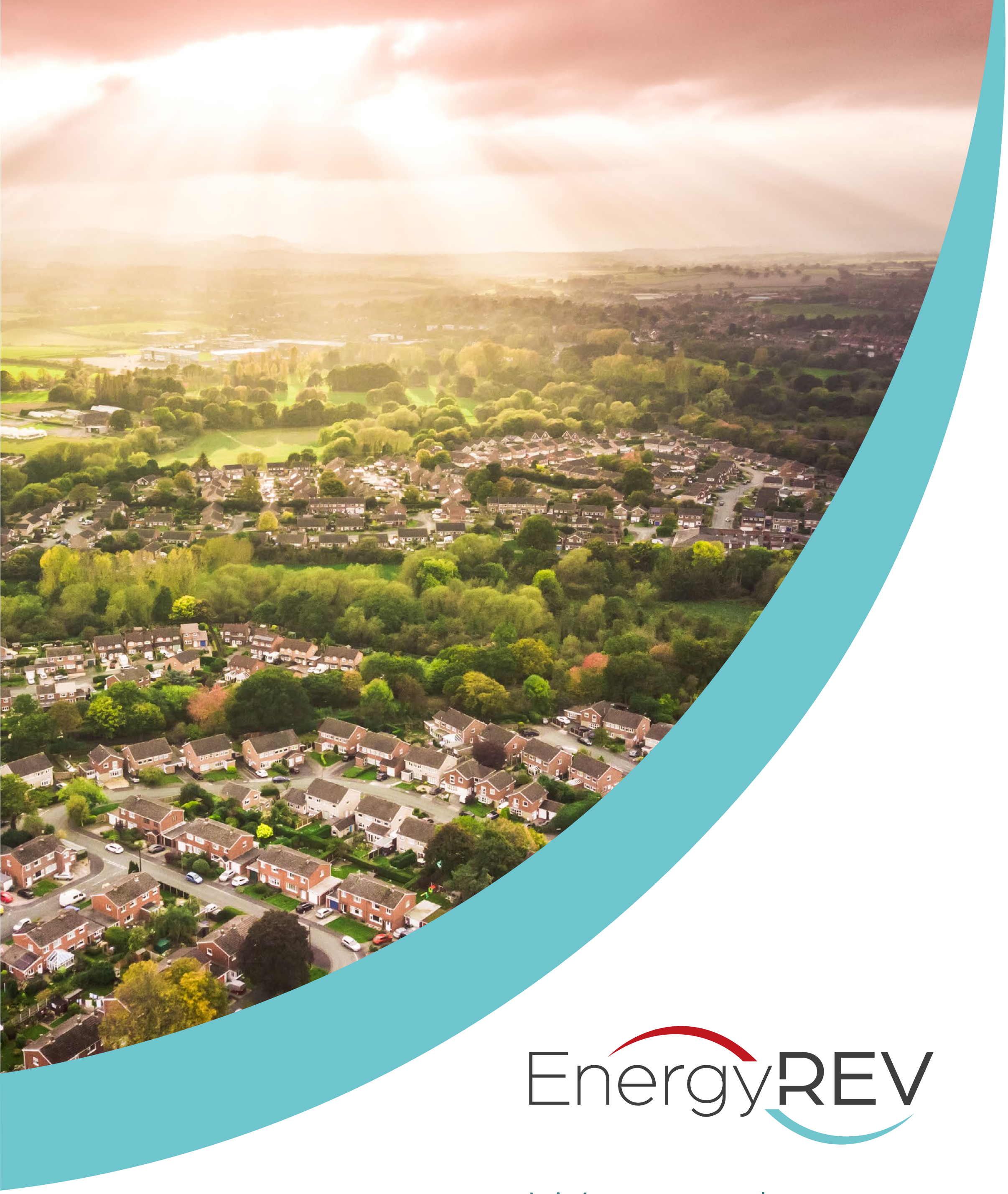

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About EnergyREV

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.

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