Options for a smart, resilient and low–carbon multi–vector energy system in the Scottish Borders

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Context

Smart local energy system (SLES) can provide value from local renewable generation and demand-side flexibility to help achieve the UK net-zero target. This report provides a high-level feasibility evaluation for three categories of options for decarbonisation. It focuses on the Scottish Borders, a region with significant renewable energy potential and an urgent need for decarbonised heating and transportation to achieve the UK and Scottish Government's net-zero target, and improve the welfare of residents. The decarbonisation of heating is particularly important in the Scottish Borders, as there are many off-gas-network households in the rural areas that heat their home with carbon-intensive fuels, like heating oil, coal, and Liquefied Petroleum Gas (LPG). In addition, these carbon-intensive fuels are more expensive than natural gas, causing a comparably large proportion of households to fall into fuel poverty.

These three options include:

1. Electrification of heating and transportation with SLES options, including Local Flexibility Markets (LFM), to alleviate the need for network upgrades and improve renewable hosting capacity
2. Seasonal Thermal Energy Storage (STES) options to use curtailed wind for district heating
3. Hydrogen options for vehicle refuelling and natural gas replacement.

This project aims to provide an initial assessment of three categories of decarbonisation options (SLES, STES, and hydrogen) in alignment with the following targets:

- The net-zero goal: how could the options contribute to net-zero?
- Economic benefits: how could these options bring economic benefits for residents, the energy system and the council? We see two types of benefits:
    - For residents. This includes fuel poverty or fuel costs that are related to residents' interests.
    - For the energy system and council. This could be the network upgrade costs or other necessary financial investments that are related to the energy system and the council.
- Renewable hosting capacity: how could these options help increase the renewable hosting capacity?

- The feasibility/credibility of these options.

Within the EnergyRev research consortium, our team focuses on unlocking the benefits of SLES by studying new market designs and proposing innovative business models that can be scaled out across the UK and internationally.

Structure of the report

The report assesses the viability of the SLES, STES, and hydrogen options in accordance with the project's objectives. Figure 1 presents an overview of the evaluated options and their corresponding analyses. The "Electrification (of heating and transportation) with SLES" is subdivided into "Smart Electric Heating" and "Smart EV Charging" due to the extensive coverage of the topic. Each option is then broken down into sub-options and analysed based on their characteristics and alignment with project targets. The analysis encompasses data from both the overall Scottish Borders Council (SBC) and selected local sites. The subsequent sections outline the key findings and recommendations derived from the analysis.

Electrification and smart local energy systems

Key findings

SPEN Distribution Future Energy Scenarios provides forecasts of the possible number of heat pumps (HPs) and electric vehicles (EVs) that will be connected to local primary substations under several future scenarios (e.g., high uptake scenario, low uptake scenario) to achieve the net-zero target. We conducted the study for the different HP and EV roll-out scenarios and we find that the electrification of heating and transportation can be beneficial in reducing carbon emissions and the fuel poverty rate. Under current electricity carbon intensity, the complete electrification of heating by HPs and transportation by EVs can reduce more than 70% of carbon emissions of residential heating and transportation respectively in the Scottish Borders. The reduction can increase to more than 90% when there are more renewable installations. Replacing non-gas heating with HPs can decrease the fuel poverty rate in Newcastleton from 49.87% to 35.32%, and reduce the fuel poverty rate in the Scottish Borders from 29.3% to 21.8%.

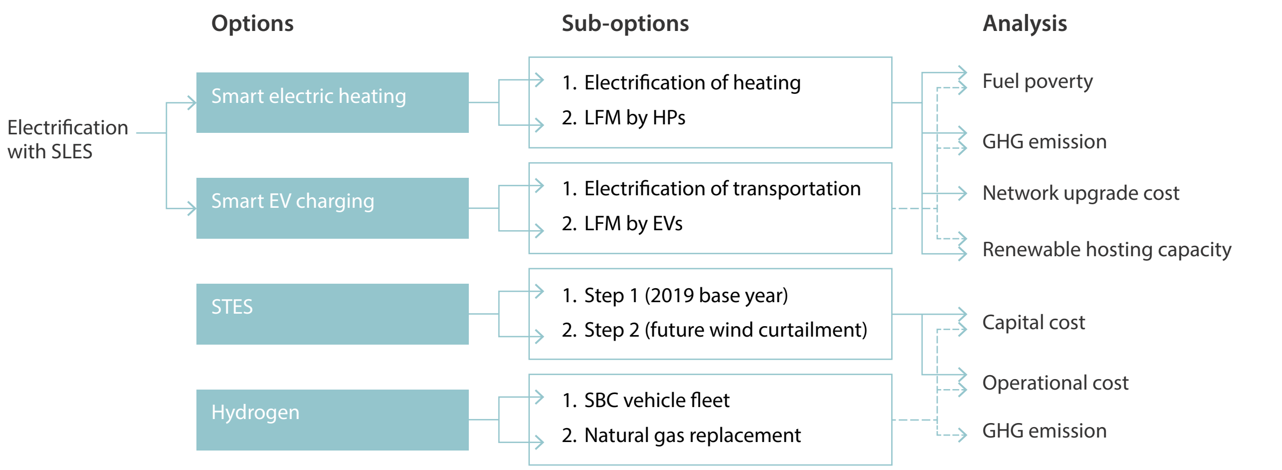

Figure 1: Report structure. GHG: Green House Gas.

However, these HPs and EVs could trigger expensive network upgrade costs. For Newcastleton primary substation only, the network upgrade costs for hosting the heating demand could be up to £24.29K. For the overall Scottish Borders, the upgrade costs for the primary substations could be up to £30.26M for the electrified heating demand and £10.24M for the electrified transportation demand in 2030.

However, this can be avoided with a LFM designed to smartly shift the demand of electrified heating and transportation. It would mean there was no need for network upgrades in the Newcastleton primary substation in 2030. For the overall Scottish Borders, a LFM can also reduce the network upgrades for hosting electrified heating by £4.14M out of the original £30.26M in 2030. The upgrade cost reduction can be up to 95% for the EV case.

An LFM can also lead to improved renewable hosting capacity, saving the upgrade costs for installing more renewables. The LFM based on HPs can improve the hosting capacity of the local primary substations for wind generation by 3.6% and 4.8% for the two 2030 scenarios in the Scottish Borders. It can also improve the hosting capacity for solar generation by 4.8% and 7.6% for the two 2030 scenarios. Coordinating the EVs by the LFM leads to higher benefits. It can improve the hosting capacity of the primary substations for wind generation by 13.1% and 22.6% (corresponding to 37.03MW and 72.46MW) for the two 2030 scenarios in the Scottish Borders. As for solar generation, the improvement could be 11.1% and 22.1% (corresponding to 36.34 and 84.1 MW) for the two 2030 scenarios.

Recommendations

Based on our feasibility analysis for these options, several recommendations are made.

- Roll out HPs, especially in areas with a high non-gas rate. The fuel poverty rate and carbon emissions could be significantly reduced by heating electrification.
- Natural gas heating needs to be replaced to reach net-zero. Replacing the existing gas with other clean energy like hydrogen could be more economic than HPs.
- Organise an LFM for HPs for areas with a high non-gas rate and weak network infrastructure as it will reduce the network upgrade costs.
- Organise an LFM for EVs because it can lead to significant reduction in upgrade cost and increase in renewable hosting capacity.

Seasonal thermal energy storage

Key findings

STES using curtailed wind and varying wholesale electricity prices is analysed based on a modelled residential district heating scheme at Galashiels.

For electricity prices and wind curtailment events in 2019, the replacement of direct electric heaters with HPs and short-term thermal energy storage reduces total system costs (combined capital costs and operating costs) by 49%, while adding STES further reduces total system costs by 1%. Therefore, there is little value in STES using curtailment and electricity prices in 2019.

In the near future (2030) and beyond (2040, 2050) wind curtailment events will be more common, and STES provides far higher value, with this analysis showing negative total system costs. However, these will be mitigated to a degree by higher non-curtailment event prices which are not included in this analysis. More detailed modelling is required to include more realistic total system costs for future years. Finally, network limitations will have impacts on the ability of these systems to respond to curtailment events.

Recommendations

STES should be considered in more detail, alongside HPs and direct electric heating, to take advantage of wind curtailment events which will increase in the future. This is contingent on access to a market mechanism to enable a discount for responding to wind curtailment events, e.g., the balancing mechanism.

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Hydrogen

Key findings

We examined the opportunity to replace SBC's current diesel powered vehicles with hydrogen fuel cell equivalents, and also briefly considered options for replacing natural gas in the public supply network.

The current diesel vehicle fleet is responsible for around 5,000 tonnes per year of carbon dioxide emissions. These would be eliminated if all diesel vehicles were replaced with hydrogen (or indeed other zero emissions technology).

To achieve this, a renewable ('green') hydrogen fuelling facility, or Hydrogen Hub, supplying around 1,500 kg hydrogen per day would be enough to supply fuel demand. This would require an average power supply of around 3MW and a water supply of around 14 m3/day. The capital investment, excluding the power supply and land, would be in the region of £2.9M.

The most cost-effective source of power supply would be a wholly-owned, or directly connected and contracted, wind turbine/s. Assuming that this is the case, the cost of the hydrogen produced should be in the region of £3.24 / kg, which would lead to, for example, running costs of a family sized car of around 2.6p/km. This compares very favourably with diesel at around 10.1p/km (at 55mpg and £1.95/litre), or grid electricity supplied through a public charger at around 8p/km. This also assumes that hydrogen produced by the council for its own use would not be subject to tax.

An optimum location for the Hydrogen Hub has yet to be determined. However, a council-owned site at Lauder has been put forward as a possibility. It is centrally located and well served with roads, gas network connection and is not far from existing wind farms. This is, however, some 20 km from the council offices at Newton St Boswells, which might lead to a cumulative significant additional travel cost and fuel requirement. This needs to be considered in more detail.

For the council's recent fuel consumption level of diesel at 1.9 million litres/year, the cost at current diesel prices of £1.95 per litre would be around £3.7 million per year (although SBC may be able to purchase bulk fuel more cheaply). Using hydrogen produced in the way described, the discounted annual equivalent cost of the 395,000 kg hydrogen required would be around £719,000 – a substantial saving of around £3,000,000 per year which would very quickly offset the initial capital costs.

Given this differential, it may also be possible to create an income stream for the council, while also encouraging the take up of hydrogen vehicles, by selling excess hydrogen to the public. However, this may create a tax situation which would need to be investigated.

Depending on the operational strategy of the council vehicles – whether or not they all return to the same base at the end of each day – it may be necessary to have one or two outlying refuelling points. These could either produce their own hydrogen in-situ, or could be supplied by tanker or pipeline from the hydrogen hub.

Vehicle cost appears at the moment to be around 54% more than a comparable diesel fuelled vehicle; however, this is a very approximate figure due to the lack of publicly available information. We would also anticipate this excess cost decreasing as the technology matures and becomes more widespread.

Hydrogen could also be used for natural gas replacement since boilers can currently use 20% hydrogen. Approximately 1170 GWh/yr, or 80,000 tonnes/year, of natural gas is used in the SBC region. To produce enough hydrogen to displace 20% by volume of natural gas used in the area (6% by energy and emissions) would require a further 5,300 kg hydrogen production, at a capital cost of approximately £7.9M, an average power demand of 10 MW and a water supply of 48 m^3/day. This would have an annualised production cost of around 4.8p/kWh, and would displace about 13,000 tonnes of carbon dioxide per year. Further investigation in co-operation with SGN is recommended.

Recommendations

- Detailed planning of a Hydrogen Hub with a capacity of 1,520 kg/day should be progressed. This should be enough to supply the SBC vehicle fleet, with pre-planned options to expand it to serve non-council demand as it develops. As the council fleet replacement is likely to take several years, there would be scope for such demand to develop within the initial capacity.

  * For context, this would be equivalent to a single medium-small sized fuelling station in Scotland supplying petrol and diesel.

- The Hydrogen Hub location should be identified as part of that detailed planning; an existing council depot at Lauder could be a viable solution with some advantages in terms of its location.
- Power the Hydrogen Hub using a dedicated and directly connected renewable electricity source. This will reduce costs substantially compared to grid sourced electricity, and will eliminate emissions associated with legacy hydrocarbon fuelled power stations still connected to the national grid. Curtailed generation might also make a useful contribution.
- Replace the existing council diesel powered vehicle fleet with hydrogen fuel cell-powered vehicles, on the currently proposed timescale for fleet replacement.
- For natural gas replacement, discussions should be held with SGN with a view to either (1) creating additional hydrogen to supply into the network at up to 5,280 kg/day average, or (2) accepting surplus hydrogen from the vehicle fuelling facilities. This last option might be valuable in the early stages, especially before demand has fully developed.

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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