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The impact of Energy System Decarbonisation and Decentralisation on Scotland's Electrical System

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1. Summary

Energy systems within Scotland have traditionally relied on large, centralised sources providing energy to homes and businesses throughout the country. However, there has recently been both desire for, and progression towards, a greater emphasis on local energy[1]. Ambition to reduce the nation's reliance on large-scale centralised resources has also coincided with recent energy policy targeting a significant reduction in carbon emissions with the aim to cut greenhouse gas emissions to net zero by 2045.

The purpose of the research of this CXC Fellowship was to gain a more detailed understanding of the implications of Scotland moving towards a future decentralised, decarbonised energy system. The research placed particular focus on understanding the impact future changes may have on electrical distribution networks.

Determining energy demands and supplies at a sub-national level is important to appreciate the types of local investments that will be required, and how policy in this area can influence a transition to a secure decentralised energy system. Accordingly, one of the main outputs of this fellowship was the Energy Flow Scotland (EFS) toolset, that uses underlying models of heat, transport and electrical demand to quantify high resolution energy flows at a sub-national level. An interactive web version of the EFS toolset can be accessed at www.caledonia-energy.net.

We have used the EFS toolset to analyse different credible future scenarios for Scotland's energy system. These scenarios are published annually by National Grid, the electricity system operator across the GB system. The release of National Grids Future Energy Scenarios (FES)[2] is designed to stimulate debate and inform decisions that help achieve carbon reductions.

Four different FES scenarios[3], released in 2018, were analysed using the EFS toolset:

- **Community Renewables (CR) scenario** – projects a decentralised approach with large growth of renewables and a large reduction in the carbon intensity of electricity.
- **Two Degrees (TD) scenario** – this pathway meets the 2050 carbon reduction target[4] through adopting a centralised approach.

[1] http://www.gov.scot/Topics/Business-Industry/Energy/CEPS2015
[2] https://www.nationalgrideso.com/insights/future-energy-scenarios-fes
[3] http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

[4] Note - FES frames each of these scenarios in terms of their potential to meet the 2050 carbon reduction target. Since the release of FES in July 2018, there has been significant publicity surrounding the UKs commitment to reaching *net-zero* carbon emissions by 2050. The recent publication of FES 2019 notes that "the 80% decarbonisation target can be

- **Steady Progression (SP) scenario** – outlines centralised future approach that makes progress towards, but does not meet the 2050, carbon reduction target.
- **Consumer Evolution (CE) scenario** – projects a decentralised energy scenario that makes progress towards, but fails to meet, the 2050 target of reducing carbon emissions by 80%.

The analysis focussed on predicting how, as a result of implementing the scenarios, peak annual electrical flows would change at different locations across Scotland's system between 2018 and 2040. In particular, we looked at the extent to which electrical substations across distribution networks would have to be upgraded to cope with future levels of demand and generation on the network, and with varying levels of transport and heat electrification.

1.1 Main findings:

- A future energy pathway of high decarbonisation and high decentralisation, similar to the CR scenario, will result in large scale upgrades being required across Scotland's electrical distribution networks. Analysis using the EFS toolset forecast that 55% of distribution substations and grid supply points (GSP)[5] would have to be upgraded between 2018 and 2040. This would equate to a minimum of 4111 MWs of additional electrical system capacity being required at the distribution level[6].
- The TD pathway (which offers HIGH Decarbonisation and LOW Decentralisation) would result in less substations having to be upgraded in comparison to the CE scenario (which offers LOW Decarbonisation and HIGH Decentralisation). However, in contrast, TD would require greater additional capacity to be made available within the electrical system compared to CE. This contradiction is likely due to a higher concentration of renewable energy at certain substations in the TD scenario forcing energy exports from these areas to grow significantly beyond existing asset limits. To offset such large increases in exported energy at particular substations, future consideration should be given to improving the balance between the integration of low carbon demand, generation and storage technologies in areas with high natural resource.
- Compared to urban areas, a higher proportion of substations in rural areas are forecast to need upgrading between 2018 and mid-2030s under all FES scenarios. However, between the mid-2030s and 2040 in the CR and CE pathways the percentage of urban substations needing reinforcement[7] increases beyond that in rural areas. This is likely due to high growth forecasts of low carbon demand technology in urban areas during that period. Under a TD pathway, the requirements for rural upgrades are steadily ahead of requirements for

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reached through multiple technological pathways but net-zero requires greater action across all solutions…at a greater scale than in any of our core scenarios." What greater actions are required, and how they would change new technological roll-out across Scotland (and the UK as a whole), are not described. It is likely that future versions of FES will account for the policy direction of achieving *net-zero* carbon emissions.

[5] A GSP (Grid Supply Point) is an electrical substation that connects the electrical transmission system with the electrical distribution network. A distribution substation (or primary substation) is connected to a GSP and located further down in the system within the distribution networks - these provide power to a smaller number of consumers than GSPs

[6] This analysis included 128 of 145 GSPs across Scotland and 251 distribution substations across SSENs network area. Due to data limitations, substations across SPENs network area were not considered here.

[7] Note that the term *reinforced* substation and *upgraded* substation may be used interchangeably.

urban upgrades. This is likely a result of the significant connection of renewable generation, combined with a reduced integration of HPs and EVs.

1.2 Conclusions for policy makers and system operators

- A highly decarbonised and decentralised energy system will require significant investment in the electrical distribution system to make it fit for purpose.
- Local areas that introduce a balance of new low carbon demand technologies (such as EVs and Heat Pumps) with low carbon renewable generation will reduce the impact on electrical substations and thus requirements to upgrade. Areas that connect significant volumes of new renewable generation, without an associated rise in EVs/HPs, will see large rises in exported energy.
- A rise in low carbon demand technologies will impact electrical distribution substations, with a high number requiring reinforcement by 2040. However, a more centralised pathway that revolves around the integration of renewable generation concentrated in areas of natural resource will incur greater overall additional electrical system capacity requirement, despite perhaps less electrical substations requiring upgrade.
- The electrical distribution system across rural areas will be impacted more than urban areas between 2018 and mid-2030s. However, a steady rise in low carbon demand technologies will result in a sharp impact on urban areas between mid-2030s and 2040.
- Meeting future carbon reduction targets may be achieved using either a centralised or decentralised approach. However, this analysis forecasts that it will cost roughly 2.6 times more to upgrade the electrical distribution system using a decentralised approach in comparison to a centralised strategy.

2 Analysis

2.1 Using the Energy Flow Scotland Toolset

The EFS toolset models across heat, transport and electricity energy vectors simultaneously within Scotland and provides the capability to:

- assess and plan how local solutions can be adopted to meet local needs to ensure local economic growth;
- understand the impact that the introduction of various heat, electricity, transport and energy storage technologies will have on local energy flows;
- identify the necessity for, and benefit of, specific technologies on an area-by-area basis;
- determine the effect that innovative local solutions will have on national systems, including the identification of necessary reinforcements or alleviation of existing constraints; and
- evaluate the benefits of local heat and energy efficiency strategies across individual local areas.

This report summarises analysis of National Grid FES scenarios using the previously developed EFS toolset. The primary aim was to determine peak annual flows on electrical substations throughout Scotland, including how these would change with increased decarbonisation and decentralisation and the general transition to electrified transport and heat solutions. Forecasted evolution of peak demands at local areas informs system operators on when, and where, system infrastructure would potentially require upgrading. As an example, Figure 1 shows the forecasted evolution of peak demands as a percentage of substation capacity at the Fort William GSP, and relevant distribution substations within the Fort William area, under the CR scenario. Network operators would begin to look at upgrading substations as peak annual demands near 100% of substation capacity.

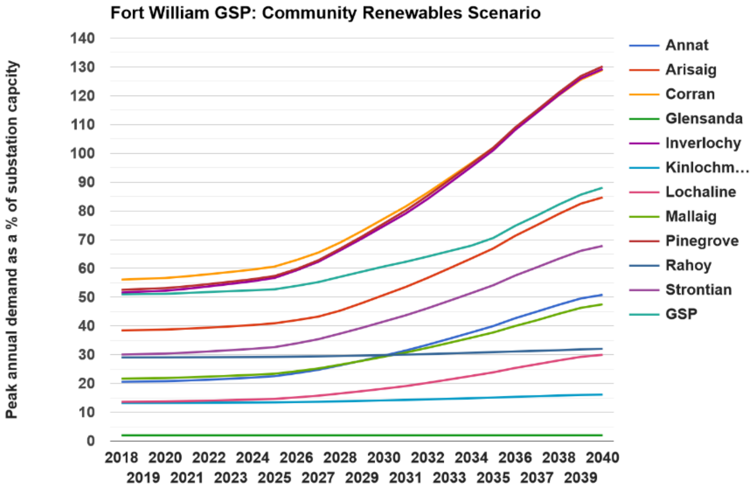

Figure 1: Use of the EFS toolset to forecast the evolution of peak annual demands at Fort William area under the CR scenario

To supplement analysis of peak annual demand the EFS toolset can be used to determine how energy demands and resources evolve at much finer (typically hourly) time resolution. This can be important for understanding how many hours throughout the year a substation flow exceeds its capacity, for example. This form of analysis is presented in an earlier report[8].

[8] https://www.climatexchange.org.uk/research/projects/the-impact-of-energy-system-decarbonisation-and-decentralisation-on-scotland-s-electrical-system/

2.2 Analysis of National Grid Future Energy Scenarios

The national Grid's FES scenarios are used for planning for developments in both the gas and electricity systems. They are widely used across the energy industry and beyond to drive debate and decision-making. In this research FES were analysed to understand the local impact different future energy pathways may have on Scotland's electrical system.

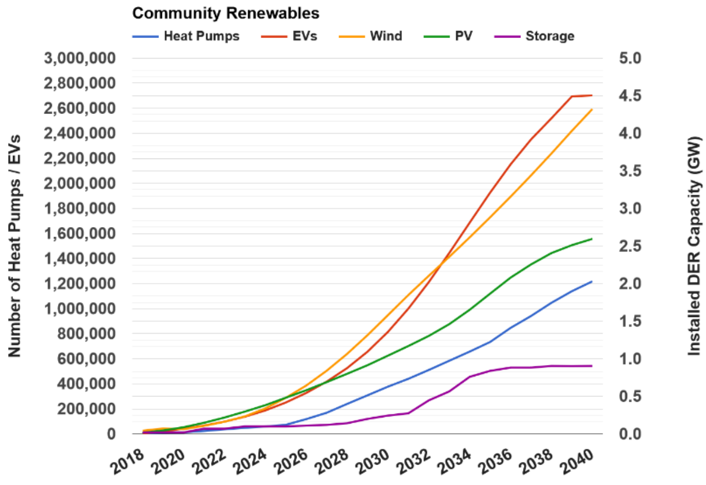

Figure 2: Low carbon technology growth between 2018 and 2040 across Scotland under the CR scenario.

FES are released by National Grid on an annual basis and describe a range of credible pathways for the UK energy system as a whole. This report describes the use of the EFS toolset to analyse scenarios that were released in 2018[9]. The FES scenario framework releases four different credible future pathways, each describing a varying level of decarbonisation and decentralisation. Figure 2 outlines an example of new low carbon technological growth across Scotland between 2018 and 2040 under the CR pathway. Table 1 summarises the level of low carbon technology integration across Scotland by 2040 under each of the four FES scenarios. It shows the percentage of GSPs and distribution substations that are forecast to require upgrading, and the associated **minimum** additional distribution electrical system capacity that will allow these levels of technology to securely connect to the electrical system.

Table 1: FES technological integration across Scotland and impact on electrical distribution system.

Scenario	No. of new EVs by 2040	No. of new HPs by 2040	New Total Installed Wind Capacity by 2040 (GW)	New Total Installed PV Capacity by (GW)	New Total Installed BES Capacity by 2040 (GW)	Substations requiring upgrade between 2018 and 2040 (%)	Minimum additional electrical distribution system capacity (MW)
CR	2,702,779	1,217,961	4.32	2.59	0.90	55	4111
TD	1,499,614	396,031	3.27	1.67	0.57	25	1562
SP	1,522,732	119,688	0.34	1.26	0.19	10	63
CE	2,645,568	560,829	0.96	1.48	0.54	36	855

High levels of decentralisation and decarbonisation result in significant upgrades and additional capacity requirements by 2040 under the CR scenario.

Analysis of the TD and CE scenarios highlight some interesting features. Table 1 identifies that, overall, the CE pathway (which does not meet 2050 decarbonisation targets) would result in 36% substations requiring upgrade while the TD pathway would require 25% upgrades.

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[9] A new version of FES was released in July 2019, but to date, these have not been updated to the level of granularity (i.e. GSP level) that is required for the studies on which this report is based. The EFS toolset has been designed to ensure that, when this data does become available (circa November 2019 to coincide with publication of National Grid's 10-year Statement), it can be easily updated to include analysis of the new scenarios.

However, the predicted additional capacity requirement under these scenarios show the opposite of this, as there would be a higher additional capacity requirement under the TD pathway (an additional 1562 MW by 2040) in comparison to the CE pathway (an additional 855 MW by 2040).

2.3 Reason to Upgrade Substations

The nature of the reinforcement actions under these two scenarios appears to be one reason for this contradiction. As detailed in Table 2, over half of the substations requiring reinforcement under the TD scenario would be due to peak **negative** power flows *i.e. local energy is exported back to the national system at substations where local embedded renewable capacity significantly outnumbers local electrical energy demand*.

Table 2: Number of Substations requiring upgrade that have positive or negative peak flows.

Scenario	Substations requiring upgrade due to a **positive** peak flow (%)	Substations requiring upgrade due to a **negative** peak flow (%)
CR	75	25
TD	48	52
SP	97	3
CE	95	5

In comparison, 95% of substations requiring upgrade under the CE scenario would be as a result of **positive** peak *flows i.e. energy is imported from the national system to meet local demand at substations with high electrical demand and minimal local renewable resources*. Essentially, it seems that the increased embedded generation in the TD scenario is concentrated across specific substations and is not dispersed across several areas throughout the country.

These characteristics highlight issues that may be brought about by introducing significant future increases in embedded renewable capacity in specific areas without relative increases in local demand, storage, or system flexibility to offset and reduce the potentially large volumes of local energy exported to the national system.

There are areas throughout the country that have an abundance of natural resources and are clear candidates for further connection of embedded renewable generation. However, the potential consequences of over integrating renewables at such areas, and the requisite network investments that would be required, should be considered within future planning.

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