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Benefits of flexibility from smart electrified transportation and heating in the future UK electricity system

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HIGHLIGHTS

- The economic and environmental benefits of smart EVs/HPs are quantified.
- This paper implements an advanced stochastic analytical framework.
- Operating patterns and potential flexibility of EVs/HPs are sourced from UK trials.
- A comprehensive set of case studies across UK future scenarios are carried out.

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ABSTRACT

This paper presents an advanced stochastic analytical framework to quantify the benefits of smart electric vehicles (EVs) and heat pumps (HPs) on the carbon emission and the integration cost of renewable energy sources (RES) in the future UK electricity system. The typical operating patterns of EVs/HPs as well as the potential flexibility to perform demand shifting and frequency response are sourced from recent UK trials. A comprehensive range of case studies across several future UK scenarios suggest that smart EVs/HPs could deliver measurable carbon reductions by enabling a more efficient operation of the electricity system, while at the same time making the integration of electrified transport and heating demand significantly less carbon intensive. The second set of case studies establish that smart EVs/HPs have significant potential to support cost-efficient RES integration by reducing: (a) RES balancing cost, (b) cost of required back-up generation capacity, and (c) cost of additional low-carbon capacity required to offset lower fuel efficiency and curtailed RES output while achieving the same emission target. Frequency response provision from EVs/HPs could significantly enhance both the carbon benefit and the RES integration benefit of smart EVs/HPs.

1. Introduction

Rapid expansion of Renewable Energy Sources (RES) is expected to make a key contribution to electricity system decarbonisation. However, high penetration of intermittent RES will increase the requirements for various reserve and frequency response services, leading to reduced carbon benefit and increased balancing cost. Moreover, large amount of additional generation capacity is required to provide “RES firming” for system security reasons, which causes additional costs associated with RES integration.

At the same time, the electrification of transport through electric vehicles (EVs) and heating systems through heat pumps (HPs) is seen as another key policy measure to further reduce the use of fossil fuel in energy supply and hence reduce carbon emissions. However, as demonstrated in the Low Carbon London (LCL) trials [1,2], this electrification may lead to an increase in peak demand that is disproportionately higher than the increase in energy consumption, which could increase the requirements for additional generation and network capacity with low utilisation levels [3]. Furthermore, as the demand associated with EVs/HPs concentrated during the periods of peak demand, it is going to be supplied by high-emission peaking plants, leading to a degradation of the system carbon performance.

On the other hand, there exists significant flexibility in temporal patterns of EVs [4] and HPs [5], providing an opportunity to utilising demand-side response (DSR) solutions facilitated by inherent storage capabilities present in EV batteries and thermal storage associated with buildings heated by HPs. Smart EVs and HPs could not only reduce the required generation/network capacity [3] and the incremental carbon emissions driven by EVs and HPs, but also

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facilitate the integration of RES through energy arbitrage [6,7] and ancillary service provision [4,8]. In this context, this paper focuses on analysing and quantifying the implications of deploying smart EVs and HPs for the carbon emissions and RES integration cost within the UK electricity system. Therefore, the key specific objectives of this paper can be summarised as:

1. Analyse the benefits of smart EVs/HPs trialled in LCL in reducing carbon emissions in a broader UK electricity system.
2. Quantify the economic benefits of carbon savings from smart EVs/HPs in terms of lower requirements to invest in zero-carbon generation capacity in order to achieve the same carbon emission target.
3. Analyse the benefits of smart EVs/HPs in reducing system integration cost of RES, including balancing cost associated with RES intermittency and investment cost associated with back-up capacity to ensure system security.

The impact of smart EVs/HPs is investigated for three future system development scenarios, with particular emphasis on different possible evolution trajectories of RES capacity. The key link between the technology-specific, bottom-up LCL trials and system-level studies presented in this paper is the effective shape of electricity demand seen by large-scale generation for different deployment levels of trialled EVs/HPs, as well as the potential to provide flexibility to the system, in particular load shifting and ancillary services. Unlike in previous published work [9,10] where the operating patterns were inferred from those associated with conventional vehicles and heating systems, the uncontrolled charging and heating patterns assumed in this paper are based on measured populations, while modelling the ability of smart EVs/HPs to shift demand and provide frequency response has been updated based on insights from LCL trials.

Given that the uncertainty and limited inertia capability of RES are expected to be a major driver for escalating system emission and integration cost, the performance of the system is analysed using the Advanced Stochastic Unit Commitment (ASUC) model. One of the key advantages of ASUC when compared with deterministic generation scheduling models used in other studies [11,12], is that it is able to dynamically allocate energy arbitrage and ancillary service provision by EVs and HPs depending on the conditions in the system. Moreover, unlike the simplified assumption on frequency response requirements typically used in other studies [4,9,13], the ASUC model is capable of explicitly quantifying the inertia-dependent frequency response requirements. Therefore, the impact of reduced system inertia driven by large-scale RES deployment on the benefits of frequency response provision from EVs/HPs is explicitly evaluated for the first time. The proposed model has been shown to be particularly suitable to analyse the benefits of flexibility provided by energy storage [14] and DSR [15] in systems with high penetration of RES.

2. Characteristics of EVs/HPs demand and their potential to provide flexibility

In this section we provide an overview of EVs/HPs investigated in LCL trials and specify their key characteristics with respect to the flexibility associated with them.

2.1. Electric vehicles

A detailed description of EV trials conducted in LCL is given in [16]. The trial included 72 residential and 54 commercial vehicles and monitored their charging at both home or office charging points, as well as around 400 public charging stations. The report quantified some of the key parameters of EV demand relevant for network planning and system analysis such as typical demand profiles and diversified peak demand for a given number of EVs.

As an illustration, the fully diversified average and peak day demand profiles for residential EV users are shown in Fig. 1. The average profile represents the charging demand for an average day, while the peak profile has been obtained by extrapolating the diversity characteristic of EV peak demand towards a very large number of vehicles, where the trials have shown that coincidence factor[1] approaches 20% [16]. Given that the typical (non-diversified) charging power for a single residential charging point was around 3.5 kW, this resulted in a diversified peak EV demand of 0.7 kW. This information has been used to calibrate annual hourly demand profiles from [13] and use those profiles as an input into the ASUC model used for this study.

Reference [16] has further assessed the flexibility of EV demand, i.e. how much of EV charging demand may be shifted in time in order to support the electricity system but without compromising the ability of the EV users to make their intended journeys. The analysis of smart charging in [16] suggested that between 70% and 100% of EV demand can be shifted away from peak hours. This analysis included the driving patterns of EV users, so that the estimation of their flexibility ensured that all of the users' journeys can be completed despite temporal shifting of charging demand (i.e. the users' mobility requirements are not compromised as the result of smart charging). Based on this, we estimate that up to 80% of EV demand could be shifted away to other times of day while supporting the same journey patterns. This flexibility parameter is used as input into the ASUC model in order to allow it to make optimal scheduling decisions on when flexible EVs should be charged from the system operation perspective.

The analysis has shown that the charging can typically be delayed by several hours when shifted away from the peak towards the night hours, as illustrated in Fig. 2, which has been taken from [16].

2.2. Heat pumps

LCL trials also involved the monitoring of residential heat pumps, as described in Report B4 [2], however due to a smaller sample size the trial results were only used to calibrate the likely non-diversified peak of residential heat pump load. In order to construct a fully diversified profile of national-level HP demand, we used inputs from previous studies [17–19]. All of these assumed a gradual improvement in building insulation levels, and estimated the hourly profiles based on representative temperature fluctuations for the UK. The diversified peak day demand for an average household with heat pump heating is shown in Fig. 3 for illustration.

We further assumed that flexible HP operation would be possible if they were fitted together with heat storage. Based on the findings of [17,20], we assumed that for the heat storage size in the order of 10% of peak day heating energy demand, the peak HP demand can be reduced by 35% through using the storage and shifting HP demand into other times of day.[2] Although the potential flexibility of HP demand would generally vary among different customers depending on their consumption, heat storage size, insulation levels or temperature settings, in this paper the aggregate heat storage has been considered to be available to support system operation.

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[1] The coincidence factor is defined as the ratio between the maximum instantaneous demand of a group of customers and the sum of their individual maximum demands. It is the inverse of the diversity factor.

[2] In [19] this assumption resulted in a hot water tank of about 140 litres per average household.

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