EV Charging: Separation of Green and Brown Energy using IoT

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Abstract
The energy drivers use to charge their Electric Vehicles (EVs) comes from various sources. Of those, some are renewable *green* energy sources such as solar photovoltaic systems (SolarPV) and home storage battery whilst some are called *brown* sources such as gas turbine, coal and oil. To analyse the behaviour of EV drivers as to how they use household green and brown energy, separating the mix is a necessity. This paper argues that the Internet of Things (IoT) can be helpful in achieving that goal and demonstrates a pilot study showing the process of separating the green and brown energy from the EV charging.

Author Keywords
Electric Vehicle; Solar Electricity; EV Charging; Internet of Things; EV Battery; Home Battery.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

Introduction
Electric Vehicles (EVs) are progressively becoming popular and helping households reducing carbon emissions [1]. However, when owners charge their EVs, the energy comes from various sources. Of those some are renewable *green* energy sources such as Solar photovoltaic systems (SolarPV) and home storage battery whilst some are called *brown* sources such as

Research Questions

RQ1: How to distinguish hypothetical flows of green and brown energy supplied from multiple sources?

RQ2: How to separate green and brown energy from the mix that is fed in by EV charger into the battery?

The research questions stated above are addressed in this paper. The first research question focuses on distinguishing the hypothetical flows; therefore, the first step of this research will be to formulate an appropriate arrangement that provides with individual energy streams. The second question particularly seeks the answer of separating the green and the brown energy and this research needs to come up with an algorithm to theoretically separate them by synchronising the individual streams.

gas turbine, coal and oil [2, 3]. This practice opens up the opportunity to expand research in the direction of analysing the usage of renewable *green* and grid-produced *brown* energy and their implications on environment, society and economy. To analyse such behaviour of EV drivers as to how they use household green and brown energy, separating the mix is a necessity and this paper attempts achieving that goal by demonstrating a case study showing the process of separating the green and brown energy from the EV charging.

Research Problem

Many households in Europe use SolarPV to produce electricity for domestic use or to export to the grid or for both. Some households also keep home storage batteries ('home battery' hereafter) that charge themselves with the help of SolarPV generated electricity during sunny time of the day and feeds in power to the household at night. Both SolarPV and home battery act as source of renewable green energy as they directly or indirectly provide with energy produced without having to emit carbon. Nevertheless, due to this renewable energy being not guaranteed because of its dependency on the sun and often not sufficient to charge full EV battery, the common setup at households demonstrate EV chargers being connected with both SolarPV, home battery and grid supply concurrently and these appliances contribute on best-effort basis [7]. As a result of this practice, energy going into the EV battery becomes a mix of both green renewable and brown grid energy with high carbon emission. Moreover, the period of carbon emission varies depending on the time of the day and thus the brownness of the grid energy also varies [4].

A branch of the current energy research focus is rapidly inclining towards behaviour analysis of EV owners with a view to enabling them charging their EV battery with renewable green energy [3, 5]. However, due to the current setup at household, it is complicated calculating the green and the brown contribution inside the EV battery and therefore this paper identifies two related research questions and attempts to find their answers through a pilot study. The research questions are presented on the left side-bar along with a brief approach line on how they are going to be solved.

```
procedure GREEN-BROWN-SEPARATION
    Battery^green ← 0
    Battery^brown ← 0
    for each day i ∈ N do
        k ← 0
        for each entry p ∈ Owl^ev do
            if consecutive Consumption_p is strictly increasing then
                Construct Event_k^owl
                k++
            end if
        end for
        l ← 0
        for each entry q ∈ Solax^battery do
            if consecutive Consumption_q ≥ 0.01 kWh found then
                Construct Event_l^solax
                l++
            end if
        end for
        for all k ∈ Event^owl and l ∈ Event^solax do
            if Midnight then
                if Event_k^owl overlaps Event_l^solax then
                    Battery^brown += (Unit_{Event_k} - Unit_{Event_l})
                    Battery^green += Unit_{Event_l}
                else
                    Battery^brown += Unit_{Event_k}
                end if
            else
                Battery^brown += (Unit_{Event_k} - GridContribution)
            end if
        end for
    end for
end procedure
```

Algorithm 1: Green-Brown Separation algorithm.

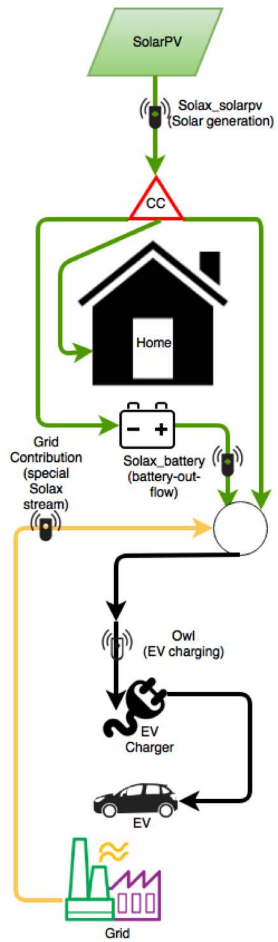

Figure 1: The IoT infrastructure used to gather required streams from the households.

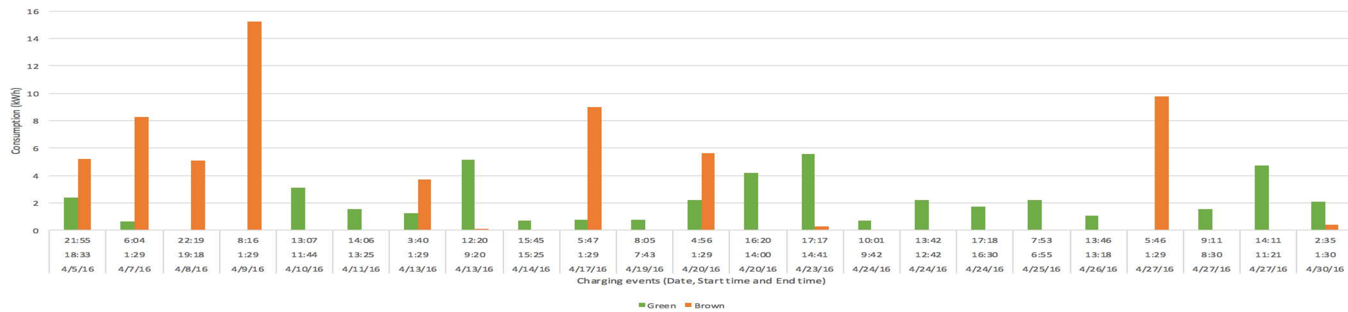

Figure 2: The results show the charging events obtained from the Household 1 (H1) in April 2016. The proposed algorithm divides each charging event into two components: green and brown. The charging amount that goes into the EV battery is shown in kWh.

Methodology

This research presents a month-long pilot study on two households located at Milton Keynes area of the United Kingdom. While addressing the first research question, it is realised that the emergence of IoT brings the opportunity to connect various household appliances to a central server with a view to making collaborative decisions [6]. Thus, this research utilises this advantage to create multiple streams of data from SolarPV, home battery, EV charger and grid with the help of IoT [7] and later an algorithm is proposed to separate the green and brown energy from the mix. At the beginning of this pilot study, each house is equipped with a SolarPV and a home battery along with a device called 'Solax X Power' (Solax hereafter) that enables these appliances to communicate with the central server. Another data recording and reporting device called 'Owl Intuition' (Owl hereafter) is connected with the EV charger that reports live EV charging data every 12 sec via wireless IP network. Besides, if grid contributes to EV charging, that stream is also monitored with an auxiliary stream provided by Solax. These streams are captured via a central server that later applies algorithm 1 on it to separate the mixed energy.

Results and Analysis

The setup is arranged at each household in such a way that it allows battery to be charged during the day from the direct solar generation whilst to discharge the energy into the EV battery during the night. The proposed algorithm calculates the contribution by the household battery which is green energy as stated above, and deducts this amount from the mix reported by the Owl to obtain the grid contribution. Similarly, during day time, SolarPV generation contributes directly to the EV charging. As battery is also gets charged during this period from the SolarPV generation, to identify the portion being contributed to the EV charging, identifying grid contribution followed by deducting that from the Owl stream is required. Any other charging outside this two period are contributed by the grid alone and considered brown.

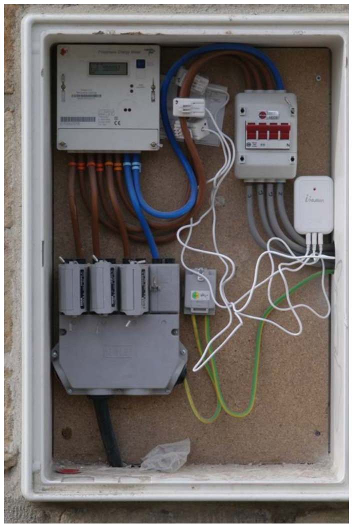

Figure 4: An 'Owl' system measuring EV charging stream.

Figure 5: A 'Solax X' Power System operating at a residence.

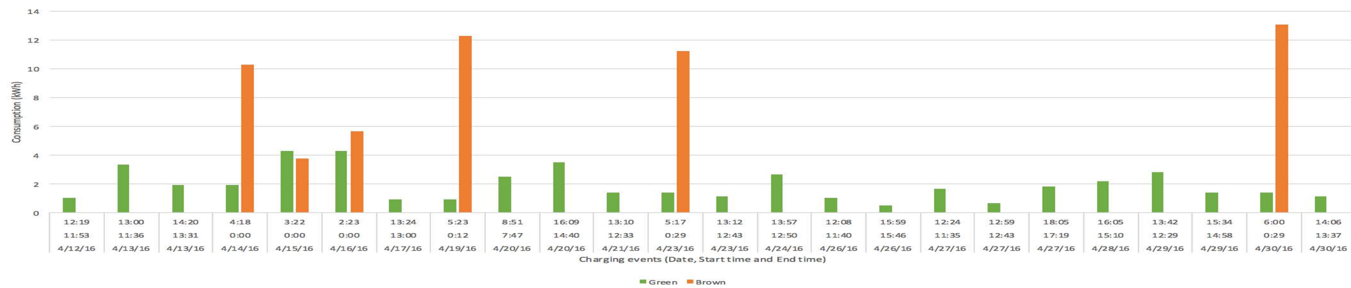

Figure 3: The results show the charging events obtained from the Household 2 (H2) in April 2016. Like the previous household, the proposed algorithm divides each charging event into two components: green and brown with showing the consumptions in kWh.

Figure 2 and 3 shows the charging events took place at each households in April 2016. With the help of the IoT infrastructure described at the earlier stage of this paper, proposed algorithm separated each event into two components: green and brown. The results show that the EV owner of H1 charged his/her EV 23 times in 17 days and H2 24 times in 16 days. It is notable from this analysis that the EV is charged by both green and brown energy at night when both battery and grid contributes in the charging. However, most day charging are green due to the fact that SolarPV generation was sufficient to charge the EV and grid contribution was not required.

With this pilot study, this research demonstrated that IoT can be very helpful in this kind of research particularly where building data stream can potentially provide opportunities to analyse certain aspects that cannot be measured straightforward. Besides, proposed algorithm along with the setup shown in this paper paves the path to investigate further in this domain by separating the green and the brown energy from the mix.

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