Electric vehicle Carbon footprint reduction via intelligent charging strategies

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***Abstract*— In recent years, electric vehicles (EVs) are seen as an effective solution to the arising environmental and sustainability concerns related to the transportation sector. As opposed to conventional vehicles, EVs do not entail tailpipe emission of CO_2 and other ambient air pollutants and require lower operational cost. However, the benefits that EVs can bring highly depend on their charging strategy. Moreover, the ever-increasing deployment of EVs on a global scale, and their uncontrolled charging (currently predominant) requirements, can cause significant burden for national grids and local distribution networks. The solutions EV could bring depend on the adopted charging strategies, i.e. dump charging, smart charging or V2G. This paper compares various EV charging strategies at the UK national level in perspective to 2030 and 2040 targets. This study clearly shows the benefits EVs could bring if their charging is intelligently controlled, resulting in a more positive impact on electricity distribution grids, a higher integration of renewable energy sources (RES) and lower CO_2 emissions.**

Keywords*— Electric vehicles, CO_2 emission, smart charging, vehicle- to- grid, renewable energy

I. Introduction

The global concern arising from climate change, caused by excessive greenhouse gasses emissions, and the continuous depletion of fossil fuels, has led the automotive industry to focus on EVs and phase out of internal combustion engine (ICE) vehicles. In addition, a positive mass acceptance and adoption have favored the growth of EV sales in recent times [1, 2]. In fact, according to future energy scenarios, it is estimated that the global EV sales will increase to around 4 million by 2030 and around 13 million by 2040 [3]. However, the environmental benefits EVs could bring are highly dependent on the national energy mix, which determines the annual CO_2 emission for transportation purpose. Although EVs have the potential of decreasing the CO_2 emission in the transportation sector, they can also lead to an increase in CO_2 emission in the electricity sector if they are charged during peak hours. In fact peak energy provision adds more fossil fuel generation in the energy mix, especially as this is connected to the merit order provision (based on price sensitivity as well as ram-up response time) of different generation sources [4]. If a large number of EVs are charged at the same time without any control, also known as dump charging, this can lead to an increase in peak demand which causes stress for the grid [5]. This can be overcome by using a controlled charging strategy known as smart charging. In this approach, the charging time of EVs is shifted according to the available power. As the prime renewable sources in Great Britain, i.e. solar and wind, are intermittent in nature, another charging strategy called V2G is also considered. Under this scenario, EVs can charge more in periods of renewable excess and discharge power to grid in case of high demand. In this way, they can be used as storage for the grid [6].

Previous researches have examined the impact on distribution system with various EV charging strategies based on the percentage of EVs penetration [4, 5], but few have discussed the outcomes in terms of CO_2 emissions through energy mix of the country i.e. Germany and Portugal [4, 7, 8, 9, 10]. Furthermore, it was assumed in these studies that EVs will be fully charged every day and at the same time, which however does not happen in reality as their charging depends on the driving requirements (and habits) of the users. Therefore, this research will focus on the daily charging requirement and times based on statistical data for the UK. Then, with predicted EV penetration levels for 2030 and 2040, the total energy demand and CO_2 emission are calculated. In this context, two case studies, each with three scenarios for EV is scheduling, namely Dump Smart and V2G charging, and three strategies regarding different charging locations, will be conducted. The two cases are namely:

1. UK total EV energy demand in 2030
2. UK total EV energy demand in 2040

This research discusses the theoretical background and methodology in Section 2, results and discussion thereof in Section 3 and concludes with our findings in Section 4.

II. Theoretical background

By using the reference of the UK total demand on a typical winter day (14/11/2017) and a typical summer day (16/06/2017) various EV charging strategies for the years 2030 and 2040 are analyzed. The additional total demand and CO_2 emissions to charge the EVs are then calculated. The difference between winter and summer allows for the quantification of the seasonal impact on the results. The aforementioned years are considered as timelines for this study based on the announcement by the UK government on the closure of unabated coal power generation units by 2025 [11] and a ban of ICE vehicles by 2040 [12].

A. *Current situation without EVs*

From Figure 1, the UK national electricity demand on a winter day is satisfied by oil, open cycle gas turbines (OCGT), combined cycle gas turbines (CCGT), coal, biomass, nuclear, solar, wind, hydro and pumped storage plant. The major share for total demand comes from CCGT, followed by coal and nuclear. A considerable unbalance between the evening peak i.e. 5 pm- 9 pm time, when the demand curve almost touches 50 GW, and night time i.e. 11 pm – 7 am, when the demand is reduced to 27- 30 GW, is observed [13, 14].

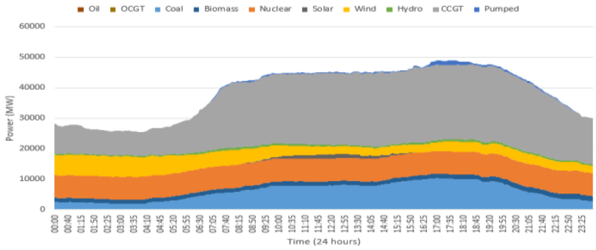

Fig. 1. Energy mix and total demand [13].

From Figure 1, the daily CO_2 emissions are calculated by using the values of CO_2 emitted per kWh of energy produced by each energy source presented in Table 1[13].

Table 1. CO_2 emissions for different generation sources

Type of power plant	CO_2 emissions (g/kWh)
Coal	870
CCGT	487
OCGT	487
Nuclear	16
Wind	11
Hydro	20
Solar	100
Biomass	435
Oil	650

Figure 2 shows the evolution of the CO_2 emissions for a typical winter day.

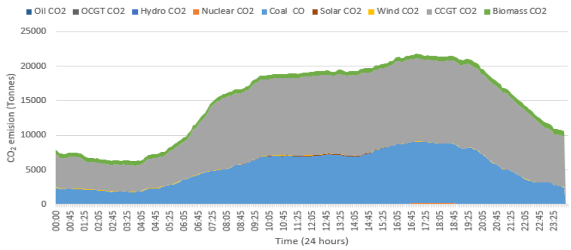

Fig. 2. CO_2 emissions for total demand [13]

B. *Methodology*

Table 2 presents the cases and scenarios that are evaluated in this paper to compare the advantages of different charging scheduling on CO_2 emissions.

Table 2. Case studies and scenario analysis

Scenarios	**Case 1: UK 2030**	**Case 2: UK 2040**
Reference scenario	No EVs	No EVs
Scenario 1: Dump charging	Strategy a Strategy b Strategy c	Strategy a Strategy b Strategy c
Scenario 2: Smart charging	Strategy a Strategy b Strategy c	Strategy a Strategy b Strategy c
Scenario 3: V2G	Strategy a Strategy b Strategy c	Strategy a Strategy b Strategy c

Reference scenario: Without EVs, a predicted energy mix and total demand of UK for the years 2030 and 2040 are analyzed. Subsequently, the total energy demand and the implicated CO_2 emission are calculated. This Reference scenario helps to compare scenarios with and without EVs.
Scenario 1: Dump charging, EVs are considered as loads and they are charged without any constraint once reaching their destinations i.e. home or (assumed here) work.
Scenario 2: Smart Charging, EVs charging times are shifted to optimal times depending on the availability RES or in periods of low demand.
Scenario 3: V2G, EVs are also discharged to provide energy back to the grid, to homes or other archetypes.

The results from Scenario 1-3 have all been compared against the Reference scenario to discuss the potential benefits of smart charging and V2G in terms of CO_2 emission and peak demand reduction. To analyze the effect of EVs charging on the total demand, the period from 5 p.m. – 9 a.m. is considered as home charging and 9 a.m. – 5 p.m. is considered as work charging. Home charging is divided into two strategies i.e. a: 5 p.m. – 9 p.m. and b: 9 p.m. – 9 a.m. in accordance to time of day respondents begin charging the vehicles and work charging is considered as strategy [15]. Table 3 provides the outline of the EV charging strategies adopted in this paper.

Table 3. Share of 2030 EVs during various strategy & timings of charging [3, 16]

Strategy & timings of charging	**Percentage of charging**	**No. of EVs**
Strategy a: Home charging 5 p.m. – 9 p.m.	38%	1,520,000
Strategy b: 9 p.m. – 9 a.m.	46%	1,840,000
Strategy c: Non-home charging 9 a.m. – 5 p.m.	16%	640,000

It should be noted that not all EVs will drive the same distance every day. To depict this diversity we divide EV charging events in three daily mileage categories. Table 4 represents the home charging for Strategy a (5:00 p.m. - 9:00 p.m.). The total number of EVs in this case is 1,520,000, derived from Table 3.

Table 4 Home charging for strategy a and Case 1, 2030

Average miles and energy required	**Percentage of average miles and number of vehicles**	**Required time and total power for charging**			
		3kW		**7kW**	
		Time (Min)	**Power (MW)**	**Time (Min)**	**Power (MW)**
Mile I: 7 mi (1.6 kWh)	56% (851,200)	35	2,533.5	-	-
Mile II: 30 mi (7.2 kWh)	38% (577,600)	145	1,733	75	4,043
Mile III: 100 mi (24 kWh)	6% (91,200)	480	273.5	240	638.5

Equation 1 – 3 provide the allocation of EV charging energy and time for Case 1, Mile I at 3kW. Under this analysis, 851,200 EVs travel 7 miles.

$$E_{1mi} = \frac{24}{100} = 0.24\ kWh \tag{1}$$

$$E_{7mi} = 7 \times 0.24 = 1.68\ kWh \tag{2}$$

$$t_{7mi} = \frac{E_{7mi}}{P_{max}} = \frac{1.68}{3} = 35min \tag{3}$$

Where E_{1mi} is the energy required to travel 1 mile, E_{7mi} and t_{7mi} are the energy and time required to travel 7 miles respectively and P_{max} is the rating of the charger. Here, charging is assumed at constant power. To charge the EVs at home, only 3kW and 7kW power cables are used whereas charging outside the home includes charging at the work place, public parking facilities and on-street charging stations. Here power cables such as 3kW, 7kW, 22kW, 43kW, 50kW are used. In the case of Mile I, it is assumed only 3kW cable are used to charge the EVs as it requires little percentage of charge.

Table 5 represents the home charging for Strategy b (9:00 p.m. - 9:00 a.m.). The total number of EVs in this case is 1,840,000, therefore only the number of vehicles falling in each mileage category, and the associated total power required will be different from the previous Table 3.

Table 5 Home charging for strategy b in Case 1, 2030

No. of vehicles for different mileage	**Total power required for charging (kW)**	
	3kW	**7kW**
I: 1,030,400	3,091	-
II: 699,200	2,097.5	4,894.5
II: 110,400	331	773

Table 6 below represents the non-home charging for Strategy c (9:00 a.m. - 5:00 p.m.). The total number of EVs in this case is 640,000. As in Table 5, only the number of vehicles in each mileage category and the total power required will defer from Table 3.

Table 6. Non-home charging for strategy c and Case 1, 2030

No. of vehicles for different mileage	**Total power required for charging (kW)**		
	3kW	**7kW**	**50kW**
I: 358,400	1,075	-	-
II: 243,000	729	1,701	-
III: 38,400	115	269	1920

III. RESULTS AND DISCUSSION

In this section, the total demand and CO_2 emissions are predicted for the years 2030 and 2040. As explained in the methodology, the scenario without EVs is considered as reference and the scenarios with EVs performing dump charging, smart charging and V2G are compared against it.

A. *Reference scenario for Case 1, typical winter day in 2030*

The UK's total demand on a typical 2030 winter day is expected to be increased by 15% of the total demand from a 2017 winter day [15]. This increase does not include EV charging. It is assumed that the weather conditions on the 2030 winter day are similar to the 2017 winter day. The production of power from each power source, are analyzed based on its installed capacity by 2030 and their capability to generate power in different periods in a day i.e. early morning, morning, afternoon, evening, and nighttime.

By 2030, the generating capacity is predicted to be around 124 GW. This is broken down in the different technologies in the mix: CCGT = 27 GW, nuclear = 8GW, biomass = 3GW, wind = 34GW, solar = 33 GW, Other renewables = 7 GW and interconnectors = 12 GW [3]. Figure 3 presents the energy mix for a typical winter day in 2030, where the major share in total demand is satisfied by CCGT followed by wind and nuclear. There is curtailment of the availability of wind energy from 11:35 p.m. – 6:20 a.m., which is not dispatched for stability reasons. The yellow curve represents the predicted total demand on 2030 winter day.

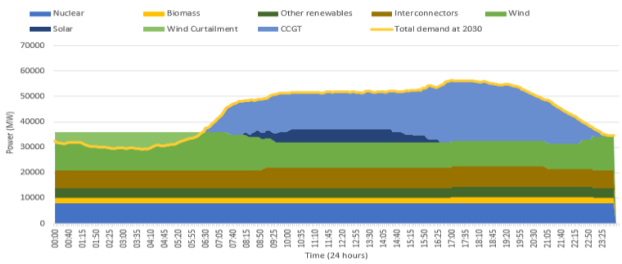

Fig. 3. National power demand for a typical winter day in 2030

Wind power generates 15 GW at mid-night and reduces to 10 GW during day time. Due to the lower solar intensity on a typical winter day in Great Britain, the generating power of solar will be around 5GW during the middle of the day and less during sunrise and sunset. At present, the UK has 4 GW of interconnectors and it is estimated to increase around 12 GW of power by the year 2030. The interconnectors provide 7- 8 GW throughout the day. Figure 4 presents the CO2 emission for a typical winter day in 2030. CCGT will dominate CO_2 emissions after the closure of coal power stations by 2025. The total CO_2 emissions for the whole day are around 1,942,687 tons, which is reduced by around 55.35% compared to a typical 2017 winter day. This reduction in CO_2 emissions is due to a higher share of renewables in the generation mix.

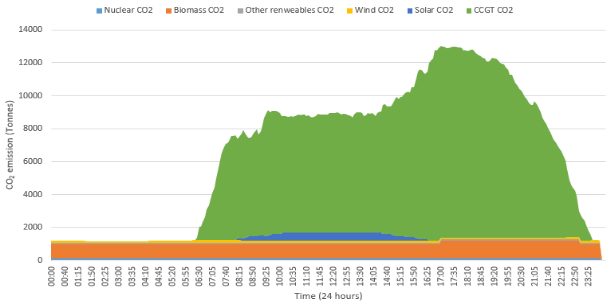

Fig. 4. National CO_2 emissions on a typical winter day in Case 1, 2030

B. Scenario 1 for Case 1, typical winter day in 2030

Figure 5 presents the total power demand in a typical 2030 winter day under Scenario 1, Dump charging. The blue curve represents the electricity demand without EVs while the remaining curves represent the additional demand required for charging EVs under different strategies. Due to dump charging, there is a rise of 4 GW at the peak times (5 p.m. – 9 p.m.) of the day. This increase in demand may potentially affect several local grids in the UK wherever very large numbers of EVs are charged at that peak load timings. This may lead to unreliable power supply if this demand is not satisfied. In any case, this will result in a higher cost for the system operator.

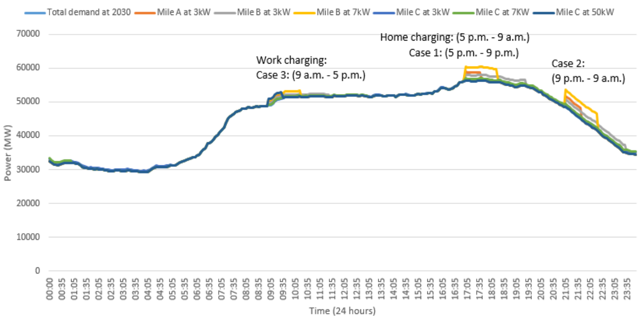

Fig. 5. Total demand with Scenario 1 for a winter day in Case 1, 2030

Due to a lower availability of solar energy during the British winter, the power required to charge EVs during dump charging is met by CCGT except the EVs charged after 11:35 pm due to availability of wind curtailment. As additional loads are met by CCGT, this leads to an increase of CO_2 emissions.

Figure 6 depicts the total CO_2 emissions in a typical winter day under Scenario 1. The blue curve represents the total CO_2 emissions without EVs and the remaining curves represent the additional CO_2 emissions by charging the EVs through dump charging. The incremental CO_2 emission account for a total amount of 108,185 tons, which gives an increase of around 5.28%, compared to the CO_2 emissions without EVs.

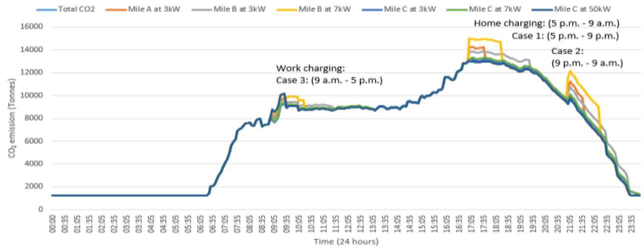

Fig. 6. CO_2 emissions with Scenario 1 for a winter day in Case 1, 2030

C. Scenario 2 for Case 1, typical winter day in 2030.

Figure 7 shows the total energy demand curve and EV charging demands for smart charging. In this instance, additional power demand is observed from 11:35 pm to 7: 35 a.m. for the EVs that are charging for 8 hours due to 3kW charging speed.

As there is a curtailment of the power generated by wind from 11:35 p.m. – 6:20 a.m., the home charging of EVs in strategy a (i.e. between 5 p.m. – 9 p.m.) and strategy b (i.e. between 9 p.m. – 9 a.m.) are shifted to charge between 11:35 pm – 7:35 a.m. Concurrently, in strategy c representing non-home (work) charging EVs are charged at different timings, between 9:00 a.m. – 5:00 p.m., to reduce the sudden rise in the load as there is no availability of wind or solar energy due to the curtailment.

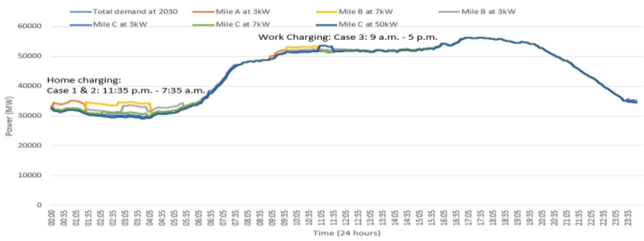

Fig. 7. Total demand with Scenario 2 for a winter day in Case 1, 2030.

Figure 8, presents the total CO_2 emissions under Scenario 2. The blue curve i.e. the one overlapped by the red curve of Mile III at 50kW in Figure 8 shows the total CO_2 emissions including the usage of the curtailed wind power to charge the EVs. The orange curve represents the additional CO_2 emissions that occurred to meet the slight additional power required to charge the EVs during their 8 hours of charging time. The remaining curve from 9 a.m. - 5 p.m. in Figure 8 represents the CO_2 emissions during non-home charging which came from CCGT due to the lack of extra renewables.

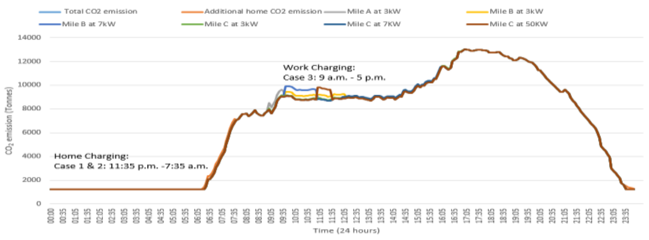

Fig. 8. CO_2 emissions with Scenario 2 for a winter day in Case 1, 2030

By charging the EVs with a smart charging logic there is a rise of around 1.44% in total CO_2 emissions compared to the case without EVs. This is because EV charging demand under strategy c is met by CCGT due to lack of extra renewables during daytime. In addition, to charge the EVs at midnight, a small amount of CO_2 emissions comes from curtailed wind power as the lifetime CO_2 emissions are included during the manufacturing of wind turbines (and extra transmission infrastructure, especially if offshore).

There is a drop of around 3.92% in CO_2 emissions compared to dump charging, which occurs because EVs are charged during the availability of renewables (i.e. wind).

D. Scenario 3 for case 1, typical winter day in 2030

In this scenario, EVs are charged smartly during the hours with available curtailed wind power and the EVs have also discharged 3.05 GW of power for a period of 4 hours (i.e. between 4:00 p.m. – 8:00 p.m.). The amount of power discharged by EVs at peak times is equal to the remaining amount of power available from curtailed wind energy after smart charging. In this way, the EVs retain the same State of Charge (SOC) for the next day.

In Figure 9, the dashed area from 4:00 p.m. – 8:00 p.m. represents the amount of power discharged from the EVs and the remaining curves represent the total energy demand at various charging times of the EV.

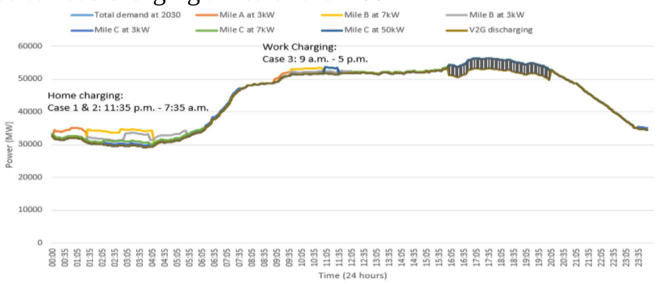

Fig. 9. Total demand with Scenario 3 for a winter day in Case 1, 2030

From Figure 10, the blue curve which is overlapped by the orange curve for Mile III at 50kW in Figure 10 shows the total CO_2 emissions, including the total curtailed wind. As EVs are discharged from 4 p.m. – 8 p.m., the reduction in CO_2 emissions can be noticed through the difference between the blue and orange curves.

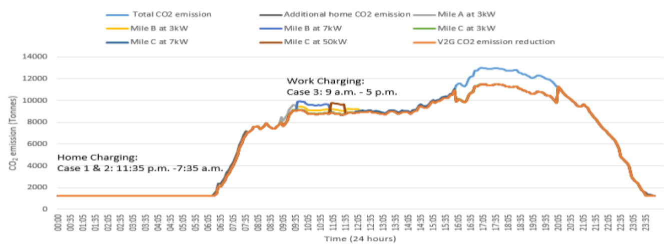

Fig. 10. CO_2 emissions with Scenario 3 for a winter day in Case 1, 2030

Charging the EVs during available of renewables and discharging them at peak demand reduces around 2.32% of the total CO_2 emissions compared to the scenario without EVs. By comparing V2G with dump charging, there is a decrease of around 7.50% in CO_2 emissions for two reasons: the reduction of peak demand that was caused by dump charging and discharging of power back to the grid at peak hours. Comparing smart charging with V2G, a drop of around 3.71% in CO_2 emissions is observed due to the discharging of power back to the grid at the peak demand time.

The same methodology has been applied to a typical summer day in 2030 and also both typical summer and winter days in 2040 to show the seasonal variation and time evolution of the benefits achievable through smart charging and V2G. The total number of EVs by 2040 in the UK is predicted to be around 13 Million [3]. For 2040, the number of EVs undertaking home charging under strategy a of 4,940,000, strategy b of 5,980,000 is assumed, and non-home charging under strategy c of 2,080,000. The total EV charging requirements in 2040 is expected to increase due to increase in number of EVs. The total energy demand, excluding EVs, is expected to be increased by around 35% compared to the total demand of a typical 2017 winter day [17]. By 2040, the generation capacity will be around 159 GW, composed of CCGT = 25 GW, nuclear = 7 GW, biomass = 4 GW, wind = 46 GW, solar = 52 GW, other renewables = 7 GW and interconnectors = 18 GW [15].

The results are presented in Table 7. For the scenario without EVs in all the case studies, i.e. typical 2030 summer and typical 2040 winter and summer days, the variations of CO_2 emissions are defined as percentage values of the CO_2 emissions in summer 2017, winter 2030 and summer 2030 respectively. The actual peak demands are also listed. This allows comparison of the incremental variation throughout the analyzed timeline. As for the other scenarios, namely dump, smart and V2G charging, the CO_2 emissions are expressed as percentage values of those of the scenario without EVs for the same corresponding year. The absolute variations of the peak demand for the three different scenarios compared to the scenario without EVs are also included. This enables a comparison of the different charging scenarios in terms of the net benefits they can bring.

Table 7. Summary of typical 2030 summer day and typical 2040 summer and winter days

Scenarios	Typical 2030 Summer day	
	Peak demand (GW)	**CO_2 emission (%)**
Without EVs	43	-60.6 (summer 2017)
Scenario 1	4.5	+11.96
Scenario 2	0	+5.01
Scenario 3	-6.5	-21.59
Scenarios	**Typical 2040 Winter day**	
	Peak demand (GW)	**CO_2 emission (%)**
Without EVs	65	-19.42 (winter 2030)
Scenario 1	14	+22.40
Scenario 2	0	+8.56
Scenario 3	-2.89	+4.21
Scenarios	**Typical 2040 Summer day**	
	Peak demand (GW)	**CO_2 emission (%)**
Without EVs	52	+1.04 (summer 2030)
Scenario 1	14	+34.76
Scenario 2	0	+10.04
Scenario 3	-5	-12

IV. CONCLUSIONS

In this paper, it has been shown that with EV dump charging there is an increase of 4 GW and 14 GW in total demand at peak times for one typical day in 2030 and 2040 respectively, in comparison to the Reference scenario without EVs. This increase in total demand will put serious stress on the central grid, as well as local distribution networks. Moreover, concerning CO_2 emissions, there is increase of 5.28% and 22.40% in CO_2 emissions for a typical winter day in the years 2030 and 2040 and of 11.96% and 34.76% for a typical summer day in 2030 and 2040 respectively. In the smart charging scenario, the load is not increased, although there is an increase of 1.44% and 8.56% in CO_2 emissions for a typical winter day in 2030 and 2040 compared to the scenario without EVs. For the typical summer day, the CO_2 is increased compared to the Reference scenario by 5.01% and 10.04% in 2030 and 2040 respectively. With V2G, there is decrease in demand of around 3 GW for 4 hours during the typical winter day in 2030 and 2040 and 6.5 GW and 5 GW for 5 hours during the typical summer day of 2030 and 2040. As for CO_2 emissions in 2030 on a typical winter day, there is decrease of 2.32%. A slight increase of around 4.21% in the CO_2 emissions for a typical 2040 winter day is noticed. This is due to more than thrice the number of EVs for strategy c in 2040 compared to strategy c in 2030. There is a decrease of 21.59% and 12% in CO_2 emissions for a typical summer day in 2030 and in 2040 respectively. The results presented here demonstrate that the integration of EVs through smart charging and V2G becomes beneficial from both a power demand and an environmental perspective. The added advantage of discharging through V2G technology in coming years is that it may substitute stationary energy storage systems with future increased renewable energy penetrations.

However, the level of benefits obtained from both smart charging and V2G depend on the season. In particular, it has been shown that the benefits are higher in summer compared to the winter due to higher PV generation and lower power demand.

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REFERENCES

[1] Lane, B. (2018). Green cars UK - Guide to low emissions cars - Next Green Car. [online] Nextgreencar.com. Available at: http://www.nextgreencar.com/ [Accessed 26 Feb. 2018].

[2] Shindell, D., Faluvegi, G., Walsh, M., Anenberg, S.C., Van Dingenen, R., Muller, N.Z., Austin, J., Koch, D. and Milly, G., 2011. Climate, health, agricultural and economic impacts of tighter vehicle-emission standards. Nature Climate Change, 1(1), p.59.

[3] National Grid (2017). Future energy scenarios, pp. 3-5. (available at: Nationalgrid.co.uk)

[4] R. Freire, J. Delgado, J. M. Santos and A. T. de Almeida, "Integration of renewable energy generation with EV charging strategies to optimize grid load balancing," 13th International IEEE Conference on Intelligent Transportation Systems, Funchal, 2010, pp. 392-396.

[5] Peças Lopes, J.A., Soares, F.J., Almeida, P.M. and Moreira da Silva, M. “Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources”, EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Norway, 2009.

[6] Noel, L., de Rubens, G.Z., Kester, J., Sovacool, B.K. (2019). Vehicle-to-Grid. Energy, Climate and the Environment. Palgrave Macmillan: Cham.

[7] Freire, R., Delgado, J., Santos, J. and de Almeida, A. (2010). “Integration of renewable energy generation with EV charging strategies to optimize grid load balancing”. 13th International IEEE Conference on Intelligent Transportation Systems, Funchal.

[8] Jochem, P., Babrowski, S. and Fichtner, W. (2015). Assessing CO 2 emissions of electric vehicles in Germany in 2030. Transportation Research Part A: Policy and Practice, 78, pp. 68-83.

[9] Kolarova, V. & Anderson, John & Hardinghaus, Michael. (2018). Indirect CO2 emissions of electric vehicles: Insights from real-world vehicle use. Transport Research Arena Conference, Vienna.

[10] Jochem, P. & Babrowski, S. & Fichtner, W. (2015). Assessing CO2 Emissions of Electric Vehicles in Germany in 2030. Transportation Research Part A Policy and Practice. 78. 68–83.

[11] Department for Energy and Industrial strategy (2016). Coal Generation in Great Britain. London, pp. 1-2.

[12] London Assembly (2018). Driving away from diesel Reducing air pollution from diesel vehicles. London Assembly: Environment committee, pp. 1-2. (available at: london.gov.uk)

[13] Gridwatch.templar.co.uk. (2017). G. B. National Grid status. [Online] Available at: http://www.gridwatch.templar.co.uk/ [Accessed 7 Dec. 2017].

[14] Gridwatch.co.uk. (2017). Live to monitor the UK electricity National Grid. [Online] Available at: http://gridwatch.co.uk/ [7 Dec. 2017]

[15] Spataru, C. (2013). Common Road to 2050 Energy Networks and Policy (ENP2050). UK energy scenarios, pp. 3-4.

[16] Screeton, J., Hutchins, R., Delmonte, E. and Stannard, J., 2013. Assessing the Role of the Plug-in Car Grant and Plugged-in Places Scheme in Electric Vehicle Take-up in England. In: European Transport Conference 2013 (Association for European Transport)

[17] Department for Transport (2016). Road use statistics Great Britain 2016, pp.1-2.