Wireless Electric Charge-on-the-move

A sustainability appraisal of the potential for the UK transport application

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***Abstract*—this paper examines whether the adoption of wireless electric charge-on-the-move technique at the scale of a country is technically feasible and based on a suitable engineering sustainable context. The work seeks to cover the gaps on the topics of technical feasibility, environment liability, and social responsibility at the magnitude of a country, thus enabling us to adopt this idea and play a significant role for a more sustainable future. Overall, it was revealed that wireless electric charge-on-the-move technology can be a major driver towards a more sustainable transport sector without undermining the environment and implying human implications.**

Keywords—carbon emissions reduction, charge-on-the-move, electric vehicles, inductive power transfer, sustainable development

I. INTRODUCTION

A growing scientific consensus signifies that climate change is mainly influenced by carbon dioxide emissions [1] of which the main source is human behaviour [2]. That awareness for irreversible damage on our planet has raised the obligation for governments to embark climate change mitigation actions and in particular, the UK government is legally obligated to reduce its greenhouse gas emissions by 80% (from the 1990 baseline) by 2050.

Certainly, transport sector in the UK has to play a crucial role as part of the effort towards a more sustainable future. Based predominantly on fossil fuels not only does it stimulate issues in relevance with climate change, but it also affects severely human and ecosystem health. This coupled with the inevitable growth of population and number of vehicles in the future [3], the necessity to strive for a sustainable transportation is at the forefront as it has never been before.

Nevertheless, no one can doubt the value of transportation as an economic activity and social stimulator and hence the challenge is how to support growth in mobility on a sustainable and environmental-responsible manner. A plethora of scenarios have been developed to reduce carbon emissions in transport sector by at least 80% by 2050. Interestingly, all of them highlight the obligation to decarbonise the road transport of the UK and if substantial progress has to be made, an adequate penetration of electric cars is prerequisite to achieve the specified targets. Indeed, targets set by the Committee on Climate Change in the UK suggest that electric cars have to capture 60% of the new car market by 2030 and above 90% by 2040.

However, the successful uptake of electric cars on the roads of UK is constrained by significant diachronic product barriers. Initially, the most major consideration is the high purchase and maintenance cost due batteries. According to a survey [4], 76% of British car buyers have or would consider buying an electric car but they are not willing to pay more than the price of a conventional car. Moreover, limited mileage range and high recharging time [5] are the next two undesirable product attributes which have negative influence on consumer choice and acceptance.

Wireless electric charge-on-the-move technology can reject the adverse characteristics of electric cars and facilitate their dominance on the roads of UK. It is about an idea whereby inductive power transfer (IPT) devices will be installed along the transport grid of UK with the purpose to provide energy to moving electric cars. The owners will not worry about the mileage range since their cars will be charged dynamically but more importantly, batteries with considerably lower capacity can be exploited instead of the bulky, heavy, and expensive ones used for current applications. This means that not only will the cars' performance be improved significantly due to lower weight and smaller volume but also the cost will be reduced dramatically. Consequently, wireless charge-on-the-move technology will establish the consumer preference for electric cars over combustion engine vehicles and drive the shifting towards a more efficient and lower-carbon transportation.

This paper examines whether the adoption of wireless electric charge-on-the-move technique at the scale of a country is technically feasible and based on a suitable engineering sustainable context. The work seeks to cover the gaps on the topics of technical feasibility, environment liability, and social responsibility at the magnitude of a country, thus enabling us to adopt this idea and play a significant role for a more sustainable future. It starts with a brief review of the technology; the methods were used to evaluate the sustainability agenda of the proposal; the results of the appraisal; and finally, emergent conclusions

II. INDUCTIVE POWER TRANSFER TECHNOLOGY REVIEW

This section reveals the existing knowledge on the subject of IPT, wireless charging for electric cars applications, and charge-on-the-move concept. Firstly, it establishes a general awareness of the associated technology portfolio and system architecture that allows us to perceive the general context and identify potential implications. Then, it uncovers the great interest in research regarding the technical aspect of technology but simultaneously, it highlights the lack of evidence beyond the 'technical-fix' to consider the proposal on a holistic oriented manner.

Initially, a number of former illustrations disclose the sufficient level of development and maturity of IPT technology. As evidence, the operation of common transformers within power networks, which step-up or step-down the level of voltage, is based on this particular technique. This widespread electric device transmits energy between the primary and secondary coils in the form of magnetic field and efficiencies up to 98% can be observed in conjunction with high magnetic core properties. In general, the unique features of IPT technology have been the reason for its extensive exploitation in a variety of applications. For instance, IPT finds purpose in harsh environments like underwater and mining applications [6], [7]; in factories application such as cable-free power supplies for moving parts on machineries [8]; in clean rooms like semiconductors fabrication rooms (Daifuku factory); lighting applications [9]; amusement parks (Conductix-Wampfler company); etc.

More recently, IPT technology has been transferred to automotive industries where it offers attractive solutions for electric vehicles charging applications [10]. The limited driver commitment to charge vehicles, due avoidance of plug-in cables and simple systems that are unaffected by weather conditions, enhances social cohesion and social acceptance of wireless charging applications. Primary applications refer to stationary charging but modern trends on transportation suggest charge-on-the-move solutions.

A typical wireless stationary charging system for electric cars may be envisaged as shown in Fig 1. Fundamentally, it comprises of two major components; the road charging unit and the vehicle charging unit. The first stage is to convert the supplied AC power from the electricity supply grid to DC and then from DC again to AC to obtain suitable frequency; since higher frequency enables higher transmission of power [11]. Afterwards, the produced current passes through the transmitting coil and the generated magnetic field is captured by the receiving coil. A specific circuit on the pick-up system is then exploited to produce a stable DC power source, as it is required for the electric motor, the batteries or other loads on board [12].

While it may be true to say that the technology for stationary charging systems has been adequately developed, on the other hand the technology for the charge-on-the-move approach has not been yet considered enough to become a commercialised service. Factors of performance, cost, and standardisation still need to be addressed [13] but the great interest on the field by research groups and automotive industry [14] sets the outline for a promising future.

III. METHODS

Although the notion of static wireless charging of electric vehicles was introduced two decades ago, the concept of charge-on-the-move at the scale of a country has not been considered yet. Therefore, the research methodology was mainly based on the critical review approach. A general awareness on the subject was established through a comprehensive review of the technology and then a new argument was proposed through analytical appraisal of previous unrelated facts.

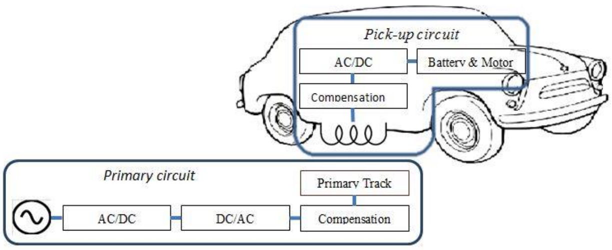

Fig 1: *Typical IPT system for charge-on-the-move applications*

The project initiated with the definition of sustainable principles in order to frame the sustainability targets that need to be achieved and thus determine the worthiness of the proposed technology. Afterwards, a preliminary environmental evaluation was discussed to determine whether it is worthwhile to continue with further investigation and then, a technical appraisal was conducted. Subsequently, major considerations were identified and after that an assessment of the sustainability credentials of wireless charge-on-the-move technology was performed using a number of sustainable principles as prompts.

A. *Uncertainty and chief data sources*

Dealing with uncertainty and eliminate risks is one of the key challenges that engineers are compelled to respond nowadays [15]. The technology's novelty coupled with the necessity to use forecasts for 30 years, make the threat of uncertainty more acute. To this end, up to date data sources have been carefully selected from reliable authorities to eliminate incredibility of data and associated risks. These include the literature, Department for Transport in the UK, Department of Energy and Climate Change UK.

B. *Set sustainable context and frame targets*

It could be argued that switching to clean fuels is one of the key challenges in transport sector for promoting sustainability; but the real challenge is to avoid getting a narrowly concept of the project without identifying all the interdependencies. The adoption of wireless electric charge-on-the-move technology can be characterised as a complex system which contains a mixture of technical, social, economic, and environmental impacts [16]. As a result, linear and mechanistic thinking is ineffective to address the system [17] and espousing a holistic approach to the system is imperative.

A plethora of sustainable principles has been suggested to date for assisting engineers and professionals involved in the development of new technologies. They are not simply a listing of goals, but a set of methodologies to accomplish the goals of sustainability of technologies of the future. They move beyond baseline engineering quality and safety specifications to include environmental, social, and economic factors [18].

Consequently, the introduction of charge-on-the-move technology should be guided by sustainable principles to respond to social demands, foster economic flourish, and consider the impacts on environment. Yet, none principle can meet the anticipatory sustainable goals of a technology in isolation since different principles enclose dissimilar features and emphasise on different capitals that technologies embody. Therefore, as we have to reject the idea to optimise one parameter of the project and embrace system scale consideration, a balancing of principles will be required to optimize the overall system solution and promote sustainability as it is really mattered.

At the beginning, the necessity to respect the environment without exhausting and contaminating the natural resources, are underlined by environmental principles. Wireless charge-on-the-move technology has to contribute significantly on decreasing our society's economic dependence on fossil fuels, thus allowing nature to rebuilt itself and replenish its resources. Simultaneously, the proposed technology has to consolidate social cohesion, social equity, and social inclusion without decaying individuals' health and well-being; in the attempt to promote a social responsible technology. Other principles urge the formulation of anticipatory view of the future and the development of interpersonal skills to communicate, negotiate, and collaborate with various stakeholders whose perspective may be different upon others' perception.

IV. RESULTS

This section includes appropriate collection of data and suitable analysis techniques, according to methodology, in order to articulate a robust argument on the subject of wireless charge-on-the-move potential for the UK transport application.

A. *Preliminary Environmental Evaluation*

According to Vehicle Licensing Statistics, in the end of 2013 there were 35 million licensed vehicles on the roads of UK, of which 29.1 million units were cars. The average CO2 emissions value for all licensed cars was 157 gCO2/km and according to National Travel Survey, the average annual travel distance per car was 8,200 miles. This means that, a car on the roads of UK in 2013 was responsible for 2.071 tCO2. Afterwards, a private survey involving 20 electric cars revealed that the average energy consumption nowadays is around 0.27 kWh/mile whereas the minimum consumption reaches a low point of 0.14 kWh/mile. In addition, the average CO2 emissions per kWh in 2013 was 470 gCO2/kWh for electricity used at the point of final consumption. Hence, an electric car emanates only 1.24 tCO2 emissions instead of 2.071 tCO2 by a conventional car, which is a 40.31% lower value; taking into consider average electricity consumption per mile, average carbon emissions per kWh, 8% electricity supply losses, and 90% efficiency for wireless chargers.

On condition that the electricity supply system will be partially decarbonised at the level of 100 gCO2/kWh by 2050 and the average energy consumption of electric cars will modestly improve at the level of the current minimum value, the average carbon emissions per car will be as low as 0.14 tCO2 per year; 93.41% carbon emissions reduction in comparison with 2013 figures.

B. *Technical appraisal*

It has been illustrated that wireless technology for electric cars has been adequately developed and will be substantially improved during the next few years. As revealed by [19], researchers at Auckland University have developed a 5 kW stationary charging pad for electric cars with over 90% efficiency across misalignments in all directions to the tune of 250 mm. Similarly, the Oak Ridge National Laboratory in the U.S. has achieved 3 kW chargers with efficiencies around 90% [20]. Finally, 95.7% DC to DC power delivery efficiency at 8 kW and across air gap of 200 mm has been illustrated at the University of Michigan [21]. Besides, a large number of requirements are taking into consider to configure a system that meets specific needs and performance parameters of automobiles, such as vehicle communications and electric specifications; thus enabling wireless electric charge-on-the-move technology to be safely integrated in automotive industry.

C. *Major considerations*

At that point, an extensive identification of potential implications is conducted to determine all the fundamental elements and necessary prerequisites to introduce that particular technology. Indicative solutions and suggesting comments are mentioned for every topic with the intention to denote the affordability of the technology.

1) *Power demand and installed capacity*

One of the greatest considerations for introducing wireless charge-on-the-move technology is related with the installed capacity to supply wireless chargers along the national transport grid. The introduction of thousand transmitters with rated capacity over 20 kW will definitely add a huge load on the electricity supply system of the country implying the necessity to examine potential augmentation of installed capacity.

Fortunately, a variety of organisations and authorities in the UK have estimated that the electricity demand will be significantly increased in the future. Several reports indicate that the electricity demand will be escalated up to 173%, compared with current figures, mainly because of the shifting towards electric transportation and electric heating. The blue colour line in Fig 2 depicts the average daily demand in the UK in 2013 whereas the red colour line indicates the estimated daily demand by 2050 according to future scenarios. The green colour line presents the anticipated installed power capacity by 2050, which will reach the level of 130GW and revealing at the same time that there will be sufficient installed capacity in the future for charge-on-the-move technology. In particular, there will be an available capacity of 50GW during the peak hours of electricity demand by 2050 for electric transportation regardless the way of power distribution (stationary or charge-on-the-move approach).

2) *Electricity supply network upgrade*

Furthermore, concerns are emerged regarding the capability of the power transmission network to deal with the new generating capacity and higher power demands. Indeed, some of the transmission lines are currently operating at their maximum capacity levels and appropriate reinforcements are imperative. According to related bodies, strategies have been developed to reinforce the national grid of UK in order to be able to accommodate the new electricity state. More importantly, those strategies will be accomplished by 2020 which is sooner than a potential implementation of wireless charge-on-the-move technology.

In a similar way, electricity distribution companies have their own role for connecting the new technology with users. This responsibility and opportunity at the same time has been recognised by distribution companies which have embarked upgrading procedures; thus enabling their networks to accommodate future demands.

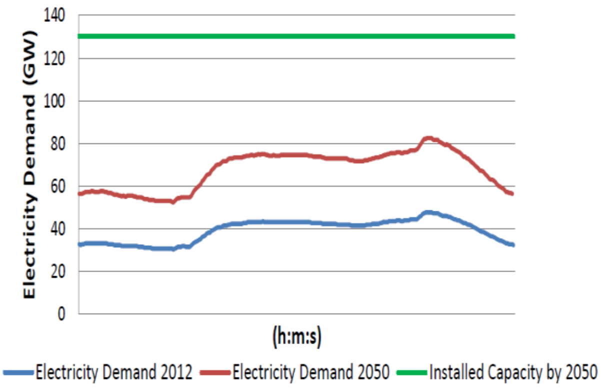

Fig 2: *Power demand and installed capacity projections*

3) *Social acceptance*

Literature signifies that a prevailing barrier for introducing a new technology is the social acceptance [22], [23]. Therefore, we need to identify the reasons that influence the consumer behaviour and may accept or reject the introduction of wireless technology. Based on the conception that social acceptance is distinguished in three interdepended dimensions, which are the socio-political, community, and market acceptance [24], a diagram has been derived to illustrate the complexity of the subject, Fig 3.

It can be revealed from the diagram that the large number of variables can significantly alter social acceptance. Some of those are enclosed in negative feedback loops and therefore goals have to be determined to ensure the stability of the system. In contrast, another amount of variables are elements of positive feedback loops which reinforce the social acceptance of wireless charge-on-the-move technology.

In particular, market acceptance (Fig 4) is reinforced by powerful variables that can totally define the behaviour of the system. Initially, the limited driver commitment required to recharge the batteries of electric cars enhances the social cohesion. Simply, effortlessly and regardless weather conditions cars' batteries will be charged instantly promoting at the same time the widespread acceptance of the technology among different groups of people. By charging on-the-move, smaller size batteries can be used instead of current heavy and expensive. Consequently, not only does the weight of vehicles is smaller which improves the performance of the car but also it reduces significantly the cost of the car.

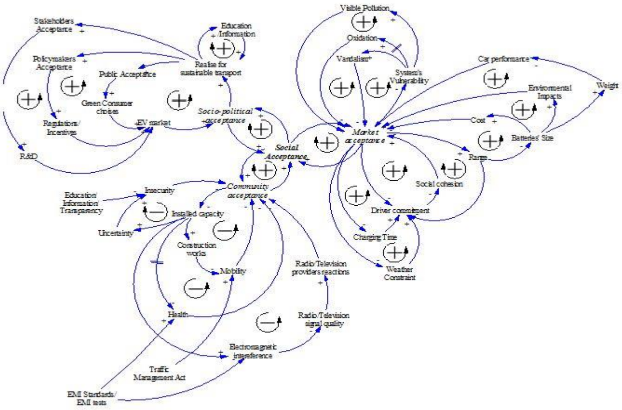

Fig 3: Social acceptance variables

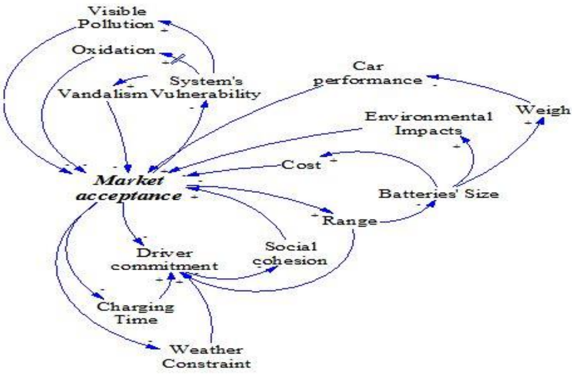

Fig 4: Market acceptance variables

As evidence, take the case of the BMWi3 electric car revealed in 2014 which has a 22 kWh lithium-ion battery. The purchase price of that particular car is around £25,000 of which £7,810 is the estimated price for its battery - £355 per kWh of battery. This allows us to argue that charge-on-the-move technology can reduce up to one third the current price of the car due to lower capacity battery exploitation. Therefore, people will become aware of the new market assets mainly in relevance with financial reasons and the adoption of charge-on-the-move technology will be the outcome of the new market demand.

4) *Electromagnetic interference*

The effect of electromagnetic interference [25] is stimulated with higher operational frequencies which lead to higher propagation of disturbance. Initially, the design of IPT systems was based on 180 Hz [26] but modern designs use at least 10 kHz frequency [27]. This coupled with the technical progress of power electronics, frequencies around 100 kHz will be dominated in the near feature [28] and the concern of electromagnetic interference is at the forefront as it has never been before.

One of the primary considerations is the interference with the moving vehicles but a considerable number of illustrations reassure that this problem is solvable. The leakage magnetic flux induces voltages on cars' chassis which causes increase of heat as well as alteration of significant vehicles' parameters. Moreover, the induced voltage is capable to interfere with electronic signals and undermine not only the proper functionality of the car but more importantly the safety of passengers. To this end, embracement of appropriate design techniques and use of non-magnetic materials is a well common method to prevent electromagnetic interference. Firstly, the lamination of surfaces exposed to magnetic fields [29] reduces the amount of power which is dissipated in the form of heat. Additionally, the use of aluminium plates as shield in the bottom surface of the car prevents the formation of induced voltages and appropriate design of coils can guide the magnetic flux in a better way [30].

According to [31], power electronics systems with inverters and rectifiers, which is common equipment of wireless chargers, draw currents with distorted waveform. The distorted current is deteriorated with the high frequencies used in our case and may lead to deleterious effects on the electricity supply network. These include significant power losses in distribution and transmission lines; alteration of utility voltage waveform which adversely affects other loads; and overloading of shunt capacitors which are exploited by distribution companies to support voltage.

In order to prevent degradation in power quality, recommended guidelines have been suggested. Power electronics have to comply with maximum harmonics limits and voltage fluctuations set out by the IEEE. Both consumers and suppliers have responsibilities of maintaining power quality [32] and harmonics levels for large consumers, such as wireless electric charge-on-the-move applications, may be defined through negotiation with distribution companies [33]. Consumers have to limit the distortion of current drawn and on the other hand, suppliers have to ensure that the voltage supplied to other users has adequate quality. The adoption of additional hardware or following specific design standards may be required from both parties to eliminate the effect of harmonics.

5) *Standardisation*

Followed by the previous statement, one of the prevalent barriers for introducing dynamic charging is the standardisation of technology. As yet, non-specific standards have been suggested for manufacturer companies and therefore, different prototypes have dissimilar specifications. It is well accepted, that standardisation not only does positively affect both innovation and technology diffusion [34] but also it benefits consumers by enhancing price competition among sellers [35].

Thereby, standardisation procedures have to be promoted to enjoy the benefits of technology. Automotive companies and their expansion of business models to include lucrative wireless charge-on-the-move systems will play a crucial role by compelling associate organisations for establishing standards and regulations or making investments to promote them [36]. Even products utilising different specifications may be designed to be compatible with each other regardless coil shapes, designs and power transfer rates. As evidence, take the case of mobiles phones and bank cards wherein despite the fact that are produced by different brands, we should consider that they all use standardised interfaces to allow compatibility.

Recently, an SAE International volunteer task force for Wireless Power Transfer of Light Duty, Electric and Plug-in Electric Vehicles, has agreed on standard frequency of 85 kHz; which is a major step towards interoperability and standardisation for future commercial developments.

6) *Health considerations*

Finally, it could be argued that passengers' exposure to magnetic flux may lead to health implications and degradation of humans' well-being. But this is not the case, as a number of research projects highlight the point that leakage flux is within international standards (ICNIRP). For instance, the magnetic flux density of a 35 kW charger at 20 kHz was 60% lower than specified limits at 1 metre of the centre of the pad [37]. Similarly, the leakage flux density for a 5 kW transmitter with working frequency at 20 kHz was again 40% lower than the maximum levels [38]. More particularly, the measurements techniques used for the experiment were proposed by international organisations (ICNIRP) taking into consider separately the exposure on the central nervous system and the whole body.

D. *Evaluate sustainability agenda*

It is generally argued that sustainable development and large infrastructure projects, such as wireless electric charge-on-the-move application, are two irrelevant concepts whose relationship is not only weak but also confusing. Currently, large infrastructure projects involving many economic, social and environmental aspects are mostly evaluated using economic instruments which dominate over environmental and social assessments. This tendency is mainly driven by the perception that sustainable development and the necessity to meet environmental needs deploys boundaries that constrain systems' efficiency. However, sustainable development and wireless charge-on-the-move application can coexist together. Social equity, environmental protection, and economic prosperity can be delivered by shifting from the traditional to a more aspirational and motive way of thinking.

Indeed, wireless charge-on-the-move proposal is not only based on a sustainable engineering context but it is also a precondition to support and enhance sustainable development. The stimulation of economic growth through supply chain and the development of new skills and expertise will be observable without anticipating loss of biodiversity, ecosystem damage, soil erosion and loss of soil fertility. Finally, the utilisation of the existing road infrastructure does not imply societal and environmental exchanges; hence, placing the country on a trajectory for greater sustainability.

1) *Sustainable principles*

Initially, a selection of the numerous sustainable principles [39] are discussed to illustrate that this particular technology comes under the agenda of sustainability. The 'precautionary principle' suggests that lack of full scientific justifications should not be used as an excuse for inaction on preventing environmental degradation. It is generally accepted that the transport sector in the UK is one of the most significant contributors for climate change implications as it produces one quarter of all carbon emissions in the region. Although there is no scientific justification to prove the linkage between the CO2 emissions and the climate change, it is our obligation to take anticipatory actions to prevent irreversible harm of the environment and damage to our planet in general. Bearing in mind, that one of the best actions related with sustainable transportation is to switch to cleaner fuels and eliminate carbon emissions emanated by the usage of passengers' cars, the proposed scheme plays a crucial role to achieve these targets.

Alternative scenarios for the transport sector in UK for the next years signify augmentation on the number of cars and the average mileage distance per car. The necessity to constantly foster the extraction of fossil fuels from the earth's crust will be inevitable to supply future commuting as well as the concentration of greenhouses emissions produced by people will be obtaining higher and higher levels. Consequently, bearing in mind the 'natural step principle', charge-on-the-move idea can provide the fundamental elements for our society to avoid conditions that undermine its capacity to meet its own needs.

By reducing the concentrations of substances which are both extracted from earth and produced by people, charge-on-the-move proposal enhances sustainable transport with the minimum environmental footprint – 'one planet living'. Besides, the exploitation of the existing infrastructure to install wireless chargers eliminates a plethora of construction related issues and protects biodiversity. Combining the needless to use additional land with the tremendous reductions of carbon emissions and dependence on fossil fuels, the proposed initiative amounts a negative 'ecological footprint' [40]. Moreover, wireless dynamic charging enables transportation mobility while minimising the impacts on the environment. This comes under the 'resource efficiency and the waste hierarchy principle' which indicate the necessity to "create more with less" towards a more sustainable exploitation of earth's limited resources.

Regarding the social aspect of the project, the 'Global Sullivan Principles of Social Responsibility and Principles of Social Sustainability' suggest among others equal opportunities, social inclusion and interaction, security, and human health through sustainable development. The negligible driver commitment to use the proposed system enables social cohesion by including people from all minority and groups. Besides, the adoption of wireless chargers will be based on suitable engineering contexts and standards that do not undermine the health and safety of individuals.

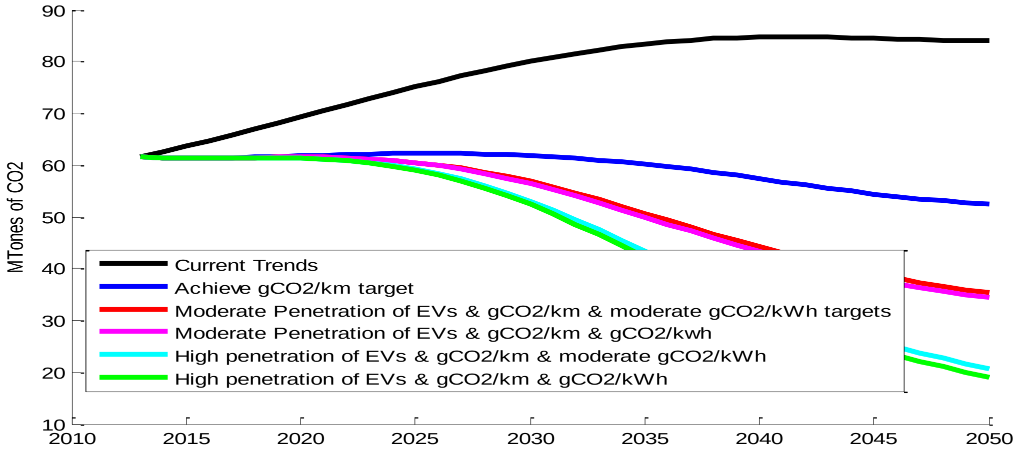

Fig 5: *CO2 emissions projections up to 2050*

2) *Carbon emissions reduction figures*

Moreover, CO2 emissions were projected to the future taking into account alternative case study scenarios where the results are illustrated in Fig 5.

In 2013, there were about 30 million cars on the roads of UK and since each car was responsible for about 2 tCO2, 60 MtCO2 were approximately emanated due car usage. If no further actions will be taken by 2050 this value will reach the level of 85

MtCO2 (black line) in the view of the fact that the number of registered cars and average mileage distance will be increased in the future. Indeed, 35.29 million cars and 40 million cars are projected to be registered on the roads of UK by 2030 and 2050 respectively according forecasts presented in Fig 6. Furthermore, the average mileage distance which is illustrated in Fig 7 has been started dropping since 2000 but according to The King Review of low-carbon cars 2007, the value of car-miles will be increased by 28% between 2003 and 2025. As a result, the average figure of car-miles is estimated to reach the level of 9,500 miles by that time, whereas afterwards, the figures will remain roughly constant because the rate people/car will be decreased in the future.

Moreover, according to European Union environmental targets, the average carbon emissions per km for all new cars by 2025 should be constrained at 95 grams; in an effort that the average CO2/km for all registered cars will have the same value by 2050 (Fig 8). This scenario is illustrated with the blue line in Fig 5 and the reader may see that the plot remains fairly constant compared with current trends.

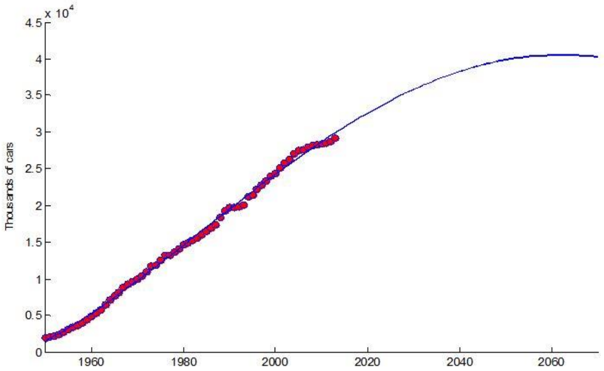

Fig 6: *Registered cars in GB 1950-2013 and forecasts 2014-2070*

Consequently, a sufficient penetration of electric cars on the roads of UK seems to be a prerequisite for decarbonising the transport sector and wireless charge-on-the-move technology can establish their preference over conventional cars. For our scenarios we distinguish a moderate and high penetration of electric cars. For the former case, electric cars will hold 60% of the new car market by 2030 and above 90% by 2050, whereas for the latter case electric cars will hold 60% of the new car market by 2050. Besides, a basic penetration of electric cars (25% of the new car market by 2050) is examined based on current figures without the contribution of wireless charge-on-the-move technology

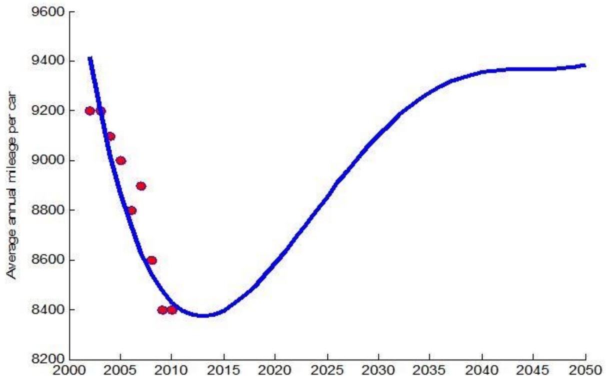

Fig 7: *Average mileage distance in GB 2000-2013 and forecasts up to 2050*

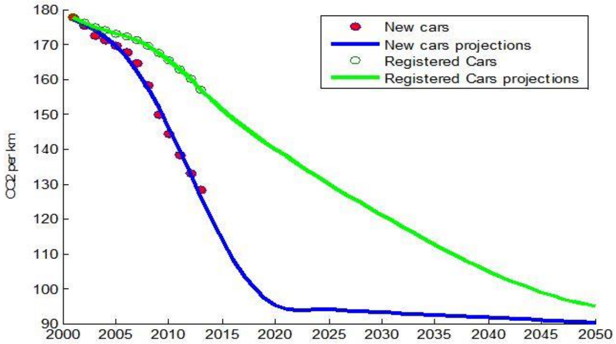

Fig 8: *CO2 per km in GB 2000-2013 and forecasts up to 2050*

Moreover, a moderate and full accomplishment of electricity supply network decarbonisation targets is distinguished. The value of carbon emission per kWh in 2013 was 470 grams and for full achievement of targets we estimate 60g CO2/kWh by 2050. This takes into consider a realistic best achievable target that would represent 33% gas; 33% nuclear; and 33% renewables. The best gas plants produce around 180 gCO2/kWh, so the national total on this basis would be around 60 gCO2/kWh. For a moderate achievement of the targets, the average carbon emissions per kWh would be higher at the level of 100 gCO2/kWh.

Even with a moderate penetration of electric cars and achievement of electricity supply targets, the trends in Fig 5 reverse their direction which implies increasing in mobility without exchanging environmental constraints. But more specifically, with a high uptake of electric cars and full achievement of electricity supply system targets, carbon transport emissions reduction for cars will reach the level of 80% in comparison with the no-actions figures.

In the end, it is worthwhile to mention that the average electricity consumption per mile of electric cars starts with 0.27 kWh in 2013 and declines gradually to the level of 0.15 kWh by 2050.

V. CONCLUSIONS - DISCUSSION

Overall, it was revealed that wireless electric charge-on-the-move technology can be a major driver towards a more sustainable transport sector in the future as a technical feasible, environmental liable and social responsible proposal. Initially, the adequate development of the existing technology at the level of individual wireless chargers makes the scalability of the expertise available at the national magnitude of UK. Wireless charge-on-the-move technology rejects the adverse attributes of electric cars and facilitates their successful penetration on the roads of the country. CO2 emissions reduction around 94% and 80% could be observed by 2050 due to single car and total car fleet usage respectively, highlighting at the same time the crucial role of wireless charge-on-the-move technology as part of the CO2 mitigation efforts. Safe, easy to use, and approachable for everyone this technology should be at the forefront of sustainability actions without undermining human well-being and implying social considerations.

In the end, everyone has to bear in mind that none technology can meet the anticipated sustainability goals of societies in isolation. Wireless charge-on-the-move technology contains a mixture of technical, social, environmental, social and economic considerations at a variety of scale levels. Dialogues and alignments between authorities are essential to be established through integrated policies and governance structures, with the aim to be appreciated and addressed more effectively. Multi-disciplinary teams have to be deployed including all the various stakeholders and make decisions through consultation negotiation and further research for a more sustainable transportation in the future.

Indeed, the expansion of expertise on the subject of wireless electric charge-on-the-move technology is imperative through additional research and investigation. The big-picture review of the proposed system based on the aspects of sustainability has revealed a great potential for the UK transport application. It is therefore expected, that this particular study will encourage academic and industrial R&D centres for pushing forward the development of technology as well as the expansion of electric cars.

Finally, a potential implementation of dynamic charging emerges a number of alternative facilities. The concepts of vehicle to grid benefits and wireless data transfer are ongoing interested topics. For the former, energy could be transferred on both directions – grid to vehicles and vehicles to grid [41]- and therefore, electric cars may stabilise the network under conditions of surplus or shortfall generation. Thereby, a passive, large, and efficient storage system should be incorporated in electricity grids, thus supporting the introduction of unstable energy power supplies –mainly renewables. Regarding data transferring, the existing infrastructure and technology may be used to establish communication links between on-motion vehicles and control centres. This knowledge comes into practise under the hot area of Autonomous Vehicles concept whose effective operation relies on reliable communication systems [42].

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