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Assessing the Business Case for Dynamic Wireless Power Transfer

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Summary

The UK has set ambitious targets to phase out all non-zero-emission HGVs by 2040. Electrifying even a proportion of the vehicle parc will lead to a significant increase in electricity demand on the distribution network. Dynamic Wireless Power Transfer (DWPT) offers the opportunity to smooth demand peaks over the whole day and lower network impacts (because charging can happen when the vehicle is in use as well as when it is parked). Minimizing vehicle downtime (from tethered conductive charging) is crucial for commercial vehicles' operating profits. But how does the economic case - the marginal cost per kWh of DWPT - compare to that of conductive charging? Six different scenarios have been modelled, of which one shows a potentially competitive business case compared to conductive charging.

Keywords: Case-study, Dynamic charging, Infrastructure, Wireless charging, Business Model

1 Introduction

With Dynamic Wireless Power Transfer (DWPT), a vehicle can charge its battery while driving along the road. Transmitter coils are placed underneath the road surface to transfer power from the grid through induction to receiver coils fitted on the undercarriage of vehicles. There are several technology providers for inductive charging, mostly for static wireless power transfer. Only a few DWPT systems have been deployed as demonstrators in projects such as the On-Line Electric Vehicle (OLEV) project buses in South Korea (2011), test tracks at universities (such as MIT and Oak Ridge National Laboratory), and projects such as FABRIC (2014-2018) with a test track of 100 meters in Satory, France. Technical feasibility has mostly been the focus of these projects. Besides research projects, commercial companies such as ElectReon have emerged, embedding

DWPT solutions into roads in cities such as Tel Aviv (Israel, 2019) and Gothenburg (Sweden, 2020) in pilot trials.

DynaCoV is a DWPT project in Coventry (United Kingdom), for which a feasibility study was conducted including the development of a business case assessment tool to model different economic scenarios. The whole infrastructure ecosystem is considered, including the vehicle retrofits/integration and the savings from the counterfactual costs of conductive charging and larger batteries.

The purpose of this business case assessment is to compare DWPT against conductive charging on a whole-of-life financial basis. Conductive charging is well understood as the 'business as usual' method used to support the electrification of vehicles. However, it has its limitations, not only in the cost of electricity network reinforcements for depots but practical limitations, such as limited space at depots for parking and plugging in vehicles or the vehicle energy requirements between depot stops leading to the need for larger, more expensive (in finance and raw material terms) batteries. The economic assessment in this article should be considered alongside different business models (who pays for what, when, and how), revenue models (how costs are recouped, from who, when, and how), and other aspects (technical, practical, legal such as the commitments to decarbonize road transport) to determine the feasibility of DWPT. This article does not specify which entities would pay for what part of the different elements of the DWPT system nor does it make recommendations for revenue models, though certain considerations and options are briefly explored in section 4.

2 Modelling methodology

A spreadsheet-based model has been developed to quantify and assess the business case of a range of DWPT rollout scenarios at the GB level. (The detail of the model is shown in Appendix 1). The key output metric of the model is the cost per kWh of energy delivered (£/kWh) by the charging system over its expected lifetime. This metric allows comparisons between DWPT and conductive charging.

The cost of purchasing the energy itself has deliberately been excluded from the calculation, to make the comparison between infrastructure options clearer. It is important to note that there could be differences in tariffs for mostly daytime charging through DWPT and overnight charging at depots. However, differences in the cost of the energy used to charge in both cases will be caused by several factors. These include when the vehicle is charging (determined by the usage pattern of the vehicle) as well as regional differences in tariffs. To complicate things further, the power price shape across the day has been evolving in recent years and will continue to change over the potential lifespan of DWPT. This is due to significant changes in the GB electricity generation portfolio. As it is so complex to calculate the different costs of electricity by the time of day for the future, and these values will likely change depending on weather conditions and generation mix, a much fairer approach is to exclude energy costs from the business case calculations.

Figure 1 shows the model inputs and how they flow through to a range of calculated values which determine the marginal cost (£/kWh).

The spreadsheet can model scenarios built from different combinations of inputs for:

- Vehicle types – Bus & Coach, HGVs, Cars & Light Commercial Vehicles (LCVs), All Vehicles;
- Road types – Urban 'A' Roads, Motorways, Trunk Roads, Urban 'A' Roads (Traffic Lights);
- Percentage of vehicles fitted with DWPT; and
- Percentage of road length installed with DWPT.

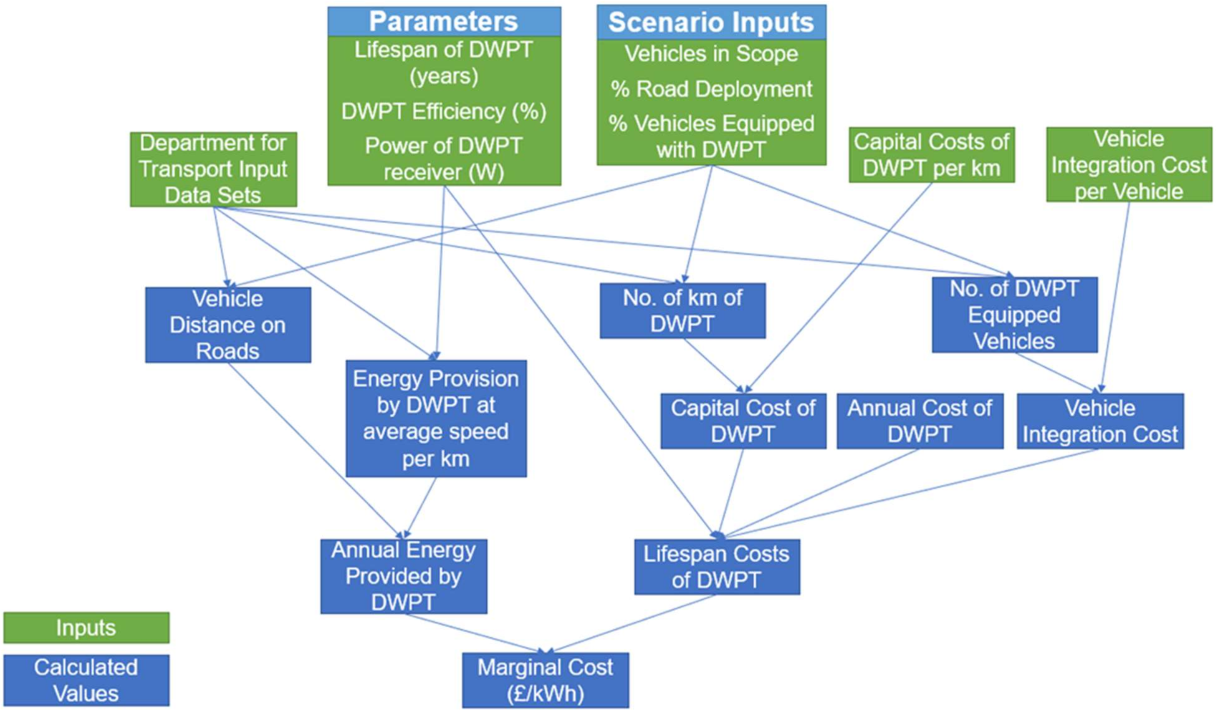

Figure 1 Business case assessment model calculation flow

2.1 Critique of methodology

The methodology applied to the problem of understanding the business case for DWPT is high level. Its strength is that easily available national data can be used to give overall indications of the properties for the different scenarios modelled. The model should give outputs that are generally true at the national level. However, the approach has inherent limitations linked to the assumptions made.

A key limitation of the model is that it cannot consider geospatial data; it assumes an even distribution of traffic along road lengths and road types. For example, the model assumes that all vehicles of a given type cover the same mileage on the road network in the scenario. In reality, this will not be the case. This generalisation will cause errors in the values of how many vehicles would be best to have DWPT capability fitted, and how much mileage on the road network these vehicles will cover.

Additionally, the model assumes an average speed is maintained by each vehicle type on each road network. This assumption makes it much easier to calculate both the energy spent by the vehicles, but also the energy delivered to them by DWPT. Fluctuations in vehicle speed are believed to be significant and will vary in both temporal and spatial dimensions.

The model accounts for a single lane installation of DWPT, which means that there is an assumption that road users with DWPT compatible vehicles will stick to this lane for the relevant stretches of road. Similarly, there is also the assumption that they will always have capacity for, and accept, the charge.

Due to the necessary assumptions made at this stage, the actual business case for DWPT will vary by location, within the explored scenarios. The modelling, however, does provide a starting point from which DWPT can be compared with other charging solutions, such as conventional conductive charging, dynamic conductive charging, or overhead catenary charging. It also gives a clear indication of which scenarios for DWPT are most promising and which are less so.

A homogenised, national modelling approach is sufficient to support decisions on the next steps for DWPT in GB, despite its weaknesses and limitations.

3 Modelling inputs and Assumptions

The green boxes in Figure 1 show the inputs to the model. These are based on data from a range of sources with differing associated confidence levels. This section explains where the numbers have come from and how or why they were chosen.

National data sources

Government national statistics are seen as a reliable source of data. Department for Transport (DfT) inputs about, for example, vehicle numbers and distanced travelled, have been taken from 2019 statistics as it is believed that pre-pandemic figures will be more representative of future travel trends. All figures not from national statistics were agreed by project partners.

Table 1 Vehicle numbers and distances travelled from national statistics

		Bus & Coach	HGVs	Cars & LCVs
	Vehicle numbers	*152,000*	*501,500*	*36,011,700*
Distance	Urban 'A' Roads	1,000	2,400	75,000
travelled	Motorways	300	12,900	99,900
(million km)	Trunk Roads	600	19,100	167,300

It is worth noting that the values in Table 1 are then adjusted by the inputs to the Scenarios:

- **percentage of in scope vehicles equipped with DWPT:**
    - reduces the annual vehicle distance, and its impact on total energy provided by DWPT; and
    - impacts the number of vehicles, feeding through to the vehicle integration costs
- **percentage of registered in scope vehicles that use in scope road network:**
    - reduces the number of vehicle with DWPT, without reducing the total mileage (thus increasing the miles per vehicle).

Modelled assumptions

It is harder to find definitive figures for parameters such as the ‘energy consumption / km’ for electric vehicles. These parameters are very variable (for example with temperature) and small changes in the ‘energy consumption / km’ figure have a significant impact when multiplied by the billions of kms travelled by the vehicles each year. The figures used come from Ricardo’s post processing of VECTO **[1]** simulations. VECTO has a city bus and a coach cycle, as well as different HGV cycles (for 12 tonne rigid and 40 tonne articulated trucks) and LCV cycles. These numbers correlate with the numbers the ViriCiti report on e-bus performance **[2]**. The energy consumption figures for cars come from an online database **[3]**.

Table 2 Energy consumption by vehicle road type

	Energy Consumption for Typical Driving Cycles (kWh per km)		
	Bus & Coach	HGVs	Cars & LCVs
Urban 'A' Roads	1.3	1.28	0.15
Motorways	1.55	1.32	0.31
Trunk Roads	1.12	1.32	0.31

The difference in the energy consumption for the Bus & Coach category between motorways and trunk roads (in Table 2) is due to the fact that the motorway energy consumption is mostly from a coach population whereas a mix of buses and coaches use trunk roads. Coaches have different loading profiles to buses.

Baseline parameters

The baseline parameters were selected as shown in Table 3. DWPT has not been around for very long, therefore there is not much data from in-service systems and the technology is evolving quickly.

Table 3 Parameter assumptions and comments

Parameter	Value	Comments
Lifespan	10 years	Though the technology could last 15-20 years, 10 years is taken as a conservative figure. This allows for other reasons why the technology may not be operational for its full lifespan including, for example, road works and significant technology advances.
Efficiency	75%	Based on the literature review (undertaken during the DynaCoV projects) results for whole system efficiency from a range of global pilots and trials.
Power per receiver	30 kW	This is the planned power per ElectReon receiver in 2022.

Cost assumptions

Cost inputs have been taken from quotes gained through and for the DynaCoV project (see). To assess the feasibility of DWPT in the long-term it is important to use aspirational figures for the costs that relate to what could be achieved beyond a demonstrator phase and once some economies of scale are achieved (see 'Aspirational' figures in). The aspirational costs have been used in the modelling.

It is believed that there will be no cost saving from quoted figures in the long-term in civil works required for DWPT installations. However, the quoted figure for the demonstrator site is for an 'A' road; to calculate a figure for a motorway installation the traffic management cost element (the largest component of the cost) was multiplied by three.

Table 4 Infrastructure capital costs of DWPT/km

	Quoted	Aspirational
Civil, works and installation	£ 872,410	£ 872,410
Civil, works and installation (motorways)	n/a	*(£ 1,081,000)*
Hardware	£ 1,462,500	£ 600,000
DNO Connection	£ 415,000	£ 415,000
Software	£ 300,000	£ 0.00
TOTAL CAPITAL COSTS	**£ 3,049,910**	**£ 1,887,410**
Operational Costs (per annum per km)	Quoted	Aspirational
Maintenance inc. Software	£ 90,000	£16,500
TOTAL OPERATING COSTS	**£ 90,000**	**£16,500**

To assess the feasibility of the technology as a whole, the model and analysis covers all DWPT costs including vehicle integration and battery cost. A DWPT system is not complete without DWPT-compatible vehicles. These costs are shown in Table 5 and include the receiver ($1,200 each), the materials and manufacture for all fixings ($750) and installation ($2,000-10,000 depending on vehicle size and number of receivers). The five-year average exchange rate from ONS of 1USD = 0.754GBP [4] is used to convert the costs. The aspirational figures (for which the aforementioned breakdown is given) are based on conversations between ElectReon and a number of automotive manufacturers considering at-scale production. The quoted figure includes all the design costs associated with a first-time integration with a new vehicle as well as bespoke manufacture of parts for two demonstrator vehicles.

Table 5 Vehicle integration capital costs of DWPT/km

Vehicle Integration Capital Cost (per km)	Quoted	Aspirational
Bus & Coach	£ 66,722	£ 7,804
HGV	£ 75,482	£ 10,820
Cars and LCVs	£ 62,342	£ 4,788

Cost savings

When calculating the cost of a DWPT solution, there are potential benefits that should be considered. The first of these is cost savings associated with a reduced battery size on the vehicles. In the absence of any other data, the model optimistically assumes that the total of the daily energy provided by the DWPT system to a single vehicle, results in a direct reduction in battery size of the same amount. This is based on the assumptions that each vehicle will cover the same route every day. A battery cost of £104/kWh [5] has been assumed.

The second benefit is that of a reduction in the requirement for conductive charging. This will differ significantly on a case-by-case basis; this model considers it in general terms only, which is reasonable given the national scale of the scenarios. Again, the daily energy provided by the DWPT system to a single vehicle has been used, but this time combined with assumptions on the number of hours a day the vehicle is available to be charged with conductive Electric Vehicle Supply Equipment (EVSE). These are used to calculate a power reduction of conductive EVSE that could be possible, which is then valued at the lifespan cost of the conductive charging solution on a per kW basis. So, the analysis includes a saving in the DWPT case of reduced total cost of conductive charging infrastructure (compared with the counter factual case of no DWPT).

Uptake scenarios

Scenarios were created to assess different use cases of DWPT within the model. In each scenario (Table 6) both the types of road and types of vehicles in scope are given. The percentage of the road networks with DWPT have been set optimistically, and to give a range of results. The upper uptake scenario for DWPT compatible vehicles varies by vehicle type because of the differences in the number of operators and vehicles within that vehicle type. For buses/coaches the aspirational uptake is modelled as 70% because there are fewer operators and vehicles these vehicles should be relatively easier to transition. The reason it is not 100% is because these fleets contain vehicles of different ages and some harder to electrify routes, as well as other competing low carbon technologies. For HGVs or cars, the maximum percentage of DWPT compatible vehicles was deemed to be 50% because of the fact there are so many more of them and many more operators/owners.

Table 6 Scenario definitions

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Road Network in Scope	Urban 'A' Roads	Urban 'A' Roads (Traffic Lights)	Urban 'A' Roads	Trunk Roads	Trunk Roads	Motorways
Percentage of Road Network with DWPT	90%	5.5%	50%	90%	90%	50%
Vehicles in Scope	Bus & Coach	Bus & Coach	All Vehicles	HGVs	All Vehicles	HGVs

Note that Scenario 2 represents DWPT being installed on Urban ‘A’ roads, but only on the approach (50 m) to traffic lights (assumed to be 5.5% of road length). This results in lower average speeds for vehicles over the DWPT strips, and relatively more energy being delivered.

The model is based on a range of national, modelled and partner-agreed assumptions. Based on these assumptions, all scenarios except 2 and 6 are to provide all the energy the vehicles require for driving on the road network in scope for the scenario. Scenario 2 provides around 34% and Scenario 6, 62% of required driving energy.

4 Results

Figure 2 shows the key results of the modelling across the six scenarios. It is clear that, between scenarios, the split of lifespan DWPT costs and vehicle integration costs vary significantly.

While the total lifespan DWPT cost (over 10 years) includes the total annual operating costs of £16,500 per km (see), the bulk of this cost comes from the capital costs derived from the aspirational figures ( ).

Cost savings associated with a reduction in conductive charger capacity requirements and reductions in battery costs are shown below the axis.

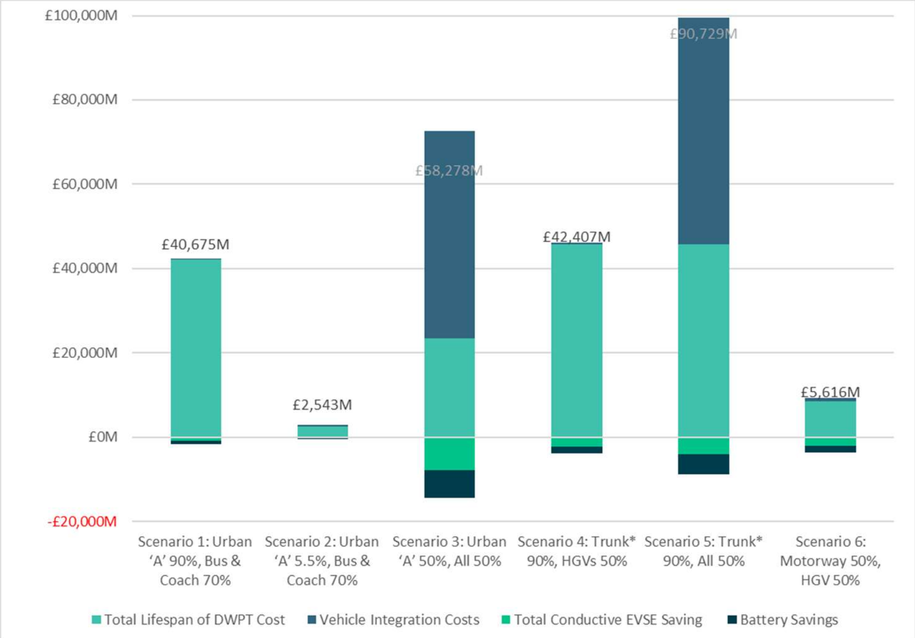

Figure 2 Modelling Results Costs Summary. (*Trunk roads form part of the Strategic Road Network *[6]* and are maintained by National Highways.)

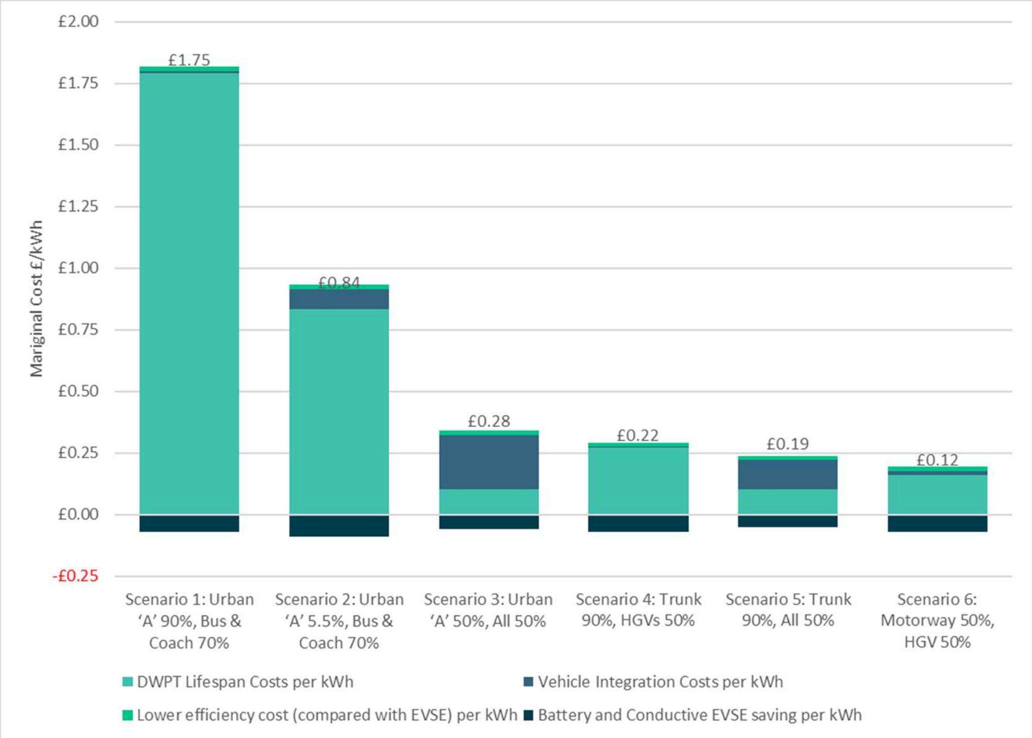

Figure 3 Modelling results marginal costs per kWh

Figure 3 shows the costs for each scenario expressed on a marginal kWh basis. In other words, the value when the total cost is spread out evenly across all energy delivered to vehicles over the lifespan of the infrastructure. On this basis, scenario 6 is the best value at around 12p/kWh. The high energy demand from the HGV fleet over a relatively short road network contributes to this value. The most expensive scenario is scenario 1, with a cost around fourteen times higher represents the opposite case of a long road network with relatively low vehicle mileage.

It is also worth noting that the lowest DWPT lifespan cost is in scenarios 3 and 5. In these scenarios, the high utilisation of the DWPT infrastructure (from having all vehicle types covered) reduces the marginal cost. The vehicle integration cost appears cheapest in scenarios 1 and 4. These more targeted scenarios maximise the energy charged on a per vehicle basis.

These costs can be compared with the costs of facilitating the electrification of vehicles through conductive chargepoints. The figures in Table 7 have been calculated using the Cenex internal chargepoint deployment investment model. The DNO costs cover connection costs calculated from an assumed DNO cost of £566/kW.

Table 7 Marginal costs per kWh of conductive chargers.

	Conductive Charge Type	
	Rapid	Ultra-Rapid
Power (kW)	50	150
Apportioned DNO Costs	£28,301.89	£84,905.66
Lifetime Costs	£31,564	£61,819
Marginal cost per kWh	£0.07	£0.11

The marginal costs/kWh are a good metric to easily compare different charging technologies. From the conductive charging marginal costs, it would seem sensible for DWPT to be aiming for a marginal cost of in the region of £0.11/kWh. And on this basis, only Scenario 6 is close to this target. However, these figures do not capture the value of being able to charge on-the-go with DWPT, versus needing the vehicle to be out of use for conductive charging. This DWPT benefit is difficult to quantify as this can alter the revenue earning potential of a vehicle particularly where there are fewer directives on working hours and breaks (as with smaller vehicles). There may also be practical reasons why a fleet may not all be able to be charged at the depot such as space limitation.

It should be noted that these marginal costs for conductive charging are calculated over the lifespan of the charging asset with a realistic gradual increase of chargepoint utilisation over time. The DWPT model takes a more optimistic approach, with the DWPT infrastructure being fully utilised from day one.

4.1 Business case for electricity networks

In general, there is the potential for total connection cost savings associated with a DWPT roll-out, as the demand is distributed more evenly around the distribution network area, resulting in reduced connection capacity requirements at charging depots. However, quantifying this potential saving has not been within the scope of this early feasibility study. The 'Total Conductive EVSE Savings' in Figure 3 gives an indication of the possible connection cost savings across GB networks for the different scenarios. This component includes hardware cost savings, so only a proportion would be attributable to connection cost savings.

The peak demand figures in

Table 8 are based on scaling up traffic flows. It is extremely difficult to compare the peak from a given DWPT scenario to a peak demand from an equivalent conductive charging scenario (as it is hard to define the equivalent conductive charging scenario without knowing where the vehicles would charge and how many would charge at the same/similar location and time). However,

Table 8 is useful for comparing the peak demand from different DWPT scenarios against each other. The 'per km' figure could be used to estimate connection sizing along the related road types.

Table 8 Peak demand figures by scenario

	Urban 'A' 90% Bus & Coach 70%	Urban 'A' 5% Bus & Coach 70%	Urban 'A' 50% All 50%	Trunk Roads 90% HGVs 50%	Trunk Road 90% All vehicles 50%	Motorway 50% HGV 50%
Peak network demand (kW)	802,404	105,077	7,604,241	5,508,678	15,112,992	1,726,892
Peak demand per km (kW)	39	84	668	247	677	462

For the case study site, it is known that a 4000 kVA connection at the National Express Bus Depot would involve a connection cost of £1m (including a 2 MW battery) whereas a 6000 kVA connection would cost £5m.

More specific impacts on DNO connection costs could be the subject of further projects.

4.2 Business case for users

The best use case for DWPT is for the largest, heaviest vehicles, travelling the longest distances and with the highest utilisation. For these vehicles, having DWPT installed along the route can mean:

- they can travel further without needing to stop and plug-in;
- depot charging needs can be met with a smaller capacity connection;
- reductions in the battery size and weight, meaning they can transport greater payloads in less time and fewer journeys.

In order to access these benefits, fleet operators will have to bear two costs:

- the capital costs for the vehicle integration; these are expected to be passed through to the consumers via the vehicle OEMs, who are likely to also add a margin to the costs; and
- the charging costs, which will likely be higher than other forms of charging.

The 'per vehicle' costs include the OEM design and bracket manufacture costs and installation costs and receiver costs (ElectReon aspires to a receiver cost of £1000, a fifth of the current cost for a receiver). This analysis shows that if HGVs were equipped with DWPT and able to access it along half of the GB's motorways (Scenario 6), then the marginal cost of charging would be roughly equivalent to the cost of ultra-rapid charging. It is possible that there could be subsidies to support the uptake of DWPT compatible vehicles or that grants and subsidies supporting the decarbonisation of transport are used to enable this scenario.

4.3 Business case for Department for Transport

If National Highways were to upgrade their road networks with DWPT this would provide justification to introduce tolls for these roads. An option to incentivise the switch to DWPT compatible EVs would be to have a tariff applied to all road users for the sections that contain DWPT, much like a toll road. This would encourage the uptake of DWPT compatible vehicles and the use of DWPT (even when a DWPT compatible vehicle passes over a DWPT road section the driver may choose not to accept and pay for the power transfer if they believe they can get cheaper charging elsewhere on their route). This revenue model would help to recover the costs of the system quicker (as well as covering the losses from the decrease in petrol and diesel tax revenues), allowing wider rollout and further enhancing the DWPT preposition. It is important, however, to think about the fairness of this type of fee model, particularly on roads that are the only or main routes between locations and for users who may use those roads most frequently and may not be able afford DWPT retrofits or DWPT compatible vehicles.

Once the DWPT system is installed and in use there are some potential secondary benefits from the data and IT systems which are a key part of the technology. The energy use data gathered during operation could have other revenue potential. Insights from the data could help to optimise the road and electricity networks. The data and IT connectivity offered by the DWPT system could also support the rollout of Connected Autonomous Vehicles which can have many benefits, in for example reducing accidents and congestion.

Should funding for the upfront capital costs be unavailable an alternative option is to procure the technology with private sector investment. ElectReon are starting to offer a fully funded model known as 'Charging-as-a-Service' (CaaS). The pricing is highly dependent on the geography and local market at the installation site.

5 Conclusion

From the scenarios explored in the modelling, only one comes close to cost parity with conductive charging on a marginal cost basis, which is scenario 6 – HGVs on the motorway network. This scenario (HGVs on the motorway network) assumes that the compatible HGVs drive 85,775 km a year on DWPT equipped roads (in this scenario motorways) compared to an average annual mileage of 100,000km [7]. In this scenario the energy provided to the HGVs is just under one third of what they require to perform their journeys on the motorway network. This illustrates that conductive charging would not be replaced, but significant savings in battery sizes on HGVs could be made. Being the most economic scenario, this is recommended for further investigation.

Applying DWPT for buses and coaches on urban 'A' roads is the least economic scenario. To attain a marginal cost of DPWT that is competitive with conductive charging for this scenario would require the DWPT capital costs to be reduced to unrealistically low levels. Being more specific on the location of DWPT is recommended, as seen in Scenario 2, where DWPT is installed only on the approach to traffic lights, resulting in approximately half the marginal cost. Given the nature and assumptions of the modelling undertaken, the possibility of targeted demonstrators for buses or coaches where the specific locations and lengths of DWPT are optimised is not being ruled out. However, from this analysis this use case is unlikely to scale well.

The modelling performed has been high level and has limitations. A more nuanced geospatial analysis is needed to provide more accurate indications of the business case for specific locations. By including data on actual vehicle movements, a clearer picture could be drawn, which could provide better information on either specific sites, or the types of sites and use cases that would be best suited for DWPT.

Even with the aspirational cost used in the scenarios modelled, the final marginal costs of energy delivered are significantly higher than conductive charging in all but one of the six core scenarios. This means that for most cases the cost of implementing the technology needs to fall even further.

Acknowledgments

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Authors

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Since 2018, Greg has been the Modelling and Simulation Lead within Cenex. He led Cenex's contribution to the Sciurus project, the world's largest domestic V2G trial, providing evidenced based modelling on V2G economics. He also designed and led development of Cenex's in house chargepoint forecasting and deployment model.

Jorden van der Hoogt is a mechanical engineer with a master's in Science, Business and Innovation: energy and sustainability track. Since 2019 he is active at Cenex Nederland, working on mobility-related projects such as SEEV4-City, CleanMobilEnergy, DynaCoV and SESA that involve innovations in energy infrastructure for charging electric vehicles such as smart charging, vehicle-to-grid and wireless charging.

Appendix

Appendix 1

The tables below show the full set up assumptions and the details behind the modelled scenarios and the results.

Power of Wireless Receiver (kW)	30	km/mile	1.609

Cost Types
Quoted
Aspirational
Aspirational (Motorway)

Vehicle Types	No of DWPT Receivers	Total Receiver Power (kW)
Bus & Coach	3	90
HGVs	5	150
Cars and LCVs	1	30
All Vehicles		All means all of the above

Road Networks	km of road in GB		
Urban 'A' Roads	11,384		
Motorways	3,742		
Trunk Roads	12,394		
Urban 'A' Roads (Traffic Lights)	11,384	5.5%	DWPT Road Deployment for traffic lights

Energy Used	Billion Vehicle km travelled per year				Average Speed (mph)			Energy consumption per km for Typical Driving Cycles (kWh)			Annual Energy Consumption (GWh)			
	Bus & Coach	HGVs	Cars and LCVs	All Vehicles	Bus & Coach	HGVs	Cars and LCVs	Bus & Coach	HGVs	Cars and LCVs	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
Urban 'A' Roads	1	2.4	75	78.4	15	18.8	18.8	1.3	1.28	0.15	1,300	3,072	11,250	15,622
Motorways	0.3	12.9	99.9	113.1	58	57	68	1.55	1.32	0.31	465	17,028	30,969	48,462
Trunk Roads	0.6	19.1	167.3	187	50	48	50	1.12	1.32	0.31	672	25,212	51,863	77,747
Urban 'A' Roads (Traffic Lights)	1	2.4	75	78.4	7	7	7	1.3	1.28	0.15	1,300	3,072	11,250	15,622

Energy Provided	Energy Provision by DWPT at average speed over 1km			
	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
Urban 'A' Roads	3.73	4.96	0.99	1.15
Motorways	0.96	1.64	0.27	0.43
Trunk Roads	1.12	1.96	0.37	0.54
Urban 'A' Roads (Traffic Lights)	7.99	13.32	2.66	3.06

Both directions?

Max Power	Hourly Traffic Flow			Max Hourly Flow in Week			No. of Vehicles per 1km of road			Max Vehicle Power Demand in Week (kW) per km			
	Bus & Coach	HGVs	Cars and LCVs	Bus & Coach	HGVs	Cars and LCVs	Bus & Coach	HGVs	Cars and LCVs	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
Urban 'A' Roads	10	24	752	23	52	1,677	0.932337	1.711335	55.44335	83.910296	256.7002	1663.3	2003.911
Motorways	9	394	3,048	21	847	6,797	0.220077	9.230273	62.11847	19.806964	1384.541	1863.554	3267.902
Trunk Roads	6	176	1,541	12	378	3,436	0.154869	4.938441	42.58596	13.938225	740.7662	1277.579	2032.283
Urban 'A' Roads (Traffic Lights)	10	24	752	23	52	1,677	1.997864	4.596156	148.905	179.80778	689.4234	4467.15	5336.381

Capital Cost of DWPT (per km)	Quoted	Aspirational	Aspirational (Motorway)		
Civil, works and installation	£ 872,410	£ 872,410	£ 1,081,089		
Hardware	£ 1,462,500	£ 600,000	£ 600,000		
DNO Connection	£ 415,000	£ 415,000	£ 415,000		
Software	£ 300,000			Assumed Capacity (kW):	
Total Capital Costs	£ 3,049,910	£ 1,887,410	£ 2,096,089		800

Operating Cost (per annum per km)	Quoted	Aspirational	Aspirational (Motorway)
Land Rental Cost			
Annual Maintenance Cost of DWPT (	£ 74,000	£ 16,500	£ 16,500
Total Annual Costs	£ 74,000	£ 16,500	£ 16,500

Vehicle Integration Costs	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
Quoted	£ 66,722	£ 75,482	£ 62,342	£ 62,539.88
Aspirational	£ 7,804	£ 10,820	£ 4,788	£ 4,882.91
Aspirational (Motorway)	£ 7,804	£ 10,820	£ 4,788	£ 4,883
	40880	49640	36500	

No. of Vehicles Licenced in UK				
	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
2019	152,000	501,500	36,011,700	36,665,200
	25,658	4,786	12,413	
	70.29560202	13.11135088	34.0072125	11,400,000

KVA	DNO Connection Cost
6000	£ 5,000,000
4000	£ 1,000,000
1500	£ 100,000
600	£ 100,000
300	£ 75,000

Public Conductive Charging Costs

Charger Type	Power (kW)	Apportioned DNO Costs	Lifetime Costs	Marginal cost per kWh	Cost Per kW
Slow	7	£ 3,962.26	£ 17,192	-£ 0.11	£ 3,021.98
Standard	14	£ 7,924.53	£ 17,192	-£ 0.07	£ 1,794.01
Fast	44	£ 24,905.66	£ 15,916	-£ 0.07	£ 927.77
Rapid	50	£ 28,301.89	£ 31,564	-£ 0.07	£ 1,197.31
Ultra-Rapid	150	£ 84,905.66	£ 61,819	-£ 0.11	£ 978.16
	265	150000			

For Conductive EVSE	Bus & Coach	HGVs	Cars and LCVs	All Vehicles
Max Daily Energy used (kWh)	131	500	38	
Available charging hours/day	8	12	14	13.95
Required chargepoint power (kW)	16	42	2.7	
Required EVSE	Fast		Standard	

Vehicle Battery Cost £ per kWh	103.66

Lifespan of DWPT (years)	10					
DWPT Efficiency	75%					
Road Network Covered	Urban 'A' Roads	Urban 'A' Roads (Traffic Lig	Urban 'A' Roads	Trunk Roads	Trunk Roads	Motorways
Vehicles in Scope	Bus & Coach	Bus & Coach	All Vehicles	HGVs	All Vehicles	HGVs
DWPT road Deployment	90.0%	5.5%	50.0%	90.0%	90.0%	50.0%
Percentage of in Scope Vehicles DWPT equipped	70%	70%	50%	50%	50%	50%
Cost Types	Aspirational	Aspirational	Aspirational	Aspirational	Aspirational	Aspirational (Motorway)
% of Registered in Scope Vehicles that use In Scope Road Network	30%	30%	55%	15%	60%	30%
	21.00%	21.00%	27.50%	7.50%	30.00%	15.00%
Row Ref	1	4	1	3	3	2
Col Ref	1	1	4	2	4	2
Scenario Information						
Road length in scope (km)	11,384	11,384	11,384	12,394	12,394	3,742
No. of km covered with DWPT	20,491	1,252	11,384	22,309	22,309	3,742
No. of vehicles with DWPT	31,920	31,920	10,082,930	37,613	10,999,560	75,225
Annual Vehicle distance of DWPT equipped vehicles on in scope roads (Mkm)	700	700	39,200	9,550	93,500	6,450
Average daily distance travelled on in scope roads per vehicle (km)	60	60	11	696	23	235
Annual Energy						
Energy spent by vehicles on roads in scope (GWh)	1,300	1,300	15,622	25,212	77,747	17,028
Energy provided by DWPT (GWh)	2,349	308	22,503	16,826	45,120	5,275
Energy demand on the grid (GWh)	3,132	410	30,004	22,434	60,160	7,033
Peak Network Demand (kW)	802,404	105,077	7,604,241	5,508,678	15,112,992	1,726,892
Peak demand per km	39	84	668	247	677	462
Costs						
Capital Cost of DWPT:						
Civil, works and installation	£ 17,876,884,826	£ 1,092,476,295	£ 9,931,602,681	£ 19,462,926,206	£ 19,462,926,206	£ 4,045,217,885
Hardware	£ 12,294,828,000	£ 751,350,600	£ 6,830,460,000	£ 13,385,628,000	£ 13,385,628,000	£ 2,245,080,000
DNO Connection	£ 8,503,922,700	£ 519,684,165	£ 4,724,401,500	£ 9,258,392,700	£ 9,258,392,700	£ 1,552,847,000
Additional DNO Connection Costs	£ -	£ -	£ -	£ -	£ -	£ -
Total Capital Costs	£ 38,675,635,526	£ 2,363,511,060	£ 21,486,464,181	£ 42,106,946,906	£ 42,106,946,906	£ 7,843,144,885
Annual Costs:						
Land Rental Cost	£ -	£ -	£ -	£ -	£ -	£ -
Annual Maintenance Cost of DWPT (inc. software)	£ 338,107,770	£ 20,662,142	£ 187,837,650	£ 368,104,770	£ 368,104,770	£ 61,739,700
Total Annual Costs	£ 338,107,770	£ 20,662,142	£ 187,837,650	£ 368,104,770	£ 368,104,770	£ 61,739,700
Vehicle Integration Costs	£ 249,100,488	£ 249,100,488	£ 49,234,017,547	£ 406,963,489	£ 53,709,837,324	£ 813,926,978
Total Lifespan Costs of DWPT	£ 42,305,813,714	£ 2,819,232,963	£ 72,598,858,228	£ 46,194,958,095	£ 99,497,831,930	£ 9,274,468,862
DWPT Cost per kWh delivered	£ 1.80	£ 0.92	£ 0.32	£ 0.27	£ 0.22	£ 0.18
Costs Offset						
Conductive charging reduction:						
Daily per Vehicle Energy from DWPT (kWh)	201.64	26.41	6.11	1,225.60	11.24	192.10
Power reduction of conductive EVSE (kW)	25.21	3.30	0.44	102.13	0.81	16.01
Type of EVSE hardware avoided?	Rapid	Standard	Standard	Standard	Rapid	Standard
Saving per Vehicle	£ 30,178	£ 5,921	£ 786	£ 183,227	£ 965	£ 28,720
Total Conductive EVSE Cost Saving	£ 963,294,847	£ 189,012,601	£ 7,929,917,173	£ 6,891,642,158	£ 10,611,496,457	£ 2,160,431,114
Reduction in vehicle battery size:						
Battery cost savings	£ 667,197,017	£ 87,371,038	£ 6,390,873,147	£ 4,778,490,359	£ 12,814,046,699	£ 1,497,988,290
DWPT Cost (inc. cost offset) per kWh delivered	£ 1.73	£ 0.83	£ 0.26	£ 0.21	£ 0.17	£ 0.11
Currently assumes a full roll out on day one and a constant uptake of infrastructure.						
For reference, the cost per kWh delivered for a Rapid Charger is around £0.07						
	£ 38,700,000,000	£ 2,360,000,000	£ 21,500,000,000	£ 42,100,000,000	£ 42,100,000,000	£ 7,840,000,000
DWPT per kWh (rounded lifespan cost)	£ 1.65	£ 0.77	£ 0.10	£ 0.25	£ 0.09	£ 0.15
		Assumed power price (£/kWh)	£ 0.10			
			Cost of losses			
DWPT	75%	1.333333333	0.033333333			
Conductive Charging	87%	1.149425287	0.014942529			
		Marginal price uplift (conductive to DWPT) £/kWh	£ 0.018			
Additional Calcs						
Total Lifespan Energy Delivered (kWh)	23,492,852,704	3,076,444,997	225,030,744,615	168,256,702,770	451,198,827,430	52,746,066,534
DWPT Lifespan Costs per kWh	£ 1.79	£ 0.84	£ 0.10	£ 0.27	£ 0.10	£ 0.16
Vehicle Integration Costs per kWh	£ 0.01	£ 0.08	£ 0.22	£ 0.00	£ 0.12	£ 0.02
Lower efficiency cost (compared with EVSE) per kWh	£ 0.02	£ 0.02	£ 0.02	£ 0.02	£ 0.02	£ 0.02
Battery and Conductive EVSE saving per kWh	£ 0.07	£ 0.09	£ 0.06	£ 0.07	£ 0.05	£ 0.07
Final DWPT cost per kWh delivered	**£ 1.75**	**£ 0.84**	**£ 0.28**	**£ 0.22**	**£ 0.19**	**£ 0.12**
Total Lifespan Energy Delivered (TWh)	23.5	3.1	225.0	168.3	451.2	52.7