ECONOMIC ANALYSIS OF DYNAMIC INDUCTIVE POWER TRANSFER ROADWAY CHARGING SYSTEM UNDER PUBLIC-PRIVATE PARTNERSHIP – EVIDENCE FROM NEW ZEALAND

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Overview

Electric vehicles (EVs) are a substitute for replacing conventional Internal Combustion Engines (ICEs) and thereby decarbonising the transport sector. With recent technological advancements in Dynamic Inductive Power Transfer (DIPT) system, EVs can be energised wirelessly by embedding a roadway charging network while travelling in-motion. However, the provision of a viable DIPT system still remains challenging, given the large-scaled investment required and some potential risks involved. This study assesses the economic viability of a DIPT system for EVs through public–private partnership (PPP), by employing a simulation model under the net present value (NPV) framework, to determine the optimal PPP ratio. The PPP model could be considered an effective pathway for leveraging capital, and alleviating uncertainties associated with construction and operation. New Zealand is used as a real-world case study. Our results indicate that, for a 15-year concession period under PPP where the private investor is expecting a 12.5% return, the government can contribute 9.46% towards the initial investment and charging roadway users a toll of 37 cents/kWh. By implementing DIPT system, EVs could also achieve a significant reduction in carbon dioxide (CO_2) emissions compared to ICEs. The robustness of the model is validated through Monto Carlo sensitivity analysis.

Methods

In order to provide a holistic picture of economics of the transport infrastructure, we follow a simulation model proposed by Chen, Liu and Yin (2017). The modelling assumptions are listed below:

- We consider a traffic corridor of a specified length of l *(km)* equipped with IPT system to charge the EVs travelling over it.
- The DIPT roadway infrastructure is assumed to have a power of P *(kW)* for charging the EVs with a recharging efficiency (ε).
- The total number of EVs using the lane is given by f as calculated in the previous section.
- The EV is considered to have a battery capacity of E *(kWh)* with an efficiency of η. The EV is assumed to be travelling at a constant speed of v *(kmph)* all along the corridor.
- The facilities are provided in such a way that no vehicle can finish the trip without recharging and the charging provided is just sufficient to complete the trip. As it is well known that 'range anxiety factor' is one of the leading barriers to the adaptation of EV (Rauh, Franke and Krems, 2015), the EV drivers are assumed to have a range anxiety factor of (1-x). Therefore, the driver can be assured with a confidence level x.

It is important to note that the model does not attempt to provide the optimal location of the charging facility. Rather, the model only calculates the length of the transmitter required for a vehicle to finish the trip. Hence, the total charge required to complete the trip is $\frac{l}{\eta}$ and the range anxiety factor is $\frac{l}{\eta} - xE$.

The cost components involved in the infrastructure are as follows:

- Construction cost per unit length of energizing section is given by C_d (*\$/km*).
- Cost of unit charger power C_p (*\$/kW*) which is a function number of inverters.
- The unit cost of charging the EV is given by C_e *(\$/kWh*).

Note that the number of transmitters is irrelevant to the total cost as all the cost units are converted to per unit length and only the length of the total transmitter segment is considered. The revenue from the system is generated by collecting toll fee for using the charging system. Net present value from the infrastructure is given by:

$$NPV = \sum_{n=1}^{T_c} \frac{Revenue - Cost}{(1+i)^n} \qquad (1)$$

where T_C is the concession period.

In order to find the optimal initial investment ratio between the public and private sectors, we adopt a simple model developed by Peng *at el*. (2014). The government investment is I_G and private investment is $I_P=I-I_G$, I being the total investment cost. Let k be the government investment ratio (i.e.) $I_G=kI$. A private enterprise expecting a rate of return of r will only consider investing in the project if and only if:

$$NPV_p \geq rI \qquad (2)$$

Hence the opportunity profit for the private investor $\bar{R}^3$ must be $\bar{R} = rI$ below which the private investor will not consider it a profitable investment opportunity.

Results

For a concession period of 15 years, as per the risk borne by the private and public sector, the minimum expected return on investment for the private enterprise is $52,532,457. The optimal investment ratio would be government contributing 9.46% towards the initial investment. This provides the maximum benefit for both private sector in achieving the return on investment and the government's target of delivering services for a minimum cost. A toll fee of $0.37 is charged for the private industry to gain a return on investment within the concession period. Moreover, for providing a safe investment opportunity, the government can offer security for 5% volatility in the uptake level of EVs. As such, for the whole concession period of 15 years, the government will need to provide the private investor a guarantee for a total of $93,792,488, against any unforeseen volatility.The environmental impact of a pure EV is compared with plug-in hybrids and traditional ICEs. Pollutants such as CO, NO_X and volatile organic compounds are compared to show emission savings by switching to pure electrics. According to the results, for a period of 30 years, pure EVs can reduce CO_2 emissions by 54.27% when compared to petrol vehicles, and 52.33% when compared to diesel engines. A Monto Carlo sensitivity analysis is performed for 100 runs on vehicle uptake model, by considering a volatility of ±5% variation in the uptake level and its effect on the net cash flow and a government guarantee for the private investment. According to the Monte Carlo analysis, the average value of the net cash flow at the end of 15 years is higher than the expected rate of return for the private industry. We can conclude that the dynamic charging infrastructure of EVs using DIPT technology is a better investment opportunity with high reliability.

Conclusions

This paper is the first to assess a charging infrastructure based on DIPT system by developing an economic model under a PPP consortium. Our results show that PPP is a viable mechanism for the public sector to attract private capital in the delivery of this novel transport infrastructure service. PPP benefits both the government and the private enterprise with the latter enjoying a 15-year concession period, plus guarantees for the return on investment. Although the initial investment for infrastructure is relatively large, payback can be achieved in a short timeframe for a given toll charge. Moreover, with the rapid development in charging technologies, the cost involved in developing this infrastructure is expected to fall. It is also important to note that by providing the correct incentives, the private sector will take the risk to invest and innovate, which will promote sustainable transportation development. Risk can be effectively managed though shared resources and investment. With the rapid uptake of EVs in mainstream transportation systems, DIPT technology can provide ease of access to charging facilities for consumers and tackle the problem of range anxiety. It can have a significant impact on long-distance travel which has been proved difficult to address.

References

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