# Reducing Carbon Emissions by Introducing Electric Vehicle Enhanced Dedicated Bus Lanes

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***Abstract— Most cities now have special lanes dedicated to buses, however these lanes are rarely used at full capacity. At the same time governments around the world are encouraging people to buy electric vehicles. This paper proposes the creation of electric vehicle enhanced dedicated bus lanes (E-DBL), by allowing electric vehicles access to bus lanes, in order to improve the use of road capacity. By opening bus lanes to electric vehicles, traffic congestion could be eased, the range of electric vehicles could be extended, and the travel times for electric vehicle owners could be reduced significantly. The paper shows how by introducing E-DBLs, the bus journey times are not significantly affected given the current uptake of electric vehicles in most developed countries.***

***This paper presents extensive simulations based on traffic situation in the city of Dublin with regard to the effect of opening up bus lanes to electric vehicles. The results show that even with very high percentages of electric vehicles the bus journey times are not noticeably affected. Opening up bus lanes to electric vehicles can even be beneficial for other road users by reducing congestion on regular lanes, which would further reduce carbon emissions.***

***Keywords—Electric Vehicles, Dedicated Bus Lanes, Smart Cities***

## I. INTRODUCTION

Every year sees an increase in the amount of $CO_2$ released into the Earth's atmosphere. This is despite growing awareness of the dangers of climate change. Governments around the world are constantly looking for ways to reduce their carbon footprint without reducing economic growth. The transport sector, particularly private vehicles, is a major source of $CO_2$. The transport sector in the USA accounted for 27% of $CO_2$ emissions in 2010, and of this 62% was emitted by passenger vehicles [1]. These figures were roughly similar in 2012, with a slight drop due to fewer miles travelled [2]. Much research has focused on improving vehicle efficiency in order to reduce net emissions. However producing higher efficiency vehicles has simply led to increased consumer demand for higher performance vehicles [3]. One possible solution to this problem is the increase in the uptake of electric vehicles (EV).

However, apart from many advantages, EVs have a number of disadvantages. EVs suffer from very short range in comparison with internal combustion engine cars (ICE). Currently, there is also very limited infrastructure for electric vehicles compared with that of ICE cars. This lack of infrastructure compounds the problem of limited range, making EVs suitable for short journeys only. EV batteries take a relatively long time to charge, when compared with the length of time for ICEs to refuel [4]. However new battery technologies [5], and introduction of schemes such as car-swapping and battery leasing [6] are attempting to address this issue. There are also cultural barriers to EVs as described by Sovacool et al. [7] whose research showed that many people viewed EVs as cheap and small.

The savings promised by EVs are not sufficient at the moment either. Diamond et al. [8] showed that fuel prices were the biggest influence, but upfront payments had strong effects. Lave et al. [9] estimate that fuel prices would have to be three times higher than today's in order to make EVs competitive.

Another possible solution to limit the amount of CO2 produced is to increase the use of public transportation. Bus lanes have become common in most developed cities as a way of making public transport more desirable. Bus-based rapid transport (BRT) is a transport system in which the buses have their own dedicated bus lanes (DBL). BRTs were first deployed in South American cities such as Bogota and they have now been planned worldwide, including in North America, Asia (China), South East Asia and Western Europe [15]. However DBLs have been criticised for making bottlenecks even worse and not using road capacity efficiently [16].

Opening bus lanes to electric vehicles is one way of solving both of these problems simultaneously. This would allow for more efficient use of road capacity, and make buses and EVs more desirable because of real or perceived reduction in journey times.

This paper proposes opening bus lanes to EV usage to form electric vehicle enhanced dedicated bus lanes (E-DBL). Extensive simulations have shown that this has a positive effect on journey times for both EVs and regular cars, without affecting bus travel times.

## II. RELATED WORKS

In the course of this research two main related areas were looked at: bus lane-related schemes and schemes aimed at favouring certain vehicle classes.

The first area of the related works deals with solutions related to using bus lanes. These help address the issue of road capacity underuse by employing various kinds of bus lanes.

*Dedicated bus lanes (DBL)* are mainly useful in roads with low traffic flow rates as they reduce capacity [16]. The problem of capacity misuse can be solved somewhat by *intermittent bus lanes (IBL)* and *bus lanes with intermittent priority (BLIP)*.

The easiest method to improve road capacity use with DBLs is to close them to regular traffic during certain times of the day only, such as rush hour period, for instance. This approach has advantages and disadvantages. When there are no buses or very few buses, during the night or Sunday, regular traffic can drive on DBLs. However during rush hours, the number of buses is highest and regular traffic also peaks, in this situation; when a road reaches full capacity, bus lanes are not that useful.

Using IBLs employing other methods, such as asking ICE vehicles to leave the bus lane when a bus appears, is difficult to enforce. Placing traffic light signals on all the roads as proposed in Viegas et al. [17] is very expensive. This approach allows ICE vehicles ahead of the bus to continue to use the bus lane, but no new vehicles may enter until the bus has passed.

BLIPs are a specific type of IBL. They use variable message signs (VMS) to request that cars leave the area if there is a bus [16]. This would be more effective than the IBLs in Viegas et al. [17] as vehicles ahead of the bus would move out of the way. However implementing VMS would require wireless communication between buses and signs, as loop detectors are not sufficient, increasing the deployment costs.

The second area of the related works deals with schemes which encourage ownership and usage of certain kinds of vehicles. Among the solutions to favour some vehicles is preference for parking space or priority at traffic lights.

Traffic signal priority (TSP) allows the traffic lights to give priority to certain types of vehicles. This is already deployed for emergency vehicles. When an emergency vehicle approaches a traffic light, the lights will change in its direction. This is safer than simply breaking the light, as other vehicles will have to stop [18]. The method used in this case is based on the emergency vehicle driver sending a message to the traffic light and the light changing immediately. For other types of vehicles there is not any justification for this type of reaction, so two alternative solutions are used. They are: *extended green* - in order to allow the favoured vehicle to benefit from the green phase, this phase is extended and *early green* in which the green light appears slightly earlier for the favoured vehicle in case it waits during a red phase. These two methods do not dramatically impede the traffic in the other direction and are described in Niu et al. [19]. Niu also showed that TSP negatively affects non-priority vehicles. However this is intuitive and might be acceptable in some cases. TSP can be used in conjunction with DBL to improve the flow for buses. Similar to DBLs, TSP loses effectiveness as the traffic gets heavier [16]. Some papers discuss giving EV favoured parking. Bruninga et al. [20] states that EVs have the advantage of availability of electricity near every parking space as Level 1 (L1) chargers can be installed everywhere. L1 chargers are simply regular plug sockets to which EVs can connect; however they are very slow at charging EVs in comparison with Level 2 (L2) chargers, recommended to be used for EVs. Hashimoto et al. [21] looks at parking times and charging of EVs to develop a parking reservation system. Such a system allows vehicle to grid (V2G) electricity transmission. EV owners can get priority by selling electricity to the car park owner. Timpner et al. [22] look at the user reserving a car space for a certain amount of time and also enable charging of the vehicle to a certain level.

## III. Electric Vehicle Enhanced Dedicated Bus Lanes

This paper proposes the introduction of *electric vehicle enhanced dedicated bus lanes (E-DBL)*, improving the current bus lane-based policy by allowing EVs to use DBLs. This has the effect of both encouraging the use of EVs by reducing the amount of charge they require and their journey time, and making better use of road capacity, otherwise not most efficiently used when employing DBLs, as mentioned earlier.

Figure III-1 illustrates how by employing E-DBLs and moving the EVs to the bus lane, reduces congestion on the regular lanes and makes better use of the bus lanes, in comparison with DBLs. In the DBL picture, the top two lanes are congested but the bus lane is in free flow. By moving some of the vehicles into the bus lane as shown in the E-DBL picture, congestion can be reduced and EVs are now in free flow.

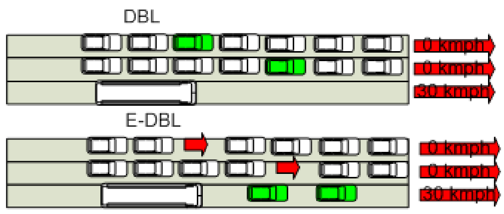


**Figure III-1 Diagram showing traffic with DBL and E-DBL**

## IV. Simulation Set-up

This section presents the settings for simulation-based testing which are performed to demonstrate the benefit of introducing E-DBLs in an urban environment. For the simulations, the road traffic simulator SUMO [30] was used. SUMO is an open source microscopic traffic simulator, which simulates each individual vehicle as opposed to just traffic flows.

For the testing scenario a map of Dublin was obtained from the openstreetmap website in the form of an xml file [31]. The map size is 1.5 km by 2 km and has the following coordinates: 53.333274, -6.291900 to 53.356862, -6.202507.

The bus lanes were added to the map xml file manually using data from a map downloaded from the DIT website [32]. This map is presented in Figure IV-2.

Vehicle counts from induction loops in Dublin are available from the Dublin City Council website [33]. The junctions which contained induction loops are marked with Xs in Figure IV-1. Vehicle traces were constructed from the vehicle counts and five traces of different Monday mornings in January were made. In the first four scenarios vehicles were considered from 6:00-6:15 in the morning. These traces contained approximately 500 vehicles each. A rush hour scenario with

780 vehicles was also made. This took vehicles in Dublin from 8:30 to 8:45 in the morning. The vehicles were considered light passenger vehicles with engines between 1.4 and 2 liters in the SUMO simulations.

The bus arrival times were obtained from the timetables on the Dublin bus website [34]. These buses were then added to the vehicle trace.

The energy consumption for EVs and fuel consumption for ICEs were recorded during the simulations.

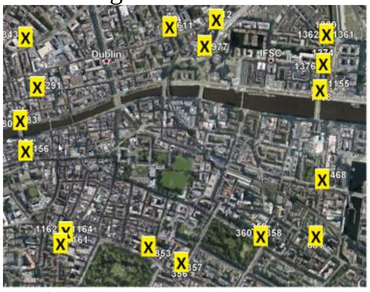

**Figure IV-1 Map of Dublin City Center with induction loops marked with Xs**

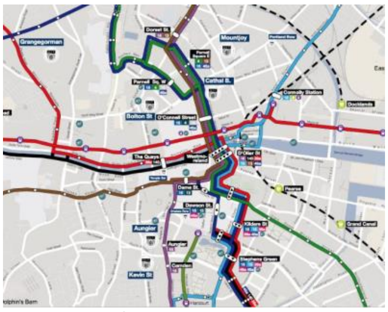

**Figure IV-2 Map of Dublin City Center with bus lanes**

In order to more accurately calculate fuel consumption, the gradients and roughness levels of the roads in the map were considered. The road gradients were obtained using Google Earth [35]. The heights of all road segment ends on the map were retrieved using the Google Maps APIs [36] and stored in a .cvs file. A Python script was then used to extract the length of all individual road segments and the heights of the start and end points of each segment, and calculate the gradients. These were then stored alongside map information in xml format.

The road roughness information was obtained from Dublin City Council in the form of IRI (International roughness index) and MPD (Mean depth profile) data. These were used to generate road roughness values of the major roads; the smaller roads' roughness was estimated from a statistics obtained from the National Roads Authority [37].

The amount of energy the electric vehicles used was also calculated. The EVs were based on basic passenger vehicles, the only difference being that their consumption was calculated in KWh instead of fuel liters. The ICE vehicles and the ICE buses were based on the basic passenger car P and the HDV models, both implemented in SUMO [38].

## V. E-DBL AND DBL COMPARATIVE TESTING RESULTS

In total 165 simulations were run. The five vehicle traces for Dublin were considered with three different lane set-ups: all the lanes open to all traffic ('All lanes open'), dedicated bus lanes (DBL) and electric vehicle enhanced dedicated bus lanes (E-DBL). The percentage of vehicles, which were EV and ICE, respectively, varied between 0-100% in steps of 10%.

The bus times, the percentage of different vehicle types which had reached their destination and the emissions were recorded for the five scenarios, for the three different lane schemes and the different percentages of EVs. These results will now be discussed in details.

### *1) Bus times*

The average arrival times of buses were recorded for the five scenarios, with the three different lanes schemes, for differing percentages of EVs. Scenario 1, 3 and 4 resulted in the same average travel time for buses of 378 seconds across all lane schemes and percentages of EVs.

Scenario 2 resulted in average travel time for buses of 378 seconds for 'all lanes open' and 499 seconds for DBL. E-DBL returned an average travel time of 499 seconds for 0%, 10% and 40% EVs with 378 seconds for the rest. Traffic congestion decreases as larger numbers of vehicles are allowed in the bus lanes.

**Table V-1 Bus arrival times in seconds for Scenario 5**

| % EVs | All (s) | DBL(s) | E-DBL(s) |
|---|---|---|---|
| 0% | 394 | 393 | 393 |
| 10% | 394 | 393 | 393 |
| 20% | 394 | 393 | 393 |
| **30%** | **394** | **393** | **393** |
| 40% | 394 | 393 | 394 |
| 50% | 394 | 393 | 393 |
| 60% | 394 | 393 | 393 |
| 70% | 394 | 393 | 395 |
| 80% | 394 | 393 | 394 |
| 90% | 394 | 393 | 394 |
| 100% | 394 | 393 | 394 |

Scenario 5 gave the following results displayed in Table V-1. More buses arrived for E-DBL for 60%, 70%, 80% and 90% EVs. This fact combined with the low average travel time compared with the other schemes makes E-DBL the best scheme in terms of bus travel times.

With the exception of Scenario 2, the bus travel times were not greatly affected by the different lane schemes. Heavy traffic congestion was the cause of the delays in Scenario 2.

### *2) ICEs and EVs*

The following graphs show the percentage of vehicles which reach their allotted destination within the 6:00 to 6:15 timeframe in the case of Scenario 1-4 or the 8:30 to 8:45 timeframe in the case of Scenario 5. The first graph for each scenario shows the results for ICE cars and the second shows the results for EVs.

#### *a) Scenario 1*

The results for Scenario 1 are now presented. This scenario contained 450 passenger vehicles.

Figure V-1 shows the results of 30 simulations. Scenario 1 was run with the three different lane schemes for ten different percentages of EVs. The percentages of EVs varied from 0% to 100%, in steps of 10%. The percentages of ICEs to reach the destination were recorded. As can be seen from the results ‘all lanes open’ was the best lane scheme for ICEs, as expected. However E-DBL gave a slight improvement when compared with DBL. This amounted to 2.5% on average. T-tests confirmed that the two sets of results were statistically different with a 90% confidence interval.

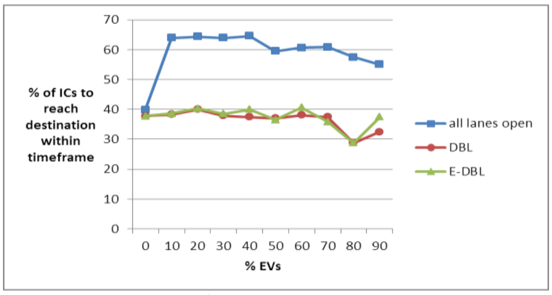


**Figure V-1 Percentage of Cars to reach destination in Scenario 1 under varying percentages of EVs.**

This is significant as the scheme aims at improving travel times for EVs, not ICEs. This shows that E-DBL positively affects all traffic.

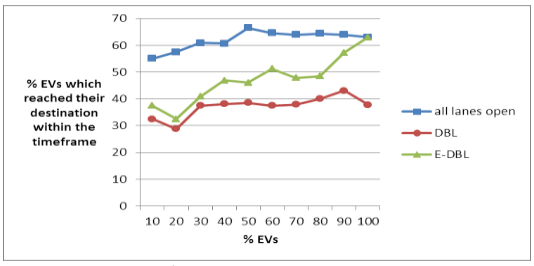


**Figure V-2 Percentage of EVs to reach destination in Scenario 1 under varying percentages of EVs.**

Figure V-2 shows the percentages of EVs to reach their destination in Scenario 1 for the three different lane schemes for varying percentages of EVs. The total number of passenger cars which were EVs varied between 10% and 100% in steps of 10%. ‘All lanes open’ showed the best results, but E-DBL dramatically outperformed DBL. The statistical difference between the results for E-DBL and those of DBL was proven with t-test with a 99.9% confidence interval. This was shown to be a 27% improvement on average. The improvement increases with the percentage of EVs.

*b) Scenario 2*

The results for Scenario 2 will now be discussed.

The traffic in Scenario 2 was slightly heavier, including in total 600 vehicles. This results in increased traffic congestion and in a lower percentage of ICEs and EVs reaching their destination within the timeframe across all the schemes. In Figure V-3 we see a similar pattern to the results in Scenario 1 for percentage of ICEs reaching their destination. ‘All lanes open’ yields the best result with a slight improvement of E-DBL versus DBL. This improvement was 9% on average with greater improvement for the higher ratios of EVs. This difference was shown to be statistically significant with a 95% confidence interval.

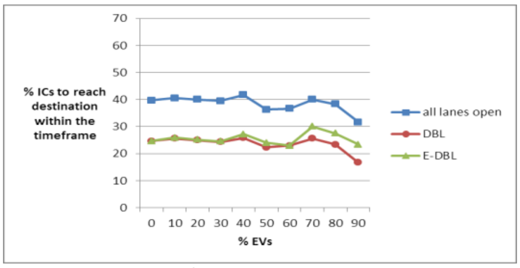


**Figure V-3 Percentage of Cars to reach destination in Scenario 2 under varying percentages of EVs.**

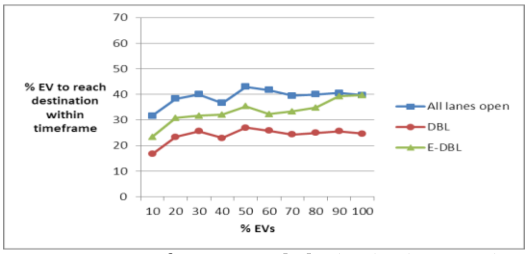


**Figure V-4 Percentage of EVs to reach destination in Scenario 2 under varying percentages of EVs.**

Again the percentage of vehicles to reach their destination was lower for EVs as well. This was due to increased traffic congestion in Scenario 2, but similar patterns were seen. ‘All lanes open’ was the best policy in terms of percentages of vehicles to reach their destination.

E-DBL outperformed DBL in these sets of results as well. The improvement was slightly higher in Scenario 2 than in Scenario 1. This is due to increased traffic congestion. Using t-tests, the difference between DBL and E-DBL was shown to be statistically significant with a 99.99% confidence interval. On average E-DBL outperformed DBL by 38%.

*c) Scenario 3*

The results for passenger cars in scenario 3 will now be discussed. Traffic in Scenario 3 was also quite heavy, 530 passenger cars entered the map during the timeframe.

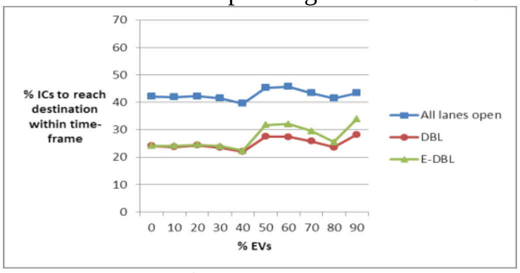


**Figure V-5 Percentage of Cars to reach destination in Scenario 3 under varying percentages of EVs.**

For the third time the same pattern is shown in Figure V-5. ‘All lanes open’ being the best scheme with E-DBL results following and DBL performing the worst. Due to the heavy traffic in scenario 3 E-DBL outperformed DBL by 8% only, with greater improvements for larger amounts of EVs. T-tests confirmed the statistical difference between the results for DBL and E-DBL with a 95% confidence interval.

The results for EVs in Scenario 3 further confirm the pattern of E-DBL being the better solution to DBL, as can be seen in Figure V-6.

The results for E-DBL and DBL was shown to be statistically significant with a 99.9% confidence interval when t-tests were performed. On average E-DBL outperformed DBL by 40%, the difference was higher for higher percentages of EVs.

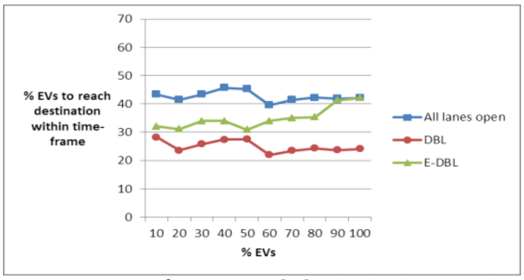


**Figure V-6 Percentage of EVs to reach destination in Scenario 3 under varying percentages of EVs.**

*d) Scenario 4*

The results for passenger cars in Scenario 4 are discussed in this section.

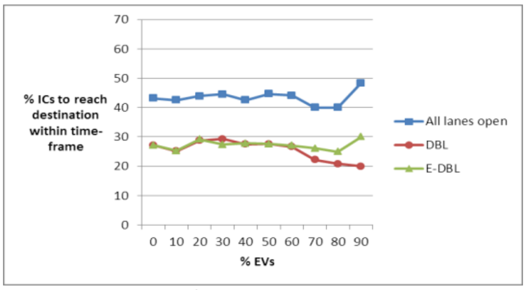


**Figure V-7 Percentage of Cars to reach destination in Scenario 4 under varying percentages of EVs.**

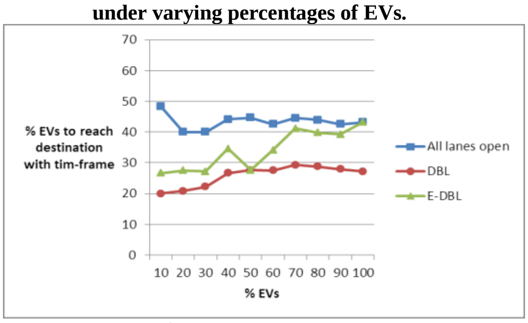


**Figure V-8 Percentage of EVs to reach destination in Scenario 4 under varying percentages of EVs.**

This vehicle trace contained 600 vehicles. The figure V-7 shows one point where DBL outperforms E-DBL. Dynamic systems such as traffic road systems have an inherent degree of randomness. This explains the result for 30% EVs.

T-tests showed a statistical difference between the results for E-DBL and DBL with a 90% confidence interval and on average. E-DBL outperformed DBL by 7%.

The results for EVs in Scenario 4 presented in Figure V-8 show the same patterns as in the previous scenarios. Once again E-DBL outperforms DBL in terms of percentage of EVs to reach their destination. T-tests confirmed a statistical difference with a 99.5% confidence interval. On average E-DBL outperformed DBL by 32%.

*e) Scenario 5*

Scenario 5 was a vehicle trace of Dublin from 8:30 to 8:45, unlike the previous four scenarios, which used vehicle traces of Dublin from 6:00 to 6:15 in the morning. Due to rush hour taking place in Dublin at around 8:30, scenario 5 has 780 vehicles.

Despite focusing on a different time, Scenario 5 resulted in similar patterns. E-DBL outperforming DBL by an average of 7% for the percentage of ICEs to reach their destination within the time-frame, which was confirmed by t-tests to be statistically significant with a 99% confidence interval.

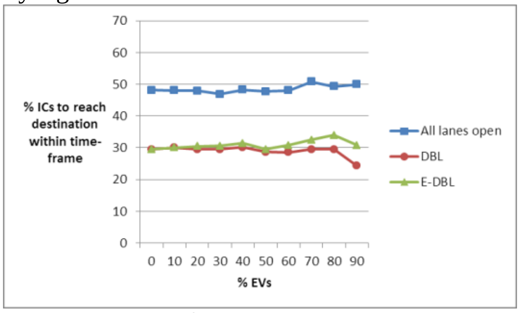


**Figure V-9 Percentage of Cars to reach destination in Scenario 4 under varying percentages of EVs.**

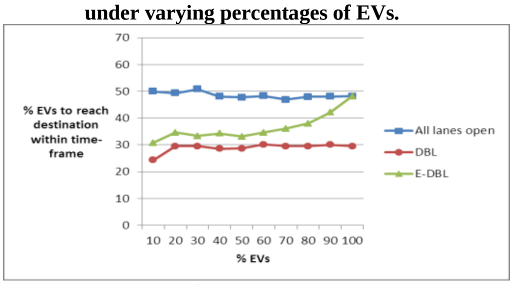


**Figure V-10 Percentage of EVs to reach destination in Scenario 5 under varying percentages of EVs.**

Finally the same pattern is shown in Figure V-10 for the results for EVs. An average improvement of 26% when E-DBL is employed is achieved in comparison with the case when DBL is used. The difference between these results is statistically significant with a 99.9% confidence interval.

As can be seen from these results opening bus lanes to all traffic is the best solution to congestion. However following the authorities' desire to maintain fast routes to public transportation via DBL, using E-DBL which opens the bus lanes to EVs is the next best solution as it reduces the congestion, not only for EVs, but the ICEs as well. This effect is magnified at increased rates of traffic congestion.

*3) Emissions*

The results for emissions are shown in the next graph.

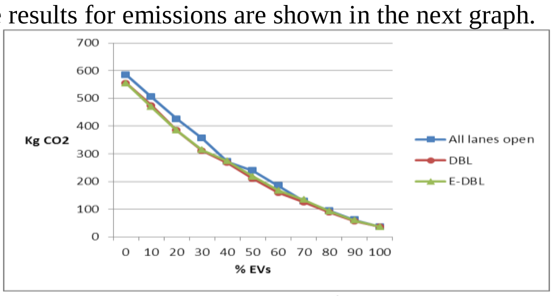


**Figure V-11 Emission of scenario 5**

As can be seen from Figure V-11, the emissions do not vary greatly between the different lane schemes. The results do however decline as the percentage of EVs increases. This is obviously expected.

'All lanes open' has higher emissions than the other schemes due to more vehicles being able to move. As the percentage of EVs increases this effect drops.

*4) Energy used by EVs*

The results for the energy used by EVs will now be presented. As can be seen from Figure V-12 all lanes open used the most energy, followed by E-DBL and DBL using the least. This is due to the fact that EVs don't use as much energy idling as ICs and the vehicles were not able to travel as far under DBL when compared with E-DBL. Distance travelled was the main input in terms of energy used by EVs in these tests. Future tests will consider energy used over distance

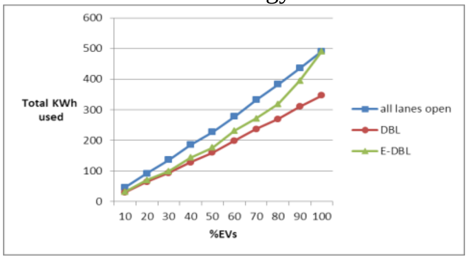


**Figure V-11 Energy used by EVs in Scenario 5**

## VI. Conclusions

This paper proposed the creation of dedicated bus lanes enhanced with Electric vehicles (E-DBL). The new bus lane system was described in detail along with its expected performance. Detailed simulation tests were performed with real data and real maps of the Dublin, Ireland. In the tests E-DBL was compared against two other lane schemes, 'all lanes open' (all vehicles had access to bus lanes) and regular dedicated bus lanes (DBL). Tests have involved recording of energy consumption and journey times of buses, EVs and ICE passenger vehicles. The test results showed how road capacity was better used when employing the proposed E-DBL. The test also showed good performance of E-DBL in terms of energy consumption. Significant benefits in travel time particularly for EVs were shown. This policy, if implemented could make EVs a much more attractive consumer choice.

## VII. Future Work

As future work a VANET-based algorithm to dynamically assign lanes to vehicles will be developed. This will have the effect of encouraging fuel efficiency while making good use of the road capacity. As can be seen from the results dedicated bus lanes do not make efficient use of road capacity.

Such an algorithm could also optimize light timing, to encourage fuel efficiency without substantially increasing emissions.

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