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Energy Behaviour Of Toyota Prius Hybrid Vehicles In Sample Irish Commuting Conditions

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Executive Summary

This document provides a summary of research that was conducted by ConsultUCD®. The objective of the research, which was commissioned and funded by Toyota Ireland, was to investigate the energy behaviour of the (new) Toyota Prius IV hybrid vehicle, under a set of conditions that may be considered representative of regular commuting patterns in Ireland.

The research consisted of recording and analysing commuting data from seven volunteers, all of whom are employees of University College Dublin. Each volunteer was supplied with a Toyota Prius IV hybrid vehicle for one calendar week during the period November 4th-19th 2018. The overall test data was built from an ensemble of 157 individual trips, which when aggregated together, cover 2018 km.

With the exception of GPS information, all measurements, including fuel consumption, were obtained directly from the standard Toyota sensors and onboard computer systems. Our main findings may be summarised as follows.

1 On average, the percentage driving in Zero Emission Mode (ZEV) mode (petrol engine stopped) was 62% of the overall travel time.

2 On average, the percentage driving in ZEV mode was 40.4% of the overall travel distance.

3 An average fuel consumption of 4.92 litres per 100 km was recorded for the overall trip distribution.

4 An average $C0_2$ emissions of 114.2 grammes per km was computed for the overall trip distribution.

5 The fuel consumption figure, and the computed $C0_2$ figure, are in remarkably close agreement with the newly introduced world-wide harmonised light vehicle test (WLTP) figures for the Toyota Prius IV vehicle that have been published by Toyota.

Start point of commute	Driver	Total Distance for each driver [km]	% ZEV Time for each driver	% ZEV Distance for each driver	Average Speed for Driver [km/h]	Average fuel/km [l/100km]	% Motorway Distance for Driver
Smithfield	Driver 1	119.7	76%	57.1%	11.0	5.438	0.0%
Wicklow	Driver 2	293.9	56.2%	40.6%	42.5	4.562	76.5%
Drogheda	Driver 3	644.2	56.6%	36.9%	33.3	4.830	48.4%
Dundrum	Driver 4	128.3	64%	49.5%	17.8	5.183	16.1%
Dundrum	Driver 5	115.6	66%	54.6%	20.3	5.317	13.6%
Blackrock	Driver 6	263.9	66.5%	48.0%	23.2	5.121	9.3%
Aughrim	Driver 7	452.6	56.5%	30.0%	39.3	4.914	29.0%
	ALL	2,018	62%	40.4%	27	4.92	28%

Table 1: Summary of trip distribution

A summary of the key data obtained for each driver is depicted in Table 1. Overall, the results indicate that in sample Irish commuting conditions, the Toyota Prius IV hybrid car may be in ZEV mode for a very significant portion of its travelling time and distance, suggesting meaningful air-quality related benefits for pedestrians and cyclist as compared to conventional combustion engine vehicles.

1. Introductory remarks

The objective of this work is to develop a better understanding of the zero emissions driving characteristics of Toyota Prius IV hybrid car in what could be considered typical Irish commuting conditions. Specifically, we wish to empirically measure the percentage distribution of the total energy delivered to the wheels between the electric drive system and the internal combustion engine. A particular interest in the fraction of time and distance during which the vehicle is in Zero Emissions (ZEV) mode.

The research, which was funded and commissioned by Toyota, was organised so that measured data was acquired in conditions that could be considered typical commuting patterns for Ireland. To do this, volunteer drivers from the pool of UCD employees were given access to a vehicle for one week. Thus, the measured trip distribution, consisted of regular commuting behaviour, and private incidental journeys, across a population of UCD employees. Note that this is a key methodological difference with a previous Toyota study in Rome[5] in which one predetermined route was considered and the ZEV behaviour was measured for this route only. Our test attempts to replicate real, day-to-day driving.

(i) Drivers were chosen with varying commute types (traffic conditions, length of commute, type of roads traversed). This resulted in a suite of measured data that may be considered indicative of everyday commuting behaviour, and incidental journeys.

(ii) Prior to commencement of the study, all drivers were given a short briefing on how to optimise the performance of a hybrid car.

(iii) No restrictions were placed on the volunteer drivers. For example, no set routes were prescribed or suggested, and there was no attempt to restrict driving behaviour in any manner. In particular, drivers were not asked to limit use of energy intensive features such as air conditioning, heating, and other in-vehicle services.

(iv) Toyota Ireland supplied Toyota Prius IV models for testing. Specifically the vehicles supplied were Luxury Grade with 17" wheels and a full suite of premium features. This grade makes up over 90% of the Prius models sold in Ireland.

(v) Fieldwork took place during November rather than during the warmer, and therefore more benign, summer months.

The study consisted of three phases: (A) test definition and set-up; (B) data gathering and processing; and (C), data analysis.

[5]Hybrid Analysis: True Test Drive, Toyota Prius IV, Technical Report, CARe−Centro di ricerca sull'Auto e la sua evoluzione Universita' degli Studi *Guglielmo Marconi* Via Plinio, 42−00195 Roma, June 2016

During phase one, volunteers were selected, and the experimental infrastructure calibrated. Measurement data was obtained from the vehicle OBD2 data port of each vehicle, using an Android® Smartphone Application that connected to the OBD2 via Bluetooth. The Android® Application records GPS traces of each journey, and these were used to link the ZEV behaviour with the geographic location of the car. All data were recorded, together with the EV activation patterns, using the *Hybrid Assistant* Application[6] which is available on the Google Play Store® for Android® devices.

Calibration of the test setup was performed in collaboration with Toyota Ireland, by comparing measurements obtained by the UCD team with measurements obtained by using the Toyota diagnostic system *Techstream*. We found that the measurements obtained using the two methodologies were in complete agreement for the parameters of interest, thereby confirming the fidelity of the measurement system. Thus, with the exception of GPS information, all measured parameters, including fuel consumption parameters, were obtained directly from the standard Toyota sensors and on-board computer systems.

During phase two, measurement data were acquired for each of the drivers that were selected to participate in the study.

In phase three, the data-sets from phase two were analysed, with relevant results and findings highlighted.

Note that all tests were performed between November 4th and November 19th, 2018.

2. Test Definition

The overall duration of the test was two weeks. In total, seven drivers participated in the test. During week 1, four drivers collected data during their daily routine. During week 2, three new drivers collected data during their daily routine.

Drivers were instructed to drive the vehicle provided by Toyota as they would normally drive for their daily activity. Thus, daily activities of each driver included:

- commuting from home to work location (UCD);
- routine scheduled activities (such as a school run);
- commuting from UCD to home;
- incidental daily and weekend journeys.

[6] http://hybridassistant.blogspot.com/p/about.html

Of the seven drivers: one was female and six were male; four of the drivers had not previously driven a hybrid car; and the overall age range was 30-65. Figure 1 depicts the test trip distribution (in terms of distances). Note that the this figure is similar to the Irish trip distributions in

C. King, W. Griggs, F. Wirth, K. Quinn and R. Shorten, Alleviating a form of electric vehicle range anxiety through on-demand vehicle access, International Journal of Control, vol. 88, no. 4, pp. 717-728, 2015,

suggesting that the journey pattern that emerged from our experiment is representative of Irish commuting behaviour (from the 2009 National Travel Survey, NTS). Overall, data for an aggregated trip distance of 2018 km were collected,

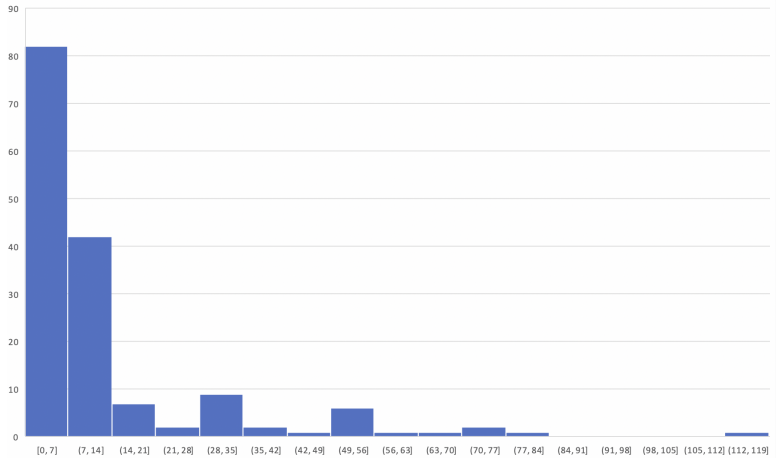

Figure 1: Test trip distribution. The horizontal axis depicts the range of journal length, and the vertical axis captures how many trips fell into this category.

with an average journey length of 12.85 km. Based on the measured data it could be surmised that:

- the trips of driver 4, driver 5, and driver 6 were mostly in urban/suburban areas;
- the trips of driver 2, driver 3 and driver 7 were mostly in non-urban areas;
- and the trips of driver 1 were mostly in urban areas.

3. Main findings

We now report our main findings.

ZEV mode analysis: For our trip distribution, the average time that Prius spent in ZEV mode was 62% of the total journey time. The average distance that the Prius spent in ZEV mode was 40.4% of the total journey distance (these values were obtained by averaging across all the trips). Figure 2 and Figure 3 provide more detailed information on the EV mode activation.

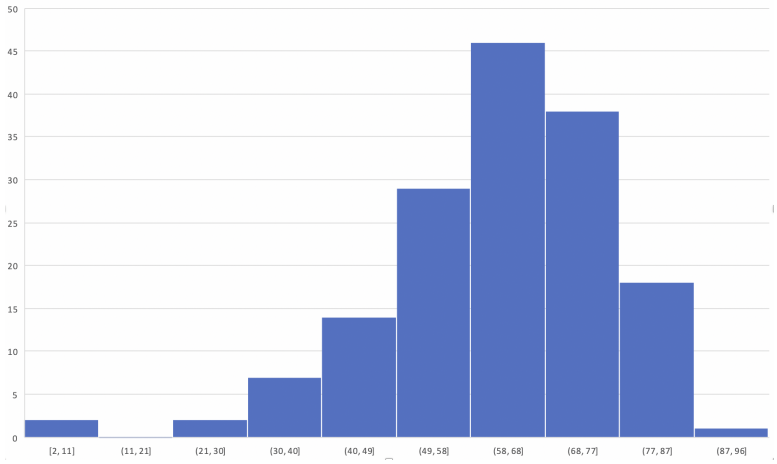

Figure 2: ZEV mode distribution. The horizontal axis depicts the range of time percentages spent in ZEV mode, and the vertical axis captures how many trips fell into this category.

We also estimated, from the available GPS traces, the percentage of motorway driving for each trip; see Figure 5 for the estimated distribution of motorway driving across the tests. The data presented in Figures 2-4 are summarised in Table 2.

Additionally, we were able to cross-reference ZEV mode information and GPS information, thus highlighting where the vehicle was in ZEV mode during each trip. In the Appendix, we give examples of representative journeys that illustrate the geographic locations where the ZEV mode was active.

Fuel useage analysis: Total carbon dioxide ($C0_2$) emissions were computed based on US EPA Emission Factors for Greenhouse Gas Inventories (9 March 2018). Details of the computation methodology can be found at:

www.epa.gov/sites/production/files/2018−03/documents/

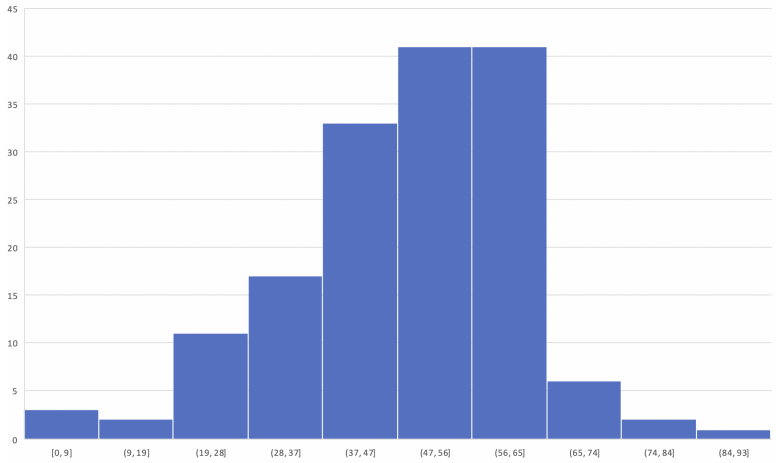

Figure 3: ZEV mode distribution. The horizontal axis depicts the range of distance percentages in km spent in ZEV mode, and the vertical axis captures how many trips fell into this category.

emission-factors_mar_2018.pdf

The average $C0_2$ emissions for all trips was calculated to be 114.2 g/km. Figure 4 depicts the distribution of $C0_2$ emissions across the test journeys. Summary data are also provided in Table 3 below. Note that nine trips were found to have $C0_2$ emissions in excess of 200g/km. However, it should also be noted that all of these were short trips (distance less than 5 km).

A total of 99.37 litres of fuel was consumed over 2018 km of the total test distance. The overall average speed was approximately 27 km/h. Consequently, the average fuel economy is 4.92 litres/100 km, and the calculated average $C0_2$ emissions is 114.2 grammes per km. It is worth noting that these are very close to the official figure for the vehicle obtained under the new world-wide harmonised light vehicle test (WLTP) emissions testing regime (given below).

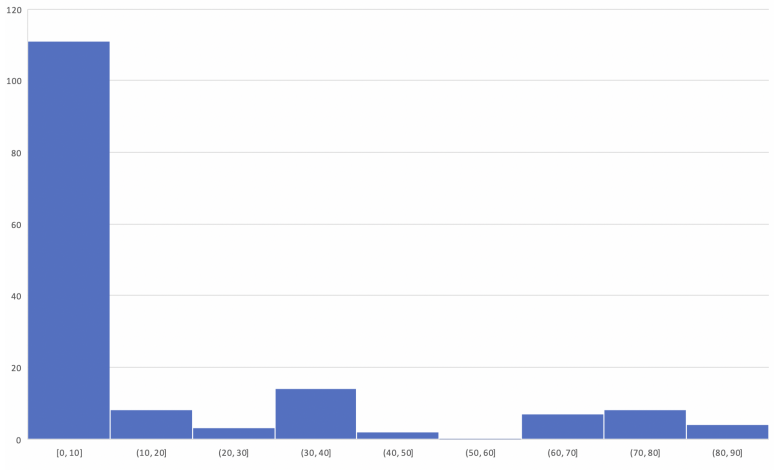

Figure 4: Estimated motorway. The horizontal axis depicts the range of distance percentages in km spent in motorway driving, and the vertical axis captures how many trips fell into this category.

Official Fuel Economy Figures (WLTP Test Procedure) Prius Luxury Saloon

EC Certificate of Conformity, 10/12/2017
Vehicle Identification number JTDKB3FU503581203
Vehicle Type XW5(EU,M)
Variant ZVW50(H)
Version ZVW50R-AHXEBW(1C)

Fuel (Combined): 4.8 litres/100 km
$C0_2$ **Emissions (Combined)**: 108 (g/km)

Comment : Note that this is one of the first real world verifications of the test figures published by Toyota. Note also that the published figures are close to the actual measured ones from our tests; fuel economy is within 2.5% of Toyota figure; and the $C0_2$ emissions figure is within 5.7% of Toyota figure.

Finally, we also estimated the fuel cost per travel. This estimate was obtained by considering an average price of €1.38 per litre of petrol. These statistics are depicted in Figure 6.

Start point of commute	Driver	Total Distance for each driver [km]	% ZEV Time for each driver	% ZEV Distance for each driver	Average Speed for Driver [km/h]	Average fuel/km [l/100km]	% Motorway Distance for Driver
Smithfield	Driver 1	119.7	76%	57.1%	11.0	5.438	0.0%
Wicklow	Driver 2	293.9	56.2%	40.6%	42.5	4.562	76.5%
Drogheda	Driver 3	644.2	56.6%	36.9%	33.3	4.830	48.4%
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Aughrim	Driver 7	452.6	56.5%	30.0%	39.3	4.914	29.0%
	ALL	2,018	62%	40.4%	27	4.92	28%

Table 2: Averages in the last row are based on aggregated trip information

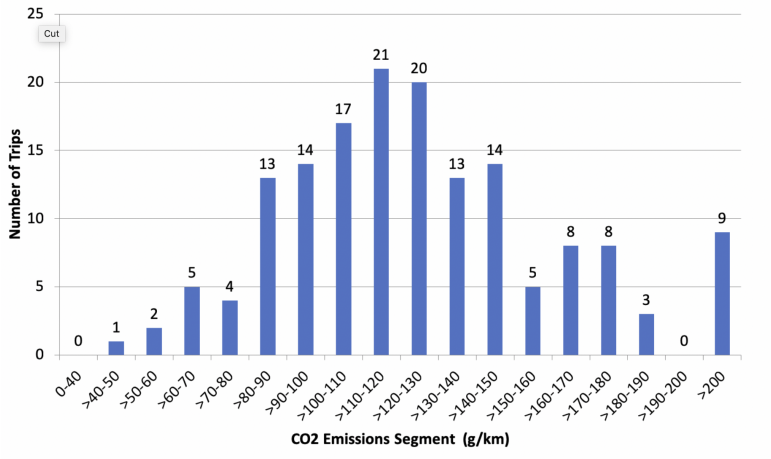

Figure 5: $C0_2$ emissions distribution

4. Conclusions

This report summarises the main findings of a study to empirically evaluate the energy consumption behaviour of the Toyota Prius IV Hybrid (luxury model), in a set of commuting conditions that may be considered typical for Ireland.

The study was funded and commissioned by Toyota Ireland.

A key methodological difference with a previous Toyota study in Rome is that the present study is based on commuting behaviour of a population of seven UCD employees, rather than a single vehicle traversing a predetermined route.

The tests were performed between 4/11/2018 and 19/11/2018. The total ag-

CO2 Emissions [g/km]	No. of Trips in CO2 Emissions segment	Total Distance for these trips [km]	EV Distance for these trips [km]	% EV Distance for these trips	Average Speed for these trips [km/h]
0-40	0				
>40-50	1	2.15	1.87	87.0%	25.8
>50-60	2	3.38	2.48	73.5%	24.1
>60-70	5	13.97	8.99	64.3%	22.3
>70-80	4	37.90	21.00	55.4%	42.6
>80-90	13	119.85	68.29	57.0%	25.9
>90-100	14	187.10	89.72	48.0%	35.3
>100-110	17	501.80	200.75	40.0%	35.7
>110-120	21	291.20	106.63	36.6%	37.0
>120-130	20	463.25	135.11	29.2%	36.5
>130-140	13	129.05	60.97	47.2%	17.5
>140-150	14	83.97	38.97	46.4%	15.8
>150-160	5	70.53	27.15	38.5%	18.7
>160-170	8	30.32	15.32	50.5%	12.4
>170-180	8	31.31	13.78	44.0%	12.2
>180-190	3	34.09	17.56	51.5%	10.6
>190-200	0	2.47	1.24	50.2%	11.9
>200	9	15.82	4.56	28.9%	8.7
ALL	157	2,018	814	40.4%	27.7

Table 3: $C0_2$ data

gregated distance was 2,018 km accumulated over 157 trips.

Overall, it was found that, on average, the car was in ZEV mode for 62% of the commuting time, and for 40.4% of the average commuting distance. These results suggest meaningful air-quality related benefits for pedestrians and cyclists encountered er-route by the Prius, when compared with conventional ICE vehicles.

An average fuel consumption of 4.92 litres per 100 km was recorded, and an average $C0_2$ emissions of 114.2 grammes per km was computed. The results, for the test population, are in remarkably close agreement with the newly introduced WLTP test, suggesting that for Toyota Prius IV Luxury model the test results may be a good guide to real world fuel economy and $C0_2$ emissions. These latter results represent one of the first verifications of the figures produced by Toyota under the new WLTP test procedure.

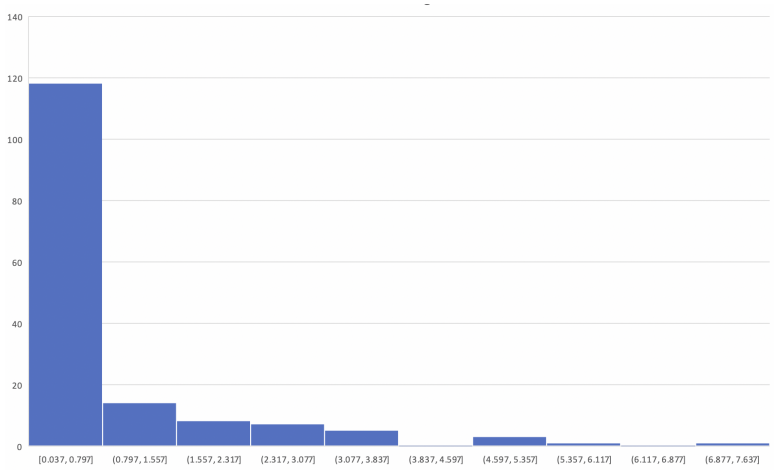

Figure 6: Trip cost. The horizontal axis depicts the range of trip cost in €, and the vertical axis captures how many trips fell into this category.

Appendix

A sample of typical routes traversed during the test are depicted in Figures 7-10 (all starting locations obfuscated). GPS points in a green colour denote activation of the ZEV mode (rpm from internal combustion engine zero).

Figures 11 and 12 depict the distributions of local ambient temperatures and humidities available from Met Eireann (Dublin Airport) during the vehicle testing period.

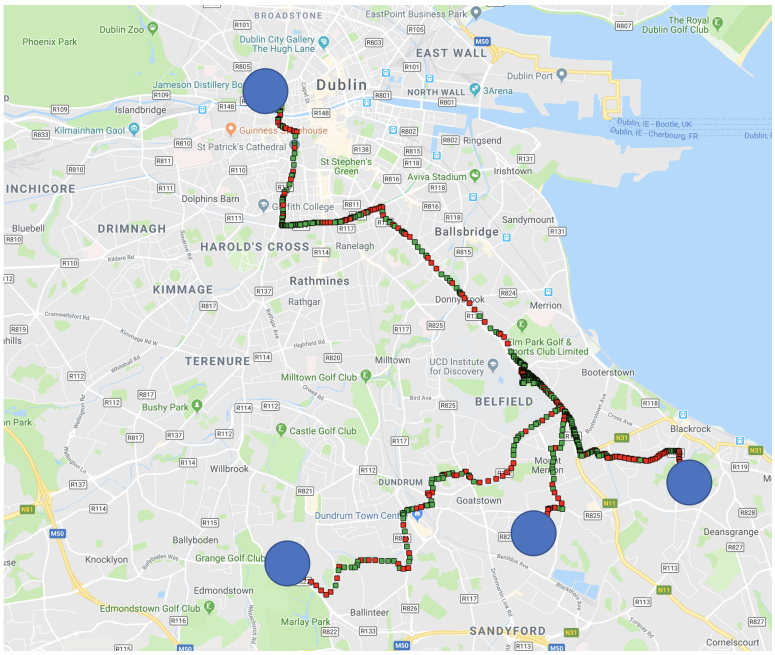

Figure 8: Sample urban journeys. GPS points in green denote activation of the ZEV mode (rpm from internal combustion engine zero). Traces are from four separate urban journeys (all different drivers).

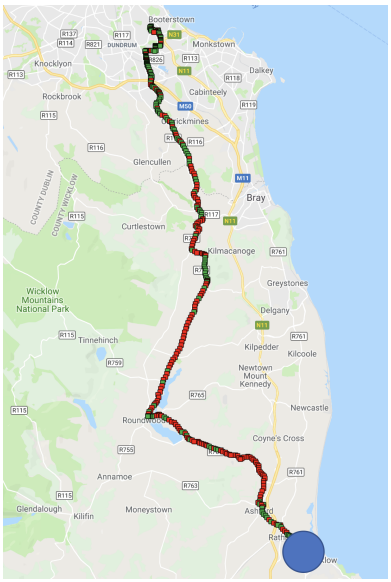

Figure 7: Sample non-urban journey. GPS points in green denote activation of the ZEV mode (rpm from internal combustion engine zero)

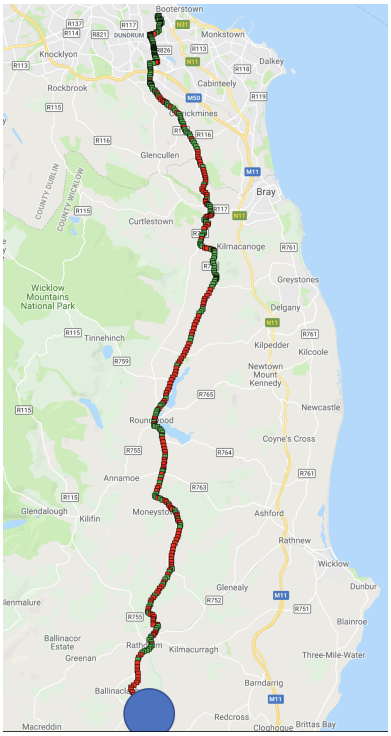

Figure 10. Sample non-urban journey. GPS points in green denote activation of the ZEV mode (rpm from internal combustion engine zero)

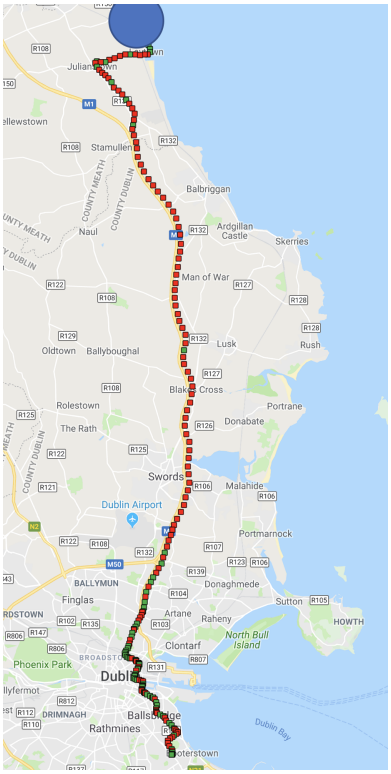

Figure 10. Sample non-urban journey. GPS points in green denote activation of the ZEV mode (rpm from internal combustion engine zero)

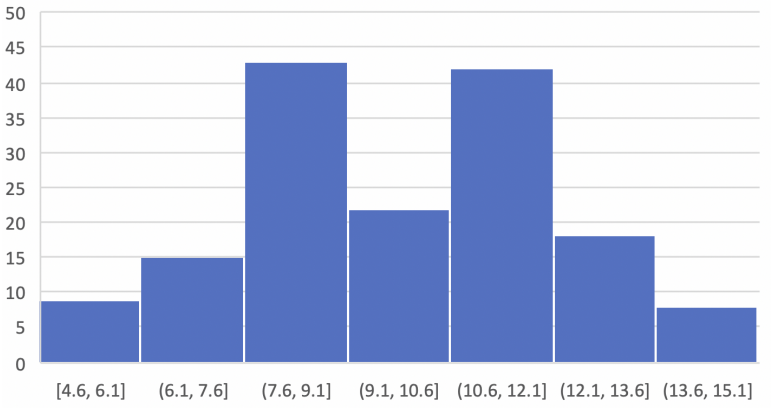

Figure 11: Distribution of ambient temperature during testing period. The horizontal axis denote the range of temperatures and the y axis captures how many trips fell in that category.

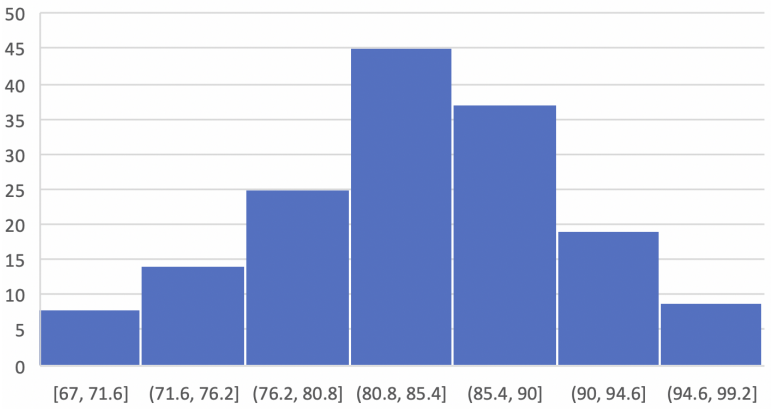

Figure 12. Distribution of background humidity during testing period. The horizontal axis denotes percentage ranges and the y axis captures how many trips fell in that category.