
# The Green Charge

## Analysis of energy and $CO_2$ emissions data from the 2011 RAC Future Car Challenge

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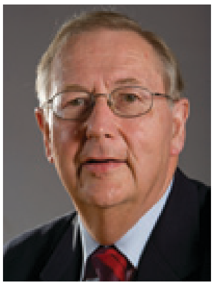
RAC Foundation

# RAC FUTURE CAR CHALLENGE.

## BRIGHTON TO LONDON 05.11.11


Photos courtesy of James Mann
(www.jamesmann.com)

# Foreword



If a week is a long time in politics, then a year is a lifetime in the rapidly evolving world of low-carbon vehicles. If you take the RAC Future Car Challenge to be any sort of guide, then the focus on electric vehicles in the industry is strong. In 2010, 19 battery-powered vehicles crossed the start line. In 2011 it was 37, and many of these are now in the showrooms.

But the availability of such cars is one thing; the extent to which people are actually buying them is another. By the end of 2011, 1,500 electric cars had been registered in the UK. Under the government's Plug-in Car Grant scheme, which has been running since the start of 2011 and provides a maximum of £5,000 towards each purchase, 892 'ultra-low-emission' vehicles had been bought by the end of the year – and with present technologies these are almost all powered by electricity.

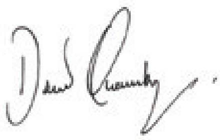
Relative to the purchase of ultra-low-emission vehicles in previous years, the Department for Transport regards what we saw in 2011 as a step change. However, relative to the total of 28 million cars presently on the UK's roads there is clearly rather more to be done.

The government has recently extended the Grant to vans. This makes a lot of sense. While many personal buyers will continue to exhibit range anxiety and worry about the availability of recharging points, commercial operators – especially in urban areas, with depot facilities – are likely to be attracted to electric vans if they can afford them and make a business case for buying them.

It will be interesting to see how the market for hybrids develops. At the moment there are some 82,000 of these vehicles being driven about. What makes them attractive is their cheap showroom price compared to pure-electric vehicles, combined with significant fuel savings. As the price of diesel continues to rise, and the differential between it and unleaded petrol increases, a growing number of those who were considering paying a premium for a diesel-powered car might now find a hybrid a viable alternative.

Perhaps the real message to take away from the Future Car Challenge so far is that the options for motorists are growing. Internal-combustion engine cars, pure electrics, hybrids, even hydrogen… these cars are out there and on the market: you pays your money and you takes your choice! Though, of course, much still depends on the size of your wallet – and will continue to.

This report shows the energy consumption and carbon emissions of over 35 different low- and ultra-low-carbon vehicles in the second Future Car Challenge held in November 2011. Although the 57-mile run from Brighton to London does not set out to be in any way an official test route, it is a real-world challenge offering traffic conditions and driving experiences similar to those faced by motorists on a day-to-day basis. That is what gives these results a sense of reality.



David Quarmby
Chairman, RAC Foundation

# The 2011 RAC Future Car Challenge took place on 5 November 2011 over a 57-mile route from Brighton to London.


The Challenge attracted more than 60 of the most environmentally friendly vehicles either already in production, soon to be available in the showrooms, or at the concept stage.

The overall winner was the Gordon Murray Design T.27.

Data collected from 39 of the entries was analysed to compare energy consumption, $CO_2$ emissions, fuel costs and driving style between four different power train technologies used in the run:

- Electric vehicles (EVs)
- Extended-range electric vehicles (E-REVs)/plug-in hybrid electric vehicles (PHEVs)
- Hybrid electric vehicles (HEVs)
- Internal-combustion engine (ICE) vehicles

**Average energy consumption, $CO_2$ emissions and fuel costs**

| Power train | Energy consumption (kWh/km) | Tailpipe emissions ($gCO_2$/km) | Well-to-wheel emissions ($gCO_2e$/km) | Fuel costs (£) |
|---|---|---|---|---|
| EVs | 0.14 | 0 | 86 | £1.82 |
| E-REVs/PHEVs | 0.30* | 68 | 81* | £3.76 |
| HEVs | 0.39 | 94 | 113 | £4.92 |
| ICE vehicles | 0.55 | 127 | 154 | £6.52 |
| **Average overall** | **0.24** | **103** | **99** | **£3.01** |

* Figure is likely to be an underestimate for reasons explained below.

The results show that the fuel economy, range and $CO_2$ emissions data recorded by the New European Driving Cycle, the official test procedure by which these figures are determined, do not reflect real-world performance measured in the Challenge. While in some cases real-world performance was better than officially claimed, the majority of vehicles performed worse in real-world conditions.

An analysis of driving style suggests that average speed did not have an impact on energy consumption; it also confirms that the less time is spent on the accelerator the less energy is consumed.

## The Challenge

As with the inaugural 2010 RAC Future Car Challenge (FCC), the 2011 event saw more than 60 vehicles complete the 57-mile route from Brighton to London in a competition to see which used the least amount of energy. There were entries from most of the major manufacturers, a number of niche producers, and private individuals.

The participating vehicles included cars already available on the market, and also pre-production cars and custom-made conversions. Certain models, such as the Nissan LEAF and smart fortwo coupé electric, were entered more than once. All entries had to be roadlegal and meet a set of technical and competition regulations to be considered for the awards, which were categorised not just by power train type, but also Euro car segment (small, regular, sports, etc.).[1]

The following abbreviations are used throughout the report:[2]

| | |
|---|---|
| **$CO_2e$** | carbon dioxide equivalent |
| **DECC** | Department of Energy and Climate Change |
| **Defra** | Department for Environment, Food and Rural Affairs |
| **EV** | electric vehicle |
| **E-REV** | extended-range electric vehicle |
| **FCC** | Future Car Challenge |
| **HEV** | hybrid electric vehicle |
| **HFCV** | hydrogen fuel cell vehicle |
| **ICE** | internal-combustion engine |
| **kWh** | kilowatt-hours |
| **NEDC** | New European Driving Cycle |
| **PHEV** | plug-in hybrid electric vehicle |

**Table 1: Number of FCC participants by power train type**

| Power train | Number of vehicles in FCC 2010 (measured) | Number of vehicles in FCC 2011 (measured) |
|---|---|---|
| EVs | 19 (16) | 37 (34) |
| HEVs | 19 (18) | 4 (4) |
| E-REVs/PHEVs | 4 (1) | 11 (4) |
| HFCVs | 3 (1) | 1 (0) |
| ICE vehicles (≤110 $gCO_2$/km) | 16 (14) | 9 (7) |
| **TOTAL** | **61 (50)** | **62 (49)*** |

* This paper analyses the energy consumption results of only 39 entries, for which sufficient data was available. For a list of vehicles that were not included in the analysis, please see endnote 3.

## Energy consumption

In order to measure energy consumption, the EVs were fitted with a data logger situated between the battery pack and the electric motor, which recorded electricity use in kWh; charging losses between the vehicles and charging points were factored in to the analysis. HEVs and ICE vehicles were measured by reading the on-board display, which is likely to have resulted in an inaccuracy of ±5%. E-REVs and PHEVs were also measured by reading the on-board display; as it was not possible to measure energy use in electric-only mode, the results for these vehicles may be an underestimation of energy consumption, and hence of emissions. A GPS device was fitted to 31 vehicles to enable analysis of energy consumption in relation to driving style.

To be able to compare like with like, the following conversion factors were used:

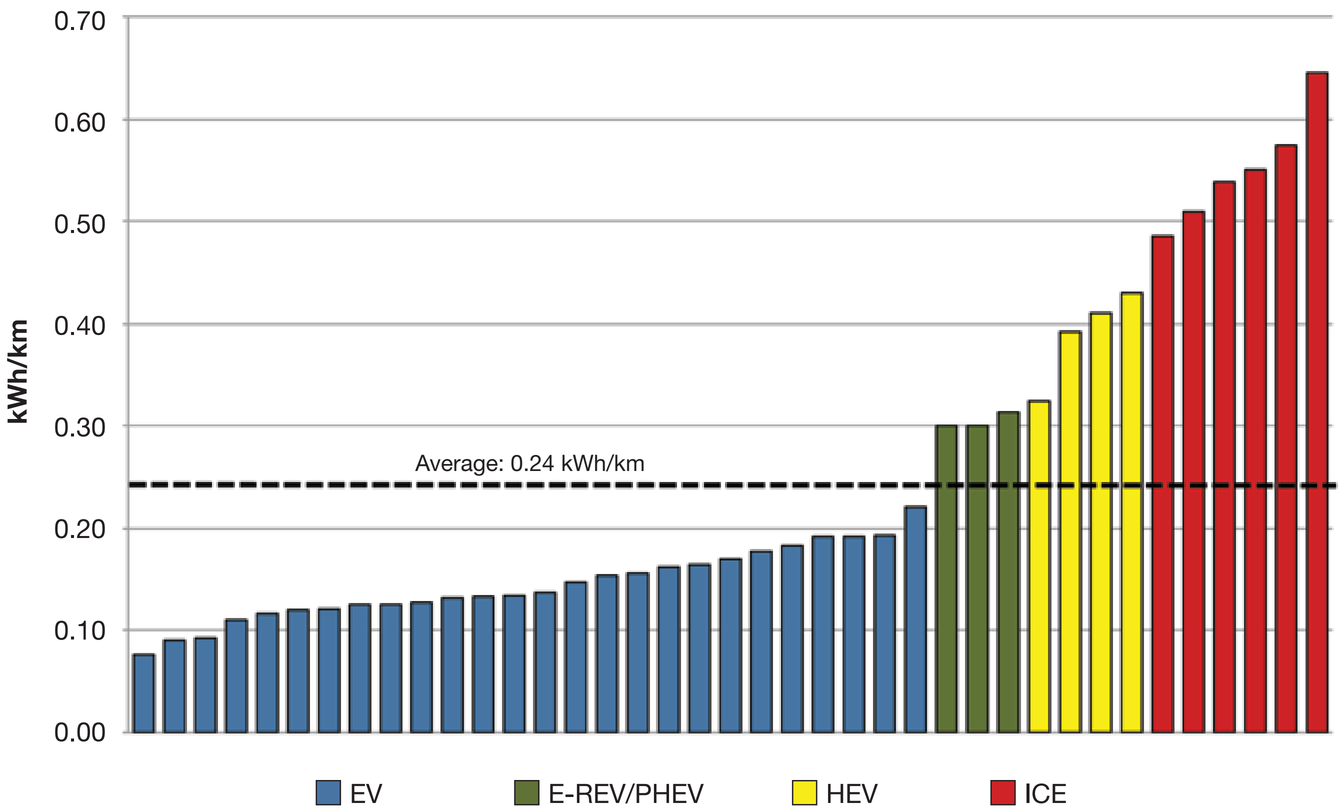
**Table 2: Conversion factors**

| Power source | Unit | Gross calorific value[4] (kWh/unit) | Tailpipe emissions[4] ($kgCO_2$/unit) | Well-to-wheel emissions[4] ($kgCO_2e$/unit) | Fuel cost[5] (£/unit) |
|---|---|---|---|---|---|
| Petrol | 1 litre | 9.61 | 2.24 | 2.67 | £1.34 |
| Diesel | 1 litre | 10.60 | 2.55 | 3.11 | £1.40 |
| Electricity | 1 kWh | 1.00 | 0.00 | 0.59 | £0.14 |

Figure 1 shows 'tank-to-wheel', i.e. vehicle-only, energy consumption. The results reveal a clear picture: EVs were the most energy-efficient, followed by E-REVs and PHEVs, HEVs and finally ICE vehicles. Thus the larger the degree of power train electrification, the more efficient the vehicle. Expressed in mpg petrol equivalents, EVs achieved 201 mpg on average, E-REVs/PHEVs 89 mpg, HEVs 71 mpg, and ICE vehicles 50 mpg – the overall average was 156 mpg. On average, EVs recuperated 12% of total energy consumed through regenerative braking, with one recuperating as much as 34%.

Within the EV category, the variation between the most efficient and least efficient vehicle was a factor of almost 3, while for HEVs and ICE vehicles it was 1.3, and for E-REVs/PHEVs virtually zero. The vehicles that were entered more than once, such as the Nissan LEAF and the smart fortwo coupé electric, used very similar amounts of energy with a variation of only about 10% in each case.

**Figure 1: Tank-to-wheel energy consumption**



It is interesting to note that six out of the top ten most efficient vehicles were small EVs, either custom-made conversions, prototypes or vehicles made by niche manufacturers, with an average kerb weight of just under 1,000 kg, which is 23% less than the average of 1,300 kg for all participating vehicles. By comparison, all EVs weighed 1,218 kg on average, E-REVs/PHEVs 1,473 kg, HEVs 1,570 kg, and ICE vehicles 1,387 kg.

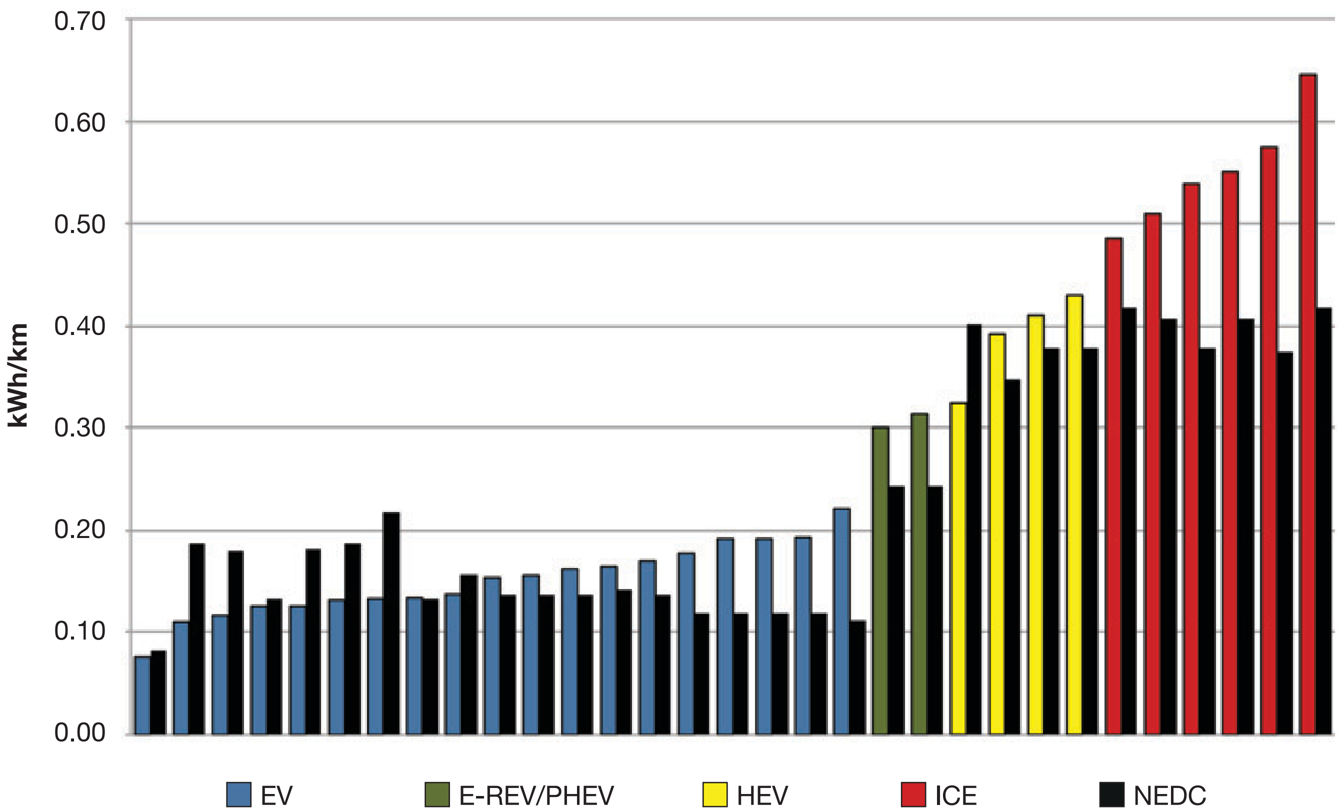
## Real-world vs. NEDC figures

The official test procedure by which fuel economy (or in the case of EVs, range) and $CO_2$ emissions are measured is the New European Driving Cycle (NEDC). While this is a useful means of comparing the performance of vehicles, there is much debate about its ability to provide figures that reflect real-world driving.

Figure 2 shows that for almost all vehicles, the NEDC fuel economy measurements (expressed here as energy consumption and illustrated by the black bars adjacent to each entry) varied markedly from actual performance. The majority of entries used more energy than would have been expected from the NEDC figures, even though the event encouraged as fuel-efficient driving as possible. The minority of vehicles which performed better than expected were all EVs, either prototypes or made by niche manufacturers.

For the more efficient EVs, the real-world range was on average 38% higher than suggested by the NEDC, while for the rest it was 25% lower. And whilst one HEV actually used 24% less energy than in the NEDC, all the other entries consumed more: on average, HEVs used 11% more energy, E-REVs/PHEVs 21% more, and ICE vehicles 27% more.

**Figure 2: Real-world vs. NEDC energy consumption**

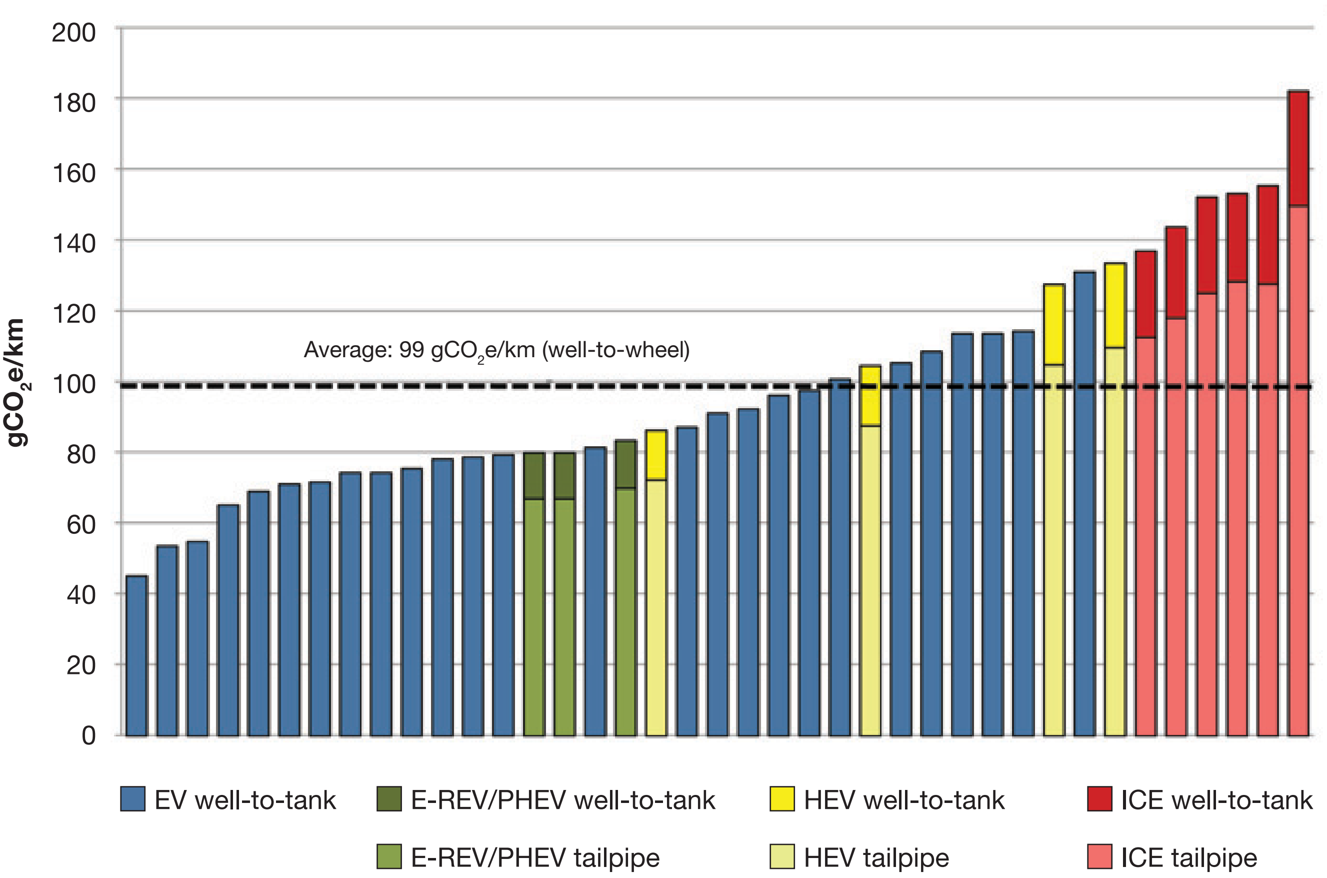


## $CO_2$ emissions

Carbon emissions were calculated by applying Defra/DECC conversion factors used by companies calculating and reporting their greenhouse gas emissions. The results are divided into tailpipe (i.e. tank-to-wheel) emissions, which currently serve as a basis for policy and regulation, and 'well-to-wheel' emissions, which give a more complete picture of vehicles' environmental impact.

In terms of tailpipe emissions, illustrated by the lighter-shaded part-bars in Figure 3, there is a clear performance hierarchy: EVs (which have no tailpipe emissions), E-REVs/PHEVs, HEVs and then ICE vehicles. On average, ICE vehicles emitted 58 $gCO_2$/km more from the exhaust than E-REVs/PHEVs, and 33 $gCO_2$/km more than HEVs. It is worth noting that although according to NEDC figures all ICE vehicles should have emitted less than 110 $gCO_2$/km from the tailpipe – the threshold specified in the entry regulations – all of them actually exceeded this limit in real-world driving.

**Figure 3: Tailpipe and well-to-wheel $CO_2$ emissions**




Note: E-REV/PHEV well-to-wheel emissions, indicated by the dark green bars, are likely to have been higher than shown, because the figures do not include emissions from electric-only mode owing to technical difficulties with measurement.

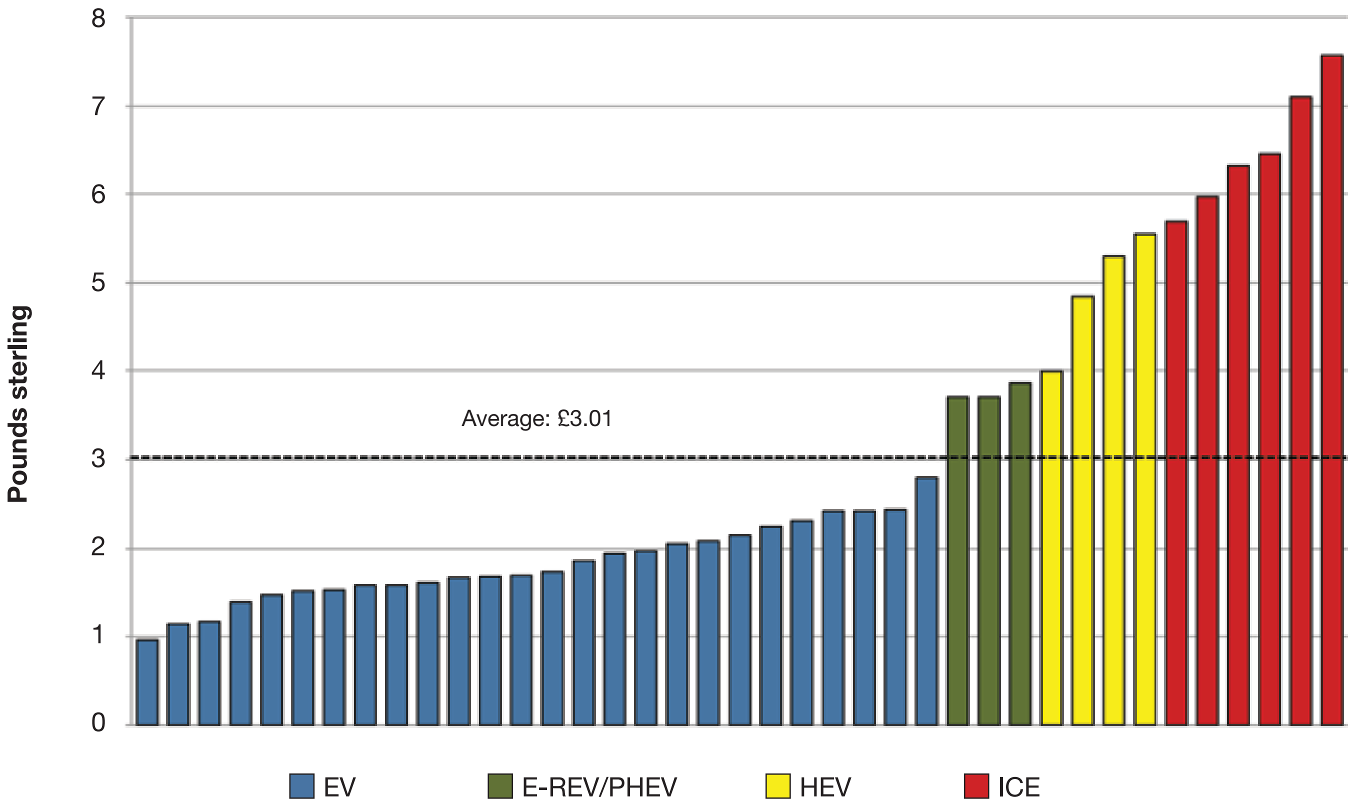
The overall well-to-wheel emission figures shown in Figure 3 include greenhouse gases emitted from the tailpipe, emissions from generating electricity (in the case of EVs and E-REVs/PHEVs), and also emissions associated with the extraction, transportation, refinement, distribution, storage and retail of finished fuels – so-called 'well-to-tank' emissions. They are expressed in $CO_2$-equivalents as they also include methane and nitrous oxide weighted according to their global warming potential. Figure 3 illustrates that, as in the case of tailpipe emissions, EVs emitted the least, followed by E-REVs/PHEVs, HEVs and finally ICE vehicles, confirming that the larger the degree of power train electrification, the lower the $CO_2$ emissions. As with energy consumption, emissions varied by a factor of almost 3 amongst EVs, while for HEVs they varied by a factor of 1.5, and 1.3 for ICE vehicles; E-REV/PHEV emissions were within a very narrow band.

EV well-to-wheel emission figures, and to a lesser extent those for E-REVs/PHEVs, are sensitive to the assumptions made about grid carbon intensity – the $CO_2$ emissions associated with generating one unit of electricity. The above analysis is based on the rolling average figure of 594 $gCO_2e$/kWh used by the UK government. However, if the vehicles had been charged at peak hours during the day, when extra electricity demand is met through the burning of abundant fossil fuels such as coal, their emission figures would increase by almost 16%. If, on the other hand, they had been charged at night, when a higher proportion of their electricity would have come from low-carbon sources, the emission figures would be 20% lower than illustrated in Figure 3.[6]

## Fuel costs

Fuel costs were calculated using the average price at the time of the FCC: £1.34 per litre of petrol, £1.40 per litre of diesel and 14p per kWh of electricity (see Table 2). The costs for the whole run ranged from just under £1 per vehicle to over £7.50, with an average cost of £3. EVs were by far the cheapest to run with fuel costs averaging £1.82, followed by E-REVs/ PHEVs with an average of £3.76. HEVs averaged £4.92 and ICE vehicles £6.52. In fact, the fuel costs of all EVs were below the overall average, while for the other power trains they were above the average. Thus the larger the ICE and liquid fuel component, the more expensive the vehicle was to run, which is mainly due to the fact that petrol and diesel are taxed through fuel duty.

**Figure 4: Fuel costs for the 57-mile run**




It is interesting to note that when compared on a price-per-kWh basis, petrol and diesel cost almost exactly the same as electricity: 14p and 13p respectively. EVs' low fuel costs are therefore not attributable to the cheapness of electricity relative to petrol and diesel, but to their superior power train efficiency over vehicles with an ICE. If the number of EVs on the UK's roads increases substantially – which seems likely in the longer term – this cost advantage may well disappear, however, as the government will have to make up for the foregone revenue from hydrocarbon fuel duties, either through taxing electricity as a transport fuel or other means such as road pricing, all of which will increase running costs.

## Driving style

An analysis of driving style reveals that average speed did not have any impact on energy consumption, which was to be expected given the relatively narrow average speed band of between 16 mph and 21 mph for the FCC (Figure 5).

**Figure 5: Energy consumption relative to average speed**

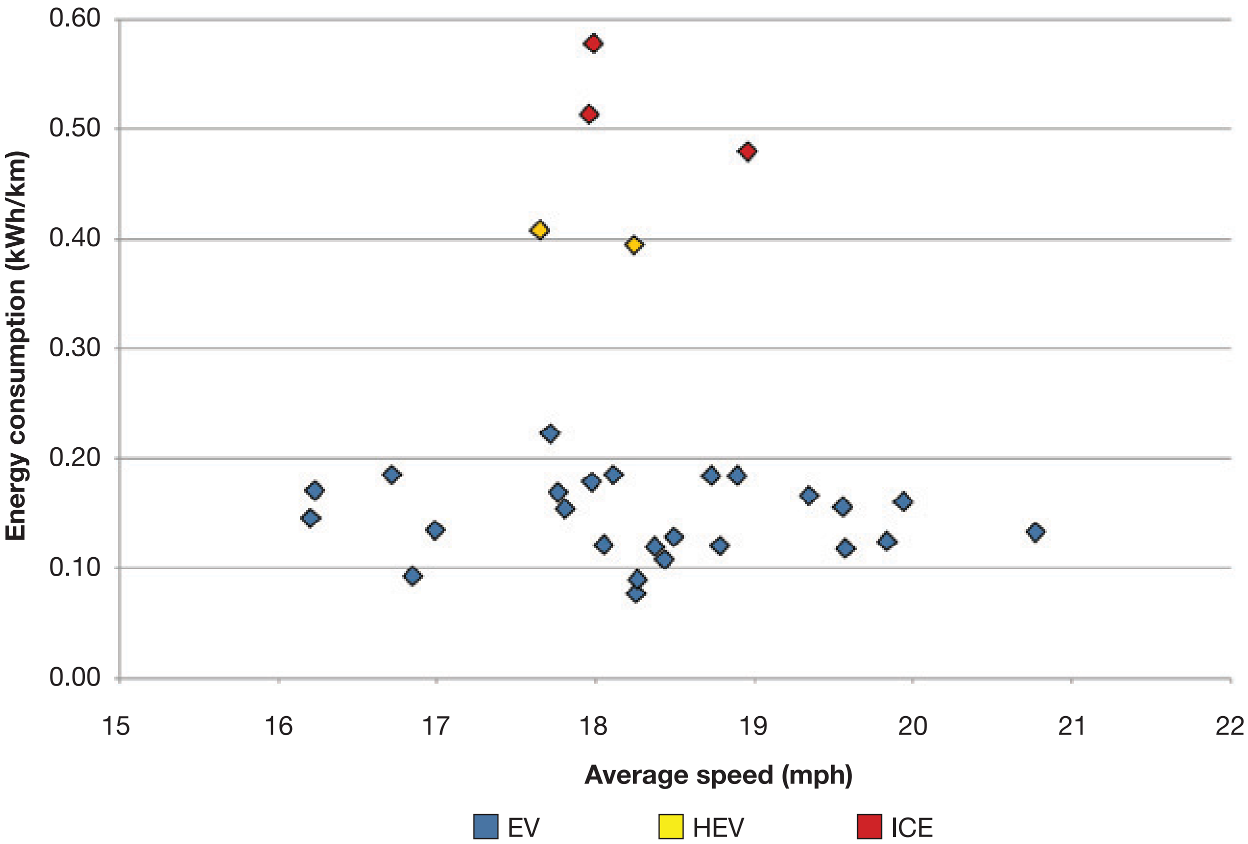
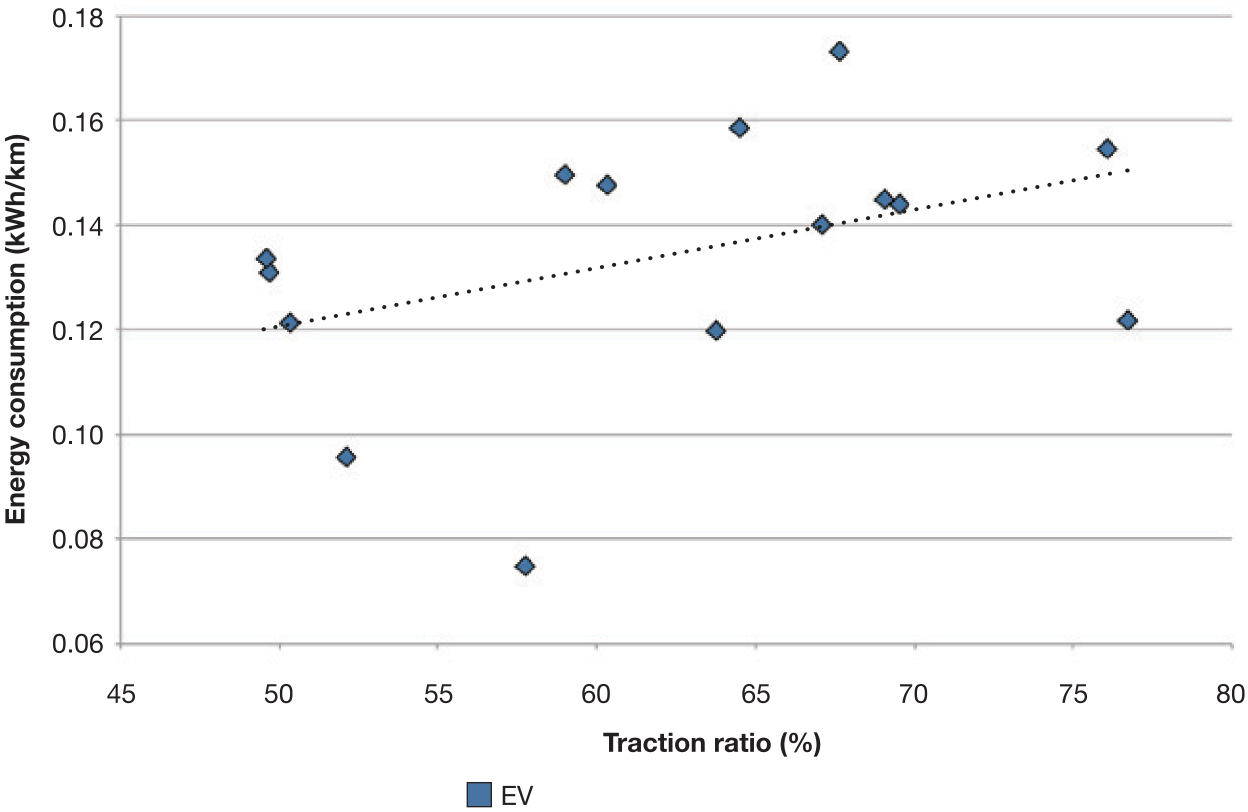



Figure 6 (which, due to availability of data, relates to EVs only) shows the relationship between the 'traction ratio' and energy consumption. The traction ratio refers to the proportion of time a vehicle spends providing propulsion force to the wheels – so-called 'traction mode'. The other possible modes are braking and coasting. Unsurprisingly, the more time is spent on the accelerator, the more energy is used. An interesting point worth noting is that a vehicle with above-average speed, yet with a lower traction ratio (i.e. a lower proportion of time spent on the accelerator), can be more efficient than the same vehicle with below-average speed but a higher traction ratio. To minimise energy consumption, therefore, the more the accelerator pedal is avoided the better.

**Figure 6: Energy consumption relative to traction ratio**




# Conclusions

- EVs used the least amount of energy, thanks to the superior efficiency of their power train. They were followed by E-REVs/PHEVs, HEVs, and finally ICE vehicles, confirming that **the larger the degree of power train electrification, the more efficient the vehicle.**
- **Tailpipe emissions were lowest for E-REVs/PHEVs, followed by HEVs and then ICE vehicles.**
- **Well-to-wheel $CO_2$ emissions were lowest for EVs and E-REVs/PHEVs, followed by HEVs and then ICE vehicles.**
- EV well-to-wheel emissions, and to a lesser extent those of E-REVs/PHEVs, depend on the assumptions made about **grid carbon intensity** and the time of day at which they are charged, potentially fluctuating between +16% and -20% from the figures in this report, which are based on a rolling average.
- The event again confirms the **discrepancy between official NEDC fuel economy, range and $CO_2$ emission figures on the one hand and real-world performance on the other**, at least over this route. While in some cases real-world performance was better, in most cases the NEDC underestimated vehicles' energy consumption and $CO_2$ emissions.
- In terms of fuel costs, **EVs were the cheapest to run**, followed by E-REVs/PHEVs, HEVs and ICE vehicles. It is interesting to note that this is not due to the supposed cheapness of electricity relative to petrol and diesel (which is not the case, as they are roughly the same price per kWh), but due to EVs' superior power train efficiency.
- An analysis of driving style suggests that **average speed did not have an impact on energy consumption** in the FCC, and **confirms that the less time spent on the accelerator the less energy is consumed.**

# About the authors

Clemens Lorf is a Grantham Institute-funded PhD student based in the Energy Futures Lab and the Mechanical Engineering Department at Imperial College London, where he is focusing his research on the optimum battery capacity for electric vehicles. As part of his research studies, he took part in the Racing Green Endurance project which developed the record-breaking electric car that drove down the Pan-American Highway from July to November 2010.

Luca Lytton is Research Manager at the RAC Foundation, where he is responsible for the environmental research brief. He has written and project-managed reports on low-carbon vehicles, and has been involved in the Foundation's ongoing work on road pricing.

# Notes

[1] RAC Future Car Challenge (2011). *Official Entry Regulations*. Retrieved 27 February 2012 from www.futurecarchallenge.com/downloads/2011-downloads/Participate%20-%2Document%20Downloads/2011%20FCC%20-%20Entry%20Regulations,%20Revised%2031%20July.pdf.

[2] For an explanation of how the different types of power trains work, please see: Lytton, L. (2010). *Driving Down Emissions – The potential of low carbon vehicle technology*. RAC Foundation. Retrieved 28 February 2012 from www.racfoundation.org/assets/rac_foundation/content/downloadables/low_carbon_vehicle_technology-lytton-report.pdf.

[3] The following entries were not included in the analysis: Bodsham Hatchback, Chevrolet Volt, Gordon Murray Design T.25, Mercedes Benz Vito E CELL, Nissan LEAF (four entries), Peugeot iOn (two entries), Proton Persona Elegance REEV, Range Rover Range_e (three entries), smart fortwo diesel, Tesla Roadster Sports, Toyota Highlander FCHV, Vauxhall Ampera (three entries), Zytek Mercedes Vito 111 Compact MPV and Zytek Mercedes Vito 111 Taxi EV.

[4] AEA Technology (2011). *2011 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*. Retrieved 21 February 2012 from http://archive.defra.gov.uk/environment/business/reporting/pdf/110819-guidelines-ghg-conversion-factors.xls.

[5] For petrol and diesel, see: DECC (2012). *Weekly fuel prices*. Retrieved 21 February 2012 from www.decc.gov.uk/assets/decc/statistics/source/prices/weeklyfuel.xls. The figures are for retail stations which include an element of biofuel. For electricity, see: DECC (2012). *Average annual domestic electricity bills for selected towns and cities in the UK and average unit costs (QEP 2.2.3)*. Retrieved 21 February 2012 from www.decc.gov.uk/assets/decc/statistics/source/prices/qep223.xls. The figure is weighted by population and payment type.

[6] Lytton, L. (2011). *Shades of Green – Which low-carbon cars are the most eco-friendly?* RAC Foundation. Retrieved 28 February 2012 from www.racfoundation.org/assets/rac_foundation/content/downloadables/shades_of_green-lytton-050511.pdf.

## Energy consumption, $CO_2$ emissions and fuel costs by entry

| Make/model | Power train | Energy consumption (kWh/km) | Tailpipe emissions ($gCO_2/km$) | Well-to-wheel emissions ($gCO_2e/km$) | Fuel costs |
|---|---|---|---|---|---|
| Gordon Murray D. T.27 | EV | 0.08 | 0 | 45 | £0.96 |
| smart fortwo coupé EVC | EV | 0.09 | 0 | 54 | £1.14 |
| Jaguar E-Type Electric | EV | 0.09 | 0 | 55 | £1.17 |
| VW Golf Blue-e-Motion | EV | 0.11 | 0 | 65 | £1.39 |
| Mercedes Benz A-Class | EV | 0.12 | 0 | 69 | £1.47 |
| Lotus Elise S1 Electric | EV | 0.12 | 0 | 71 | £1.51 |
| MG MGF Electric | EV | 0.12 | 0 | 72 | £1.53 |
| Delta E4-Coupe | EV | 0.13 | 0 | 74 | £1.58 |
| Proton Saga EV | EV | 0.13 | 0 | 74 | £1.58 |
| VW Lupo Electric | EV | 0.13 | 0 | 76 | £1.61 |
| VW Golf Blue-e-Motion | EV | 0.13 | 0 | 78 | £1.67 |
| BMW Mini E | EV | 0.13 | 0 | 79 | £1.68 |
| Delta E4-Coupe | EV | 0.13 | 0 | 79 | £1.69 |
| BMW Active E | EV | 0.14 | 0 | 81 | £1.73 |
| Citroen Nemo Van EVC | EV | 0.15 | 0 | 87 | £1.86 |
| Nissan LEAF | EV | 0.15 | 0 | 91 | £1.94 |
| Nissan LEAF | EV | 0.16 | 0 | 92 | £1.97 |
| Nissan LEAF | EV | 0.16 | 0 | 96 | £2.05 |
| Tesla Roadster | EV | 0.16 | 0 | 98 | £2.08 |
| Nissan LEAF | EV | 0.17 | 0 | 101 | £2.15 |
| smart fortwo coupé ed | EV | 0.18 | 0 | 105 | £2.24 |
| Lightning GT | EV | 0.18 | 0 | 108 | £2.31 |
| smart fortwo coupé ed | EV | 0.19 | 0 | 114 | £2.42 |
| smart fortwo coupé ed | EV | 0.19 | 0 | 114 | £2.42 |
| smart fortwo coupé ed | EV | 0.19 | 0 | 114 | £2.44 |
| Radical SRZero | EV | 0.22 | 0 | 131 | £2.79 |
| Toyota Prius PHEV | PHEV | 0.30 | 67 | 80 | £3.71 |
| Proton Exora REEV | E-REV | 0.30 | 67 | 80 | £3.71 |
| Toyota Prius PHEV | PHEV | 0.31 | 70 | 83 | £3.87 |
| Honda Insight | HEV | 0.32 | 72 | 86 | £4.00 |
| Toyota Auris Hybrid | HEV | 0.39 | 88 | 105 | £4.84 |
| Peugeot 3008 Hybrid4 C. | HEV | 0.41 | 105 | 127 | £5.30 |
| Peugeot 3008 Hybrid4 C. | HEV | 0.43 | 110 | 133 | £5.55 |
| Peugeot 508 HDi | ICE | 0.49 | 113 | 137 | £5.69 |
| VW Passat Blue-Motion | ICE | 0.51 | 118 | 144 | £5.97 |
| MINI Cooper Diesel | ICE | 0.54 | 125 | 152 | £6.32 |
| BMW 320d ED | ICE | 0.55 | 128 | 155 | £6.45 |
| Fiat 500 TwinAir | ICE | 0.57 | 128 | 153 | £7.09 |
| Peugeot 508 HDi | ICE | 0.64 | 150 | 182 | £7.57 |
| **Average** | **–** | **0.24** | **103** | **99** | **£3.01** |


Gordon Murray Design T.27
Overall winner of the 2011 RAC Future Car Challenge

Fore more information about the RAC Future Car Challenge please visit **www.futurecarchallenge.com**.

The Royal Automobile Club Foundation for Motoring is a transport policy and research organisation which explores the economic, mobility, safety and environmental issues relating to roads and their users. The Foundation publishes independent and authoritative research with which it promotes informed debate and advocates policy in the interest of the responsible motorist.

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