ELECTIC AND CONVENTIONAL DRIVE VEHICLES – A COMMENTARY

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Nomenclature and notes

In this note Internal Combustion powered vehicles, ICVs, are diesel powered or powered by the MUSIC experimental petrol engine under development by MUSI Engineering. Improved ICVs would have regenerative braking, zero idling losses (engine off when stationary) and higher engine efficiencies. Improved electric powered vehicles, EVs, are also assumed to have both higher efficiencies and motors mounted on the wheels thereby eliminating transmission losses.

Summary

The UK Government's belief that EVs will emit 40% less carbon than ICVs depends on the claims of manufactures, see "Investigation into the Scope for the Transport Sector to Switch to EVs and Plug in Hybrid Vehicles" dated October 2008 at http://www.berr.gov.uk/files/file48653.pdf.

In contrast our analysis depends on assigning energy efficiencies to the various links in the chain from refinery, or power station, to the road surface. The parameters used are open to discussion. However, the figures do suggest that:

(1) The Government's claim is supported only if the unrealistic comparison is made between an EV, operating at theoretical optimum efficiency, i.e. at constant speed and ambient temperature, and a diesel powered vehicle operating in congested conditions.

(2) Under realistic conditions present EVs may emit 15% **less** carbon than the best existing diesels operating on congested roads but 55% more when on rural roads, Table 1

(3) Improved EVs may emit between the same as improved diesels and 20% more than the amounts likely from the MUSIC, Tables 2 and 3

Our calculations do not take account of the energy and emissions required to manufacture and scrap an EV's battery or of the risk that large scale electrification would extend the life of coal fired power stations thereby effectively doubling the carbon emissions that should be associated with EVs.

Separately from that, The Government's analysis claims that an EV would be cheaper to run than a conventional one. However, the comparison does not allow for the tax on fuel. That biases the energy costs in favour of the EV by a factor of three. In contrast our calculations suggest diesel or petrol costs would have to rise greatly before the resource costs of the EV's fuel would be the smaller, Tables 4(1) to 4(3)

Against that background it may well be better to invest in improving ICVs rather than in the electric route. Indeed the latter may prove to be an environmental disaster, emitting substantially more carbon that the most efficient ICVs would, let alone the problems of disposing of e.g. 30 million lithium-ion batteries.

Recommendation.

Rather than acting on our conclusion, where there must be contention about the parameters used, or on the report that underpins the UK Government's belief (a) proper tests should be carried out to establish the real fuel consumptions of EVs and ICVs of the same body shape and carrying capacity and performance and (b) there should be an assessment of the possible improvements to both EV's and ICVs.

THE DETAIL

The UK Government's belief, that EVs are more efficient and emit less carbon than those powered by the internal combustion engine, stems largely from the study cited above. That study was undertaken by Arup and Cenex on behalf of the Department for Business Enterprise and Regulatory Reform (BERR) and the Department for Transport (DfT).

A key finding is: “EVs have the potential to offer significant carbon dioxide and greenhouse gas emissions reductions compared to conventional petrol/diesel fuelled internal combustion engines. This applies over a full life cycle, taking account of emissions from power generation and emissions relating to production and disposal. Based on the current UK grid mix there are already significant benefits of the order of approximately 40% reduction; these benefits have the potential to become much greater with further decarbonisation of the UK power mix”.

However, instead of providing the fundamental data upon which calculations should depend there is generalised reference to the GaBi4 suite and to the claims of manufacturers. Consequently we lodged a Freedom of Information request that included the following:

(a) The percentage of the energy burnt in power stations that reaches end users, namely “the plug”.
(b) The CO2 per KWh of primary burn.
(c) The ratio of the energy delivered to the drive chain to the energy taken from the plug for the presumed EV.
(d) The assumed thermal efficiency of the presumed internal combustion engine.
(e) The energy used to manufacture and scrap an electric car’s battery divided by the energy that the battery may deliver during its life.

In summary, the response, available via the HTML version of this note, is that the GaBi4 grid mix for 2010 delivers 31% of the primary burn to the plug, rising to 50% in 2030 and that the carbon emissions are in the paper referred to, when they are not, see note (i), further, with regard to efficiencies we read:

“*We [Arup] did not look at individual element losses within the vehicle, only the overall efficiency figures as supplied by manufacturers.”*

And with regard to the energy and emissions associated with battery manufacture and scrappage:

“*We* [Arup] *could find no quantitative data on the energy required to manufacture a lithium ion battery. Neither was there any data available on the energy required for recycling the battery”*.

We are astonished. After all, (a) without knowledge of the energy used to manufacture batteries how can anyone calculate the whole of life carbon emissions and (b) manufacturers’ claims are notoriously optimistic, as illustrated by the following anecdotes.

(1) An electric car provided to a journalist for tests was alleged to have a 70 mile range. The journalist decided to be safe and planned a 50 mile trip only to find the specially prepared car failed at 37 miles.
(2) A user of a G-Wiz found that the battery expired after 2 years and 3 months instead of after the hoped for 5 years.
(3) Jeremy Clarkson of Top Gear found that the Tesla ran out of power after 55 miles on his test track rather than after the 220 miles claimed by the manufacture.
(4) An electric Ford Transit sized van provided to a manufacturer, who wants to remain anonymous, was alleged to have a range of 100 miles. The manufacturer found that on the level, and with no load, the vehicle managed 60 miles, but that on hills in Wales in managed six (yes six).
(5) Adverse weather conditions are said to reduce battery performance by 40% to 50%

Further, section 6 of the paper cited above “demonstrates” that the cost of running EV will be less than that for an IC powered vehicle. However, the costs assigned to petrol and diesel include tax. In contrast, our analysis shows that diesel costs would have to rise dramatically if the resource costs of the EV’s fuel, void of tax, were ever to be the lower.

Against that background we regard the paper as an entirely inadequate basis for national policy.

Our analysis is in the appendix below. The parameters used are open to discussion. However, the figures do suggest that money may be better invested on improving conventional vehicles than on the electric route. Indeed the latter may prove to be an environmental disaster, emitting perhaps 20% more carbon that the most efficient IC vehicles would, let alone the problems of disposing of e.g. 30 million lithium-ion batteries.

Other factors to consider include:

(a) large scale electrification may extend the life of coal fired power stations. If so the emissions for EVs should be doubled

b) We have made no allowance for the energy expended and carbon emitted in manufacturing and scrapping an electric car's batteries

(c) In cold climates waste heat from the IC engine runs the car heater.

Recommendation. Rather than acting on our preliminary conclusion, or on the ARUP report, proper tests should be carried out to establish the real fuel consumptions of electric and IC vehicles of the same body shape, carrying capacity and performance. For example identically shaped vehicles could be driven similarly over a range of speeds and stopping scenarios and the fuel consumptions compared. Only then would anyone be in a reasonable position to determine policy.

Of course, if oil ran out then the only option would be the electric route. However, if oil and other fossil fuel failed within 10 or 20 years then the energy shortage would be so acute that motoring would be the preserve of the truly wealthy or essential services. In that context Tables 4(1) to 4(3) show that diesel prices would have to rise hugely before the resource cost would exceed that of electrical power.

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(i) Subsequent inquiry provided the GaBi4 numbers of: 0.62892 kg CO2/kWh in 2010: 0.41128 kg CO2/kWh in 2020: 0.35567 kg CO2/kWh in 2030. The 2010 value is substantially above that the value generally accepted for the UK generating industry of circa 0.5 kg CO2/kWh and above our value of 0.542. We believe that is because theGaBi4 value includes some of the emissions prior to the burn in power stations.

APPENDIX

Interpreting the data – it is the efficiency ratios or the emission ratios at the bottom of the spread tabulations that compare the vehicles. The ratios of the mean values are the ones referred to in the text.

Sensitivity tests can be carried out rapidly by varying the parameters used in the Excel version of the tabulations.

The data that determines the relative fuel efficiency and carbon emissions of the vehicles are:

(1) The energy loss refining and transporting fuel to filling stations.
(2) The thermal efficiency of the internal combustion (IC) engines.
(3) The proportion of the energy burnt in power stations that reaches the plug.
(4) The efficiency of the charging, battery and motor combination.
(5) The drive chain losses.
(6) The energy lost in braking.
(7) The energy, if any, recovered from braking.
(8) The rolling loss.
(9) The weight of the vehicle.
(10) The idling losses, if any.
(11) The carbon emitted per KWh of primary energy burnt.

The MUSIC in the following is an experimental two stroke petrol engine under test at MUSI Engineering.

Charging losses are set to 8%

Battery discharging losses are set to 10% for current EVs falling to 5% for aspirational ones

Electric motor losses are set to 10%.

A realism factor of 0.6 has been applied to current EVs. That appears sensible in the light of the anecdotes cited above. For aspirational EVs the realism factor has been set to 0.8.

Engine efficiencies for diesels have two sets of five values. These are linear interpolations covering (a) the current realistic range of 25% to 30% and (b) the aspirational range of 36% to 40% where the higher value of each pair may be appropriate for constant speed or rural running and the lower value for variable speed and the most congested urban conditions. The range for the MUSIC is set to 43.2% to 48% following MUSI Engineering's advice.

Drive chain losses have been set to (a) 25% for existing EV and ICV and (b) 0% for the future or aspirational EVs on the basis the wheels and motors will then be combined as one so eliminating transmission losses.

Braking losses will vary greatly according to the driving conditions. We have provided the range 5% (representing uncongested rural conditions) to 40% (representing congested urban conditions).

Regenerative braking for EVs appears to be established and is said to recover 50% of braking energy losses. For conventional vehicles Flybrid systems have a flywheel based arrangement which they claim may recover up to 70% of braking losses and which may be available in 4 to 6 years on standard vehicles. Where applicable we have used 50% for both systems.

Rolling loss has been set to 50% of the energy reaching the wheel leaving the balance for overcoming wind resistance.

Weight: EVs are said to weigh 25% more than conventional ones. Flybrid's mechanical regenerative braking may add 5% to the vehicle weight. Hence, where applicable, the transmission, braking and rolling losses are inflated by those amounts.

Idling losses on EVs need not arise. Idling losses for conventional vehicles have been assigned the range 2.5%, when the braking loss is 5%, through to 20%, when the braking loss is 40%, except that, where regenerative braking is assumed, the idling loss has been set to zero (following the BMW system which switches the engine off when the vehicle is stationary).

On that basis, if we compare the **"realistic" EV** (Table 1) with **existing diesels** then the diesels may use 50% less fuel than the EV and emit 14% less carbon. If we improve the EV by setting the transmission losses to zero, (Table 2), but also improve the diesel by assigning to it aspirational engine efficiencies, regenerative braking and zero idling then the EV would use 26% more energy than the diesel but the emissions of the two types of vehicle would be the same. If we compare the improved EV with the MUSIC, Table 3, then the EV would use 41% more fuel and emit 22% more carbon its competitor.

Only if we make the, in our view, entirely unrealistic comparison of a **theoretical** electric car with a current diesel operating in congested conditions do we find the EV emitting circa 40% less carbon than the diesel, as claimed by the Arup report, Table 1

Fuel costs: Tables 4(1) to 4(3) provide a range of costs per KWh available to overcome wind resistance for the various scenarios examined. In all cases it is clear that the price of diesel or petrol would have to rise a great deal before the cost of the EV's fuel would be the cheaper

NOTES TO CALCULATIONS

The principles. There are various points in the chain from primary burn to end point at which the fuel efficiency of a vehicle could be calculated. Our previous calculation did that with respect to the upstream end of the vehicle's drive chain (immediately downstream from the engine or motor). The present calculation does that with respect to the downstream side of rolling. That provides the ratio of (a) the energy available to overcome wind resistance to (b) the energy used in the primary burn. The ratio is subsequently referred to as the vehicles efficiency.

Dividing the efficiency of one vehicle by the same for another vehicle provides the relative energy consumptions needed to power the down steam requirements. I.e. if the ratio of vehicle **one's** efficiency to vehicle **two's** is 1.5 then vehicle **two** uses 50% **more** energy than vehicle **one.**

In more detail we define the losses across each phase in percentage terms as follows:

Refinery/Generating industry burn to plug losses		L1 leaving residual of (1-L1) =E1
Battery charging losses	)	
Battery discharging losses	)	
Electric motor losses	)	L2 leaving residual of (1-L2) =E2
IC engine losses	)	
Transmission losses		L3 leaving residual of (1-L3) =E3
Braking losses		L4 leaving residual of (1-L4) =E4
Rolling losses		L5 leaving residual of (1-L5) =E5

Hence, if P is the primary energy burnt and if X is the residual for overcoming wind resistance we have an efficiency, defined as X/P = E1 x E2 x E3 x E4 x E5 ....(1)

If there is regenerative braking returning R% of the initial braking loss, L4, then the actual braking loss becomes (L4 - (L4 x R)) and E4 should be replaced by (1 - (L4 - (L4 x R))) which reduces to: 1 + L4(R-1) ....**(1a)**
Hence the spread calculations use the formula:
Efficiency, X/P = (1-L1) x (1-L2) x (1-L3) x (1+L4(R-1)) x (1-L5)................ **(1b)**
Where L4 is the braking loss prior to regeneration.

Weight: If energy **losses** in transmission, braking and rolling are proportional to weight then before comparing the efficiency of a heavy vehicle, such as an electric powered car, with a conventional one the energy at the drive chain of the heavier vehicle should be increased by **adding** the additional losses attributable to the greater weight.

For example, if the **losses** in transmission amounted to e.g. L3% of the energy available to the drive chain then, if the downstream energy is to remain the same when the weight is increased by W% the upstream energy should be increased by **adding** (L3 x W) to the upstream energy's so providing a multiplier to the light vehicle upstream energy of: 1 + (L3 x W) ... (2)
The overall efficiency of the heavier vehicle for comparison with the lighter vehicle would then be the lighter vehicle's efficiency divided by (1 + (L3 x W)) .... (3)

Hence the divisor yielding the comparative heavier vehicle efficiency, reference (1) and (1b) above, would be [(1 + (L3 x W)) x (1 + (L4 x W)) x (1 + (L5 x W))] .... (4)
That could be extended to:
[(1 + (L3 x K3 x W)) x (1 + (L4 x (R-1) x K4 x W)) x (1 + (L5 x K3 x W))] .... (5)
Supposing anyone can estimate the K values.

Emissions: Dividing the carbon emission per KWh produced by the primary burn by the fuel efficiency provides the carbon emission per KWh available to overcome the downstream requirements. The ratios of carbon those carbon emissions then compare the vehicles.

Electric generating industry efficiency

Table 5.6, of the Digest of UK energy Statistics, the DUKES, 2009 edition, provides, for 2008, 952,722 GWh energy burnt in power stations and, in table 5.5, net usage (as delivered to "the plug") of 342,127 GWh. Hence the ratio of power used by end users to fuel burnt is 0.359. That is less than a value of 40%, commonly cited by others, probably because others cite the efficiency with respect to the supply to the grid, i.e. before taking account of grid losses. That error is mirrored in the carbon estimates – see below.

Carbon emissions – electricity generation

Table 5C of the DUKES provides 497 tonnes per GWh supplied. According to Julian Prime of the BERR that value relates to the supply of 373,322 GWh in table 5.6. Instead of using the 497 we note the energy burnt (including nuclear) was 952,722 GWh of which **342,127** reached "the plug". Hence there were 542 Tonnes of CO_2 per GWh **at the plug** and 195 Tonnes per GWh burnt in the power stations.

We comment, the difference between the 497 and the 542 highlights what appears to be a systematic error in the ARUP and other reports as to the emissions associated with the KWh consumed by end users. Those reports overlook either the grid losses or energy industry use.

We also note that the value does not take account of the emissions attributable to mining and delivering the fuel to the power stations

Carbon emissions from diesel

The 3.15 Kg of CO_2 are emitted per Kg of diesel burnt. The KWh per Kg diesel is to 13.1. Hence there are 0.24 Kg of CO_2 per KWh of diesel burnt. As with electric power this value does not take account of the emissions in refineries and transporting the fuel to filling stations.

Fuel costs

Tables 4(1) to 4(3) provide the costs per KWh of the residual energy available to overcome wind resistance for each of the various scenarios using the following.

If (a) p is the cost per KWh at the plug or at the filling station (b) q1 is the overall efficiency and (c) q2 is the efficiency, power station burn to plug, or refinery to filling pump then the price per KWh available to overcome the wind is p/q1/q2.

NOTE = EXCEL VERSION OF THE FOLLWONG TABLES ARE AVAILABLE FROM THE HTML VERSION OF THIS NOTE.

Table 1Current EVs and existing diesels

ELECTRIC CAR DATA	From urban....................................... to rural						GENERAL NOTES
Power Sta. to plug loss (i)	64.1%						(a) If motors were wheel-mounted the transmission loss may be zero for the EV.
Charging loss	8.0%						
Battery discharging loss	10.0%						
Motor loss	10.0%						
Transmission loss, (a)	25%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	50.0%						
Rolling loss R	50%	50%	50%	50%	50%		(b) ASSUMING that the motor and battery each operate at the theoretical efficiencies.
Added weight	25%					**Means**	
Theoretical efficiency (b)	8.03%	8.53%	9.03%	9.53%	9.78%	**8.98%**	
WEIGHT- NORMALISED	6.39%	6.88%	7.37%	7.87%	8.13%	**7.33%**	
kg C02 per KWh for the wind	3.049	2.836	2.646	2.476	2.398	**2.681**	
Realism factor	60.0%						
Realistic efficiency	4.82%	5.12%	5.42%	5.72%	5.87%	**5.39%**	
WEIGHT- NORMALISED	3.84%	4.13%	4.42%	4.72%	4.88%	**4.40%**	
kg C02 per KWh for the wind	5.082	4.726	4.410	4.127	3.996	**4.468**	
DIESELS: Present day efficiencies, no Regenerative braking or idling suppression							
Loss: refinery to filling station	10.0%						
	From urban ---------------------------- to rural					**Means**	
BTE Diesel	25.0%	26.3%	27.5%	28.8%	30.0%	**27.50%**	
Transmission loss	25%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	0.0%						
Rolling loss	50%	50%	50%	50%	50%		
Added weight %	0%						
Idling losses	20.0%	15.0%	10.0%	5.0%	2.5%		
Fuel efficiency (wind energy divided by primary burn)							
Not weight normalised	4.1%	5.3%	6.7%	8.3%	9.4%	**6.74%**	
Weight Normalised	4.1%	5.3%	6.7%	8.3%	9.4%	**6.74%**	
CO2 emissions per KWh available to wind resistance							
CO2 Weight Normalised	5.937	4.562	3.598	2.898	2.564	**3.912**	
EFFICIENCY RATIOS: WEIGHT- NORMALISED data							
Diesel / Theoretical EV	0.633	0.767	0.907	1.053	1.153	**0.919**	
Diesel / Realistic EV	1.056	1.278	1.511	1.756	1.922	**1.532**	
EMISSION RATIOS: WEIGHT- NORMALISED data							
Theoretical EV / Diesel	0.514	0.622	0.735	0.854	0.935	**0.685**	
Realistic EV / Diesel	0.856	1.036	1.226	1.424	1.559	**1.142**	

EMISSION PARAMETERS	
KWh per Kg of diesel	13.1
CO2 per Kg of diesel	3.15
Kg CO2 per KWh burnt -electric (ii)	0.195

(i) Table 5.6, of the Digest of UK energy statistics, DUKES, provides for 2008, 952,722 GWh energy burnt in power stations and, in table 5.5, net usage (as delivered to "the plug") of 342,127 GWh. Hence the ratio of power used by end users to fuel burnt is 0.359.

(ii) Table 5C of the 2009 Digest of UK energy statistics provides 497 tonnes per GWh supplied gross. That value relates to the 373,322 GWh (table 5.6 - supplied). Fuel burnt (including non-thermal) was 952,722 GWh of which 342,127 reached "the plug" (Table 5.5) Hence the we have 542 Tonnes per GWh at the plug and 195 Tonnes per GWh burnt in the power stations.

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Table 2 Aspirational EVs and Aspirational diesels

ELECTRIC CAR DATA	From urban... to rural						**GENERAL NOTES**
Power Sta. to plug loss (i)	64.1%						(a) If motors were wheel-mounted the transmission loss may be zero for the EV.
Charging loss	8.0%						
Battery discharging loss	5.0%						
Motor loss	10.0%						
Transmission loss, (a)	0%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	50.0%						
Rolling loss R	50%	50%	50%	50%	50%		(b) ASSUMING that the motor and battery each operate at the theoretical efficiencies
Added weight	25%					**Means**	
Theoretical efficiency (b)	11.30%	12.00%	12.71%	13.41%	13.77%	**12.64%**	
WEIGHT- NORMALISED	9.56%	10.28%	11.02%	11.78%	12.16%	**10.96%**	
kg C02 per KWh for the wind	2.039	1.896	1.769	1.656	1.604	**1.793**	
Realism factor	80.0%						
Realistic efficiency	9.04%	9.60%	10.17%	10.73%	11.01%	**10.11%**	
WEIGHT- NORMALISED	7.65%	8.23%	8.82%	9.42%	9.73%	**8.77%**	
kg C02 per KWh for the wind	2.549	2.371	2.212	2.070	2.004	**2.241**	
ASPIRATIONAL DIESELS: higher efficiency, regenerative braking + idling suppressed							
Loss: refinery to filling station	10.0%						
	From urban ----------------------------------- to rural					**Means**	
BTE Diesel	36.0%	37.0%	38.0%	39.0%	40.0%	**38.00%**	
Transmission loss	25%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	50.0%						
Rolling loss	50%	50%	50%	50%	50%		
Added weight %	5%						
Idling losses	0.0%	0.0%	0.0%	0.0%	0.0%		
Fuel efficiency (wind energy divided by primary burn)							
Not weight normalised	9.7%	10.6%	11.5%	12.5%	13.2%	**11.51%**	
Weight Normalised	9.3%	10.2%	11.1%	12.0%	12.7%	**11.04%**	
CO2 emissions per KWh available to wind resistance							
CO2 Weight Normalised	2.593	2.369	2.173	2.001	1.898	**2.207**	
EFFICIENCY RATIOS: WEIGHT- NORMALISED data							
Diesel / Theoretical EV	0.970	0.987	1.004	1.021	1.042	**1.007**	
Diesel / Realistic EV	1.212	1.234	1.255	1.276	1.302	**1.259**	
EMISSION RATIOS: WEIGHT- NORMALISED data							
Theoretical EV / Diesel	0.786	0.801	0.814	0.828	0.845	**0.812**	
Realistic EV / Diesel	0.983	1.001	1.018	1.035	1.056	**1.016**	

EMISSION PARAMETERS	
KWh per Kg of diesel	13.1
CO2 per Kg of diesel	3.15
Kg CO2 per KWh burnt -electric (ii)	0.195

(i) Table 5.6, of the Digest of UK energy statistics, DUKES, provides for 2008, 952,722 GWh energy burnt in power stations and, in table 5.5, net usage (as delivered to "the plug") of 342,127 GWh. Hence the ratio of power used by end users to fuel burnt is 0.359.
(ii) Table 5C of the 2009 Digest of UK energy statistics provides 497 tonnes per GWh supplied gross. That value relates to the 373,322 GWh (table 5.6 - supplied). Fuel burnt (including non-thermal) was 952,722 GWh of which 342,127 reached "the plug" (Table 5.5) Hence the we have 542 Tonnes per GWh at the plug and 195 Tonnes per GWh burnt in the power stations.

Table 3 Aspirational EVs and MUSIC power vehicles

ELECTRIC CAR DATA	From urban...				to rural		GENERAL NOTES
Power Sta. to plug loss (i)	64.1%						(a) If motors were wheel-mounted the transmission loss may be zero for the EV.
Charging loss	8.0%						
Battery discharging loss	5.0%						
Motor loss	10.0%						
Transmission loss, (a)	0%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	50.0%						
Rolling loss R	50%	50%	50%	50%	50%		(b) ASSUMING that the motor and battery each operate at the theoretical efficiencies.
Added weight	25%					**Means**	
Theoretical efficiency (b)	11.30%	12.00%	12.71%	13.41%	13.77%	**12.64%**	
WEIGHT- NORMALISED	9.56%	10.28%	11.02%	11.78%	12.16%	**10.96%**	
kg C02 per KWh for the wind	2.039	1.896	1.769	1.656	1.604	**1.793**	
Realism factor	80.0%						
Realistic efficiency	9.04%	9.60%	10.17%	10.73%	11.01%	**10.11%**	
WEIGHT- NORMALISED	7.65%	8.23%	8.82%	9.42%	9.73%	**8.77%**	
kg C02 per KWh for the wind	2.549	2.371	2.212	2.070	2.004	**2.241**	
MUSIC: Even higher efficiency +Regenerative braking + idling suppressed							
Loss: refinery to filling station	10.0%						
	From urban ----------------------------------				to rural	**Means**	
BTE MUSIC	43.2%	44.4%	45.6%	46.8%	48.0%	**45.60%**	
Transmission loss	25%						
Braking loss	40.0%	30.0%	20.0%	10.0%	5.0%		
Breaking energy recovered	50.0%						
Rolling loss	50%	50%	50%	50%	50%		
Added weight %	5%						
Idling losses	0.0%	0.0%	0.0%	0.0%	0.0%		
Fuel efficiency (wind energy divided by primary burn)							
Not weight normalised	11.7%	12.7%	13.9%	15.0%	15.8%	**13.81%**	
Weight Normalised	11.1%	12.2%	13.3%	14.4%	15.2%	**13.24%**	
CO2 emissions per KWh available to wind resistance							
CO2 Weight Normalised	2.161	1.974	1.811	1.667	1.582	**1.839**	
EFFICIENCY RATIOS: WEIGHT- NORMALISED data							
MUSIC / Theoretical EV	1.164	1.185	1.205	1.225	1.250	**1.208**	
MUSIC / Realistic EV	1.455	1.481	1.506	1.531	1.562	**1.510**	
EMISSION RATIOS: WEIGHT- NORMALISED data							
Theoretical EV / MUSIC	0.944	0.961	0.977	0.993	1.014	**0.975**	
Realistic EV / MUSIC	1.180	1.201	1.222	1.242	1.267	**1.219**	

EMISSION PARAMETERS	
KWh per Kg of MUSIC	13.1
CO2 per Kg of MUSIC	3.15
Kg CO2 per KWh burnt -electric (ii)	0.195

(i) Table 5.6, of the Digest of UK energy statistics, DUKES, provides for 2008, 952,722 GWh energy burnt in power stations and, in table 5.5, net usage (as delivered to "the plug") of 342,127 GWh. Hence the ratio of power used by end users to fuel burnt is 0.359.
(ii) Table 5C of the 2009 Digest of UK energy statistics provides 497 tonnes per GWh supplied gross. That value relates to the 373,322 GWh (table 5.6 - supplied). Fuel burnt (including non-thermal) was 952,722 GWh of which 342,127 reached "the plug" (Table 5.5) Hence we have 542 Tonnes per GWh at the plug and 195 Tonnes per GWh burnt in the power stations.

Table 4(1)Fuel costs of Existing EVs and existing diesels

EVs						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	3.8%	4.1%	4.4%	4.7%	4.9%	4.4%
Efficiency plug to wind	10.7%	11.5%	12.3%	13.2%	13.6%	12.2%
Pence per KWh at the plug	Cost per KWh available to wind resistance,					
10	93.6	87.0	81.2	76.0	73.6	81.6
15	140.4	130.5	121.8	114.0	110.4	122.5
20	187.1	174.0	162.4	152.0	147.1	163.3
25	233.9	217.5	203.0	189.9	183.9	204.1
30	280.7	261.0	243.6	227.9	220.7	244.9
Current diesels						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	4.05%	5.27%	6.68%	8.30%	9.38%	6.74%
Efficiency Filling station pump to wind	4.5%	5.9%	7.4%	9.2%	10.4%	7.5%
Pump price, pence per litre ex. tax	Cost per KWh available to wind resistance					
20	41.5	31.9	25.2	20.3	17.9	25.0
30	62.3	47.9	37.8	30.4	26.9	37.5
40	83.1	63.8	50.3	40.6	35.9	50.0
50	103.8	79.8	62.9	50.7	44.8	62.4
60	124.6	95.7	75.5	60.8	53.8	74.9
70	145.4	111.7	88.1	71.0	62.8	87.4
80	166.1	127.7	100.7	81.1	71.8	99.9
90	186.9	143.6	113.3	91.2	80.7	112.4
100	207.7	159.6	125.9	101.4	89.7	124.9
110	228.5	175.5	138.5	111.5	98.7	137.4
120	249.2	191.5	151.0	121.7	107.6	149.9
130	270.0	207.4	163.6	131.8	116.6	162.3
140	290.8	223.4	176.2	141.9	125.6	174.8
150	311.5	239.3	188.8	152.1	134.5	187.3

KWh/litre	10.7

Comment - The comparison suggests diesel prices will have to rise hugely before the resource fuel cost of the electric vehicle would be the lower

(a) from Table 1

TABLE 4(2) Fuel costs of Improved EVs and improved diesels

EVs						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	7.6%	8.2%	8.8%	9.4%	9.7%	8.8%
Efficiency plug to wind	21.3%	22.9%	24.6%	26.2%	27.1%	24.4%
Pence per KWh at the plug	Cost per KWh available to wind resistance,					
10	46.9	43.6	40.7	38.1	36.9	40.9
15	70.4	65.5	61.1	57.2	55.4	61.4
20	93.9	87.3	81.4	76.2	73.8	81.9
25	117.3	109.1	101.8	95.3	92.3	102.4
30	140.8	130.9	122.2	114.3	110.7	122.8
Improved diesels						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	9.27%	10.15%	11.07%	12.02%	12.67%	11.04%
Efficiency Filling station pump to wind	10.3%	11.3%	12.3%	13.4%	14.1%	12.3%
Pump price, pence per litre ex. tax	Cost per KWh available to wind resistance					
20	18.1	16.6	15.2	14.0	13.3	15.2
30	27.2	24.9	22.8	21.0	19.9	22.9
40	36.3	33.1	30.4	28.0	26.6	30.5
50	45.4	41.4	38.0	35.0	33.2	38.1
60	54.4	49.7	45.6	42.0	39.8	45.7
70	63.5	58.0	53.2	49.0	46.5	53.4
80	72.6	66.3	60.8	56.0	53.1	61.0
90	81.6	74.6	68.4	63.0	59.8	68.6
100	90.7	82.9	76.0	70.0	66.4	76.2
110	99.8	91.1	83.6	77.0	73.0	83.8
120	108.8	99.4	91.2	84.0	79.7	91.5
130	117.9	107.7	98.8	91.0	86.3	99.1
140	127.0	116.0	106.4	98.0	93.0	106.7
150	136.1	124.3	114.0	105.0	99.6	114.3

KWh/litre	10.7

Comment - The comparison suggests diesel prices will have to rise hugely before the resource fuel cost of the electric vehicle would be the lower

(a) from TABLE 2

Table 4(3)Fuel costs of Improved EVs and the MUSIC

EVs						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	7.6%	8.2%	8.8%	9.4%	9.7%	8.8%
Efficiency plug to wind	7.6%	22.9%	24.6%	26.2%	27.1%	24.4%
Pence per KWh at the plug	Cost per KWh available to wind resistance,					
10	130.7	43.6	40.7	38.1	36.9	40.9
15	196.1	65.5	61.1	57.2	55.4	61.4
20	261.4	87.3	81.4	76.2	73.8	81.9
25	326.8	109.1	101.8	95.3	92.3	102.4
30	392.2	130.9	122.2	114.3	110.7	122.8
The MUSIC						
	From urban ....to rural					Means
Efficiency: primary burn to wind (a)	11.13%	12.18%	13.28%	14.42%	15.20%	13.24%
Efficiency Filling station pump to wind	12.4%	13.5%	14.8%	16.0%	16.9%	14.7%
Pump price, pence per litre ex. tax	Cost per KWh available to wind resistance					
20	15.1	13.8	12.7	11.7	11.1	12.7
30	22.7	20.7	19.0	17.5	16.6	19.1
40	30.2	27.6	25.3	23.3	22.1	25.4
50	37.8	34.5	31.7	29.2	27.7	31.8
60	45.4	41.4	38.0	35.0	33.2	38.1
70	52.9	48.3	44.3	40.8	38.7	44.5
80	60.5	55.2	50.7	46.7	44.3	50.8
90	68.0	62.1	57.0	52.5	49.8	57.2
100	75.6	69.0	63.3	58.3	55.3	63.5
110	83.1	76.0	69.7	64.2	60.9	69.9
120	90.7	82.9	76.0	70.0	66.4	76.2
130	98.3	89.8	82.3	75.8	71.9	82.6
140	105.8	96.7	88.7	81.6	77.5	88.9
150	113.4	103.6	95.0	87.5	83.0	95.3

KWh/litre	10.7

Comment - The comparison suggests diesel prices will have to rise hugely before the resource fuel cost of the electric vehicle would be the lower