NGC Rating Methodology (United Kingdom)

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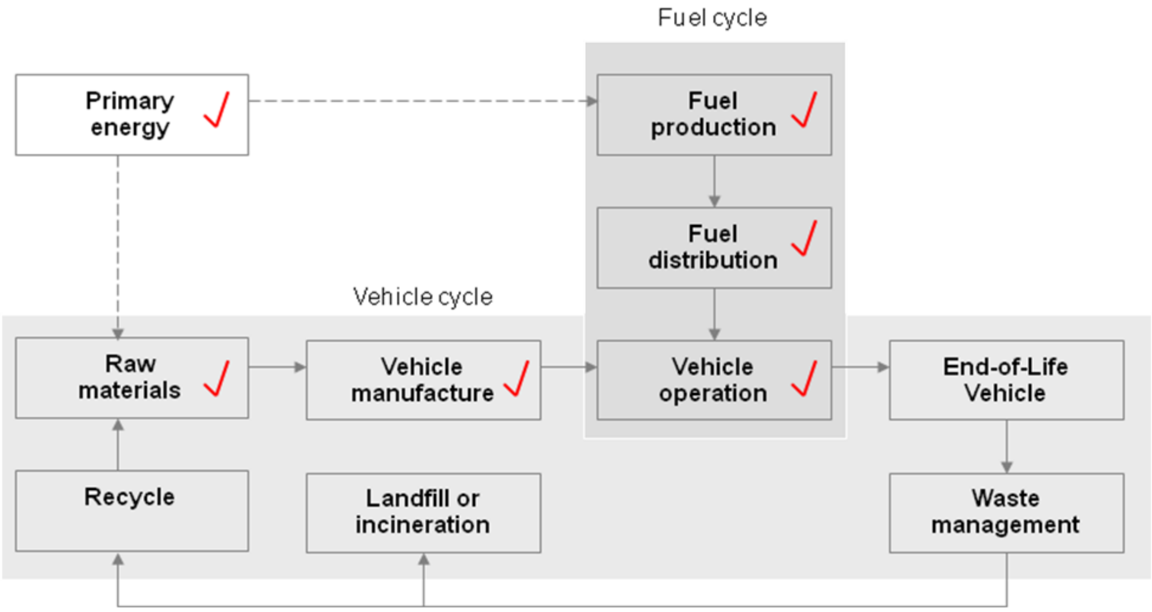
1 Methodology overview

Road transport emissions are generated during fuel production, vehicle manufacture, vehicle operation, and vehicle recycling/disposal. These emissions can be categorised as either ***direct***, produced during operation of the vehicle, or as ***indirect***, being generated during the production of the fuel, and the manufacture and disposal of the vehicle.

The **NGC Rating** takes into account both direct (tailpipe) and indirect emissions, the latter forming a significant proportion of total emissions generated. Furthermore, in cases where all-electric vehicles are used, all emissions associated with these models are produced upstream at the power generation plant.

The NGC Rating assesses the impacts of air emissions arising from the fuel and vehicle cycles (see Figure 1).[1] The emissions assessed include: carbon monoxide (CO), oxides of nitrogen (NOx), hydrocarbons (HCs), particulates (PM_{10}), and sulphur dioxide (SO_2); and the three main greenhouse gases associated with road transport: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Figure 1 Direct and indirect emissions assessed by the NGC Rating



The methodology used for the NGC Rating includes a comparison of the life cycle emissions generated for each of the vehicles assessed (i.e. it includes an emissions *inventory*). In this respect, the methodology follows a similar approach to the GREET project[2] and the *Well-To-Wheels Analysis of Future Automotive Fuels and Power-trains* published by the European Joint Research Centre.[3]

[1] Note that secondary impacts are not quantified – these include: impacts associated with the construction of energy generating, refinery, process plants, road infrastructure, and changes in land use, resource depletion and waste disposal.
[2] The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. URL: https://greet.es.anl.gov
[3] Joint Research Centre-EUCAR-CONCAWE collaboration. URL: http://iet.jrc.ec.europa.eu/about-jec/downloads

The methodology also quantifies the environmental *impact* of the pollutants generated. This is achieved by the application of methods first developed by the European Cleaner Drive Programme in 2001. Next Green Car's methodology is, therefore, a comprehensive life cycle **impact assessment** – and is similar to the approach previously used for the UK project *Life Cycle Assessment of Vehicle Fuels and Technologies*.[4]

By including both direct and indirect emissions, the NGC Rating is able to compare emissions for a large range of vehicle fuels (e.g. petrol, diesel, electric, etc.) and vehicle technologies (e.g. internal combustion engines ICEs, battery-electric vehicles BEVs and plug-in hybrid electric vehicles PHEVs).

2 Direct and indirect emissions

For petrol, diesel and other vehicles which employ an internal combustion engine (ICE), the combustion of the on-board fuel produces **direct emissions** (at point-of-use) which include: carbon monoxide (CO), hydrocarbons (HCs), particulate matter (PM_{10}), nitrogen oxides (NOx), carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O), all of which are emitted at the tailpipe (exhaust) and have significant environmental impacts.

Battery electric vehicles (BEVs) emit no direct emissions, there being no on-board ICE. For hydrogen fuel cell vehicles (FCVs), the only direct emission is water vapour.

In the case of most liquid and gaseous vehicle fuels, **indirect emissions** are generated during the fuel production cycle which includes the following processes:

- Feedstock production – production of raw materials to obtain the fuel needed
- Feedstock transport – raw materials transported to refineries or processing plants
- Fuel production – refining/processing of the raw materials into standard fuel
- Fuel distribution – distribution of the fuels to fuel stations

For petrol and diesel, the feedstock production and distribution stages involve the extraction and separation of crude oil or gas, gas flaring and venting, and the use of gas turbines to provide on-site power where required. After transport by tanker or pipeline to the refinery, the crude oil undergoes simple distillation with the possible addition of fluid catalytic cracking or hydro-cracking processes to maximise the yield of useful distillation products. In most cases these are then distributed by pipeline to a terminal and then by road tanker to fuel stations for use.

For electric vehicles, electricity is generated using fossil fuels, nuclear fuel or renewables. When fossil fuels are used, energy and emissions are generated during the extraction, transport and processing of the fuel feedstock. These fuels are then used in coal-fired, oil-fired or gas-fired generating stations. For nuclear electricity, uranium must first be mined, then enriched and processed into a form suitable for the reactor type. Excluding the environmental impacts associated with construction and infrastructure, renewably generated electricity (from solar, wind and hydro-electric) produces virtually no emissions during the generation stage. For all sources of electricity, energy losses occur during transmission to point-of-use.

[4] Life Cycle Assessment of Vehicle Fuels and Technologies. Conducted by Ecolane for the London Borough of Camden, 2006.

Indirect emissions are also generated during the vehicle production cycle which includes the following processes:

- Material production – the materials used include steel, plastics, non-ferrous metals such as aluminium, glass, rubber and composites such as glass fibre
- Vehicle assembly – energy required for vehicle assembly and manufacturing plant
- Vehicle distribution – transport of a vehicle to the dealerships
- Vehicle maintenance – maintenance and repair over the lifetime of the vehicle;
- Vehicle disposal – end-of-life vehicles (ELVs) are shredded and a proportion of some materials are recycled for further use

3 Data sources and preparation

For **direct emissions** emitted by light-duty vehicles (passenger cars and vans) that are powered by petrol, diesel or electricity (in full or in part), official emissions figures are sourced from the UK Vehicle Certification Agency (VCA)[5] which provides official data for all new cars available in the UK and includes:

- Official combined fuel economy (in litres/100km and miles-per-gallon), and
- Tailpipe vehicle emissions of CO_2, CO, HCs, NOx, PM_{10} (in g/km).

Associated data for electric vehicles (including energy use kWh/100km for BEVs, weighted combined data for PHEVs) is also sourced from the VCA or manufacturers websites.

Indirect fuel production emissions for all fuels are sourced using published data quoted on an energy delivered basis (g/GJ) for: CO, HCs, NOx, PM_{10}, SO_2, CO_2, CH_4, and N_2O. For vehicles used in the UK, data is sourced from the Department for Environment Food & Rural Affairs (Defra), the European Joint Research Centre (JRC)[6] and, where no reliable UK data is available, information based on the North American GREET model adapted for a UK context.[7] These values are then multiplied by vehicle fuel economy (MJ/km), and a unit conversion factor to give the fuel production emission in g/km.

Given that emissions data for indirect vehicle production is not generally available for all models, an approach developed for the North American GREET project is used to quantify vehicle cycle emissions. This method enables an estimate to be made for the emissions associated with vehicle production. Combined with assumptions about lifetime mileage, a value for emissions can be calculated in terms of g/km-kg.[8]

The approach taken by the GREET methodology requires an analysis of the following information for each vehicle type assessed: vehicle mass (kerb weight in kg), the vehicle composition by mass (kg) using a system of over 18 material category types, the emissions associated with the production of each material category (g/kg) and the total energy required for vehicle assembly (MJ). For each vehicle, the mass of each of the constituent materials is multiplied by the respective emissions per unit mass associated with the

[5] Vehicle Certification Agency. URL: http://www.dft.gov.uk/vca/
[6] Joint Research Centre-EUCAR-CONCAWE collaboration. URL: http://iet.jrc.ec.europa.eu/about-jec/downloads
[7] The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. URL: https://greet.es.anl.gov
[8] Vehicle lifetime is assumed to be 150,000 km.

material's production. This provides an estimate of the manufacture emissions profile associated with that particular vehicle type.

Given the variation in vehicle composition of different vehicle types, seven vehicle types are assumed to represent all the vehicles analysed as part of this assessment (petrol ICE, diesel ICE, petrol hybrid HEV, bi-fuel ICE, battery electric BEV, plug-in hybrid electric PHEV and fuel cell FCV). For petrol, diesel, petrol hybrid, and fuel cell vehicles, GREET data is used. For other vehicle types, a Next Green Car methodology is used, one which is similar approach to that adopted by GREET but based on a set of 12 material types (rather than 18).[9]

4 Real-world emissions factors

It is widely accepted that the official data for emissions are far from accurate, measured as they are in the laboratory. The NGC Rating therefore uses **Real Driving Emissions (RDE)** where available to provide an accurate indicator of environmental impact.

Next Green Car has partnered with **Emissions Analytics** to improve the NGC Rating through the use of model specific Real Driving Emissions (RDE) data for NOx, CO_2 and MPG. This data is measured using portable testing equipment during real-world driving. Real world emissions and MPG are based on the EQUA Indices as provided by Emissions Analytics.[10]

In cases where no RDE data is available, real-world **fuel economy** and **direct CO_2 emissions** are estimated by applying 'mpg factors' published by the International Council on Clean Transportation (ICCT)[11] which quantify the discrepancy between test and on-road data for petrol and diesel cars. These factors vary by year from 1.07 in 2000 to 1.39 (estimated) in 2015. This means for example that the fuel use and CO_2 emissions for a petrol or diesel car registered in 2015 are typically 39% higher than the official test figures.

In the absence of RDE data, real-world **direct NOx emissions** are estimated by applying 'conformity factors' to official figures. These factors, which vary by Euro standard: Euro 2 (1.0), Euro 3 (1.5), Euro 4 (2.4), Euro 5 (3.6), Euro 6 (5.5 est.), are published by COPERT 4 and the ICCT which quantify the discrepancy between test and on-road NOx emissions for diesel cars. This means for example that the NOx emissions for a Euro 6 diesel car are typically 5.5 times higher than the official test figures.

For all vehicle types, **indirect fuel production** emissions are also increased in cases where the fuel/energy economy factor is greater than unity. Given that more fuel used by a vehicle will require more fuel to be supplied, all indirect fuel production emission are affected. The increased emissions are estimated by applying the 'mpg/kWh factor' for a specific vehicle to the published data which is quoted on an energy delivered basis (in g/GJ). These values are then multiplied by the vehicle's real-world fuel economy (in litres/100km or kWh/100 km) and the fuel's energy density to estimate the indirect fuel production emissions in g/km.

[9] Life Cycle Assessment of Vehicle Fuels and Technologies. Conducted by Ecolane for the London Borough of Camden, 2006.
[10] To find out more about Emissions Analytics' EQUA database, or to view the EQUA Indices for specific UK models, visit the Emissions Analytics website: http://equa.emissionsanalytics.com.
[11] International Council on Clean Transportation. URL: http://www.theicct.org/

5 NGC Rating methodology

To assess the environmental *impact* of direct and indirect emissions, the **NGC Rating** extends the methodology of the Car Environmental Rating Tool originally developed by the European Cleaner Drive Programme in 2001 which used 'external costs' to establish the relative weight to attach to different emissions – these are monetary values that reflect the damage to the environment and to human health.[12]

The basic principle underlying the methodology is to multiply each emission by its external cost to produce a cost-measure of its environmental impact. For each emission, the direct and indirect elements are assessed. Using external cost methodology allows the emissions from different vehicle types and models to be compared on equivalent terms. It also allows comparisons to be made between different impact types (e.g. climate change, air quality).

For example, the external cost for CO_2 is calculated using the sum of the products of emissions and external costs for each of the individual CO_2 emission sources, according to:

$$\mathbf{Q_{CO2}\ (CO_2\ external\ cost\ in\ €/km) = (TP \times EC) + (FP \times EC) + (VP \times EC) \qquad (i)}$$

TP = direct tailpipe emissions (g/km), FP = indirect fuel production emissions (g/km)
VP = indirect vehicle production emissions (g/km), EC = external cost of emission (€/g)

As external costs quantify environmental impacts, air quality emissions generated in urban areas have higher values than those in extra-urban areas. The methodology therefore uses extra-urban cost values for indirect emissions and a weighted average of urban and extra-urban values for direct emissions – these are weighted to reflect the national average split between urban and extra urban mileage.

In order to simplify the format of the final NGC Rating, the methodology 'normalises' the external costs by dividing the total external cost by a 'maximum' value (which represents a high polluting vehicle) and multiplying by 100. For the CO_2 example above, the NGC Rating (CO_2) is calculated by:

$$\mathbf{NGC\ Rating\ (CO_2) = 100 \times Q_{CO2}\ (external\ cost) \div Q_{CO2}\ (‘max’\ external\ cost) \qquad (ii)}$$

The resulting NGC Rating is therefore a dimensionless value (no units) from 0 to 100 which scales with the magnitude of external costs. Lower emission vehicles have a lower NGC Rating with a rating of 0 (zero) implying zero environmental impact.

Grouping the eight emissions assessed into those which impact on climate change and air quality, the NGC Rating methodology generates three ratings:

- GHG Rating for greenhouse gases (CO_2, CH_4, N_2O)
- AQ Rating for air quality (NOx, HCs, CO, PM_{10}, SOx)
- NGC Rating for all emissions (CO_2, CH_4, N_2O, NOx, HCs, CO, PM_{10}, SOx)

[12] For the NGC Rating, several changes have been made to the Cleaner Drive methodology. Whereas the original project only included the fuel cycle emissions, Next Green Car has extended the method to include emissions associated with the vehicle cycle. Also, the external costs originally used by Cleaner Drive for European vehicles have been updated to reflect other estimates of the external costs that apply in a UK and/or European context.

For greenhouse gases (GHGs), the rating scale is calibrated such that the maximum NGC Rating of 100 represents the environmental impact of the following emissions:

- Direct and indirect fuel and vehicle GHG emissions associated with a petrol powered ICE light-duty vehicle with official fuel economy of approx. 13.0 litres/100km with direct CO_2 emissions of 310 g/km.

For regulated air pollutants affecting air quality (AQ), the rating scale is calibrated such that a NGC Rating of 45 represents the environmental impact of the following emissions:

- Direct AQ emissions equivalent to petrol Euro 3 petrol ICE light-duty vehicle;
- Indirect fuel and vehicle AQ emissions associated with a petrol ICE light-duty with a fuel economy of 13.0 litres/100km with direct CO_2 emissions of 310 g/km.

In detail, the equations used to calculate each of these three NGC Ratings for a particular vehicle are as follows:

The **greenhouse gas (GHG) external cost** is calculated by summing the products of emissions and external costs for each of the individual GHG emissions, according to the formula:

$$Q_{GHG}\text{ (vehicle)} = \sum_i p_i.c_i \quad (1)$$

Q_{GHG} = vehicle GHG external cost in €/km
p_i = emission of greenhouse gas i in g/km
c_i = external cost of emission of greenhouse gas i in €/g

The **GHG Rating** is then calculated using the formula:

$$\textbf{GHG Rating} = 100 \times Q_{GHG}\text{ (vehicle)} / Q_{GHG}\text{ (maximum)} \quad (2)$$

The **air quality (AQ) external cost** is also calculated by summing the products of emissions and external costs for each of the individual AQ pollutants, according to the formula:

$$Q_{AQ}\text{ (vehicle)} = \sum_i p_i.c_i \quad (3)$$

Q_{AQ} = vehicle AQ external cost in €/km
p_i = emission of pollutant i in g/km
c_i = external cost of emission of pollutant i in €/g

The **AQ Rating** for a particular vehicle is then calculated using the formula:

$$\textbf{AQ rating} = 100 \times Q_{AQ}\text{ (vehicle)} / Q_{AQ}\text{ (maximum)} \quad (4)$$

The **total (TOTAL) external cost** is calculated from the sum of the air quality (AQ) external cost and the greenhouse gas (GHG) external cost, according to the formula:

$$Q_{TOTAL}\text{ (vehicle)} = Q_{AQ}\text{ (vehicle)} + Q_{GHG}\text{ (vehicle)} \quad (5)$$

The **NGC Rating** is then calculated using the formula:

$$\textbf{NGC Rating} = 100 \times Q_{TOTAL}\text{ (vehicle)} / Q_{TOTAL}\text{ (maximum)} \quad (6)$$

6 Worked examples

4.1 VW PASSAT SALOON 2.0 TDI GT 150PS BMT – Euro 6 Diesel – 2015

Direct CO_2 and NOx emissions, adjustment factors and vehicle weight

Vehicle emissions std: Euro 6 diesel	CO_2	CH_4	N_20	CO	HC	NO_x	PM_{10}	SO_2
Official direct emissions (g/km)	109	-	-	0.137	0.000	0.067	0.000	-
MPG and NOx factors	1.35	-	-	-	-	5.5	-	-
Real-world direct emissions (g/km)	147	0.000*	0.008*	0.137	0.000	0.369	0.000	-
External costs per g (€/g)	46	966	14260	3.5	1900	2600	122130	-
External costs per km (€c/km)	0.677	0.000	0.011	0.000	0.000	0.096	0.000	-
Direct external costs (€c/km)	**0.688**			**0.096**				

*Notes: Direct CH_4 is assumed to be 20% HC tailpipe emissions; N_2O is assumed to be 0.008 g/km for diesels

Indirect fuel production emissions (diesel)*

Official fuel econ: 4.1 lit/100km	CO_2	CH_4	N_20	CO	HC	NO_x	PM_{10}	SO_2
Fuel production (g/GJ)	14200*	-	-	4.6	103.6	36.1	1.1	47.6
Real-world direct emissions (g/km)	28*	-	-	0.009	0.212	0.074	0.002	0.097
External costs per g (€/g)	46	966	14260	0.3	1900	2600	8730	4500
External costs per km (€c/km)	0.130	0.000	0.000	0.000	0.040	0.019	0.002	0.044
Indirect fuel external costs (€c/km)	**0.130**			**0.105**				

*Notes: Diesel energy density: 35.9 MJ/litre; Figure for CO2 emission shown is for 'CO_2 equivalent' (includes other GHGs)

Indirect vehicle production emissions (diesel)

Vehicle kerb weight = 1400 kg	CO2	CH4	N20	CO	HC	NO_x	PM10	SO_2
Vehicle production (g/tonne-km)	19.03	0.034	0.000	0.096	0.056	0.045	0.008	0.066
Indirect emissions (g/km)	27	0.048	0.000	0.134	0.078	0.063	0.011	0.092
External costs per g (€/g)	46	966	14260	0.3	1900	2600	8730	4500
External costs per km (€c/km)	0.123	0.005	0.000	0.000	0.015	0.016	0.010	0.042
Indirect veh external costs (€c/km)	**0.127**			**0.083**				

Total direct and indirect external costs

	Greenhouse Gases (GHG)	Air Quality (AQ)
Total external costs (€c/km)	**0.945**	**0.281**
Maximum external cost (€c/km)	**2.009**	**1.341**

From eqn. (2) GHG Rating = 100 × Q_{GHG} (vehicle) / Q_{GHG} (maximum)

GHG Rating = 100 × (0.945 / 2.009) = 47.1 (1 dec. pl.)

From eqn. (4) AQ Rating = 100 × Q_{AQ} (vehicle) / Q_{AQ} (maximum)

AQ Rating = 100 × (0.281 / 1.341) = 20.9 (1 dec. pl.)

From eqn. (6) NGC Rating = 100 × Q_{TOTAL} (vehicle) / Q_{TOTAL} (maximum)

NGC Rating = 100 × (0.973 + 0.253) / (2.009 + 1.341)

NGC Rating = 100 × (1.226 / 3.350) = 36.6 (1 dec. pl.)

Record published: http://www.nextgreencar.com/view-car/52911/vw-passat-saloon-2.0-tdi-gt-150ps-bmt-diesel-manual-6-speed/

4.2 Nissan LEAF Acenta – Battery Electric (Real World estimate)

Direct CO_2 and NOx emissions, adjustment factors and vehicle weight

	CO_2	CH_4	N_20	CO	HC	NO_x	PM_{10}	SO_2
Official direct emissions (g/km)	0.000	-	-	0.000	0.000	0.042	0.000	-
EV Range and NOx factors	1.25*	-	-	-	-	1.0	-	-
Real-world direct emissions (g/km)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
External costs per g (€/g)	46	966	14260	3.5	1900	2600	122130	-
External costs per km (€c/km)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-
Direct external costs (€c/km)		**0.000**				**0.000**		

*Notes: Method assumes real-world energy use approx. 25% higher than official figure

Indirect fuel production emissions (electric average UK mix)*

Real energy use: 18.8 kWh/100km	CO_2	CH_4	N_20	CO	HC	NO_x	PM_{10}	SO_2
Fuel production (g/GJ)	139146	251.8	2.75	56.7	255.2	301.0	7.94	311.0
Real-world direct emissions (g/km)	94	0.170	0.002	0.038	0.173	0.204	0.005	0.210
External costs per g (€/g)	46	966	14260	0.3	1900	2600	8730	4500
External costs per km (€c/km)	0.433	0.016	0.003	0.000	0.033	0.053	0.005	0.095
Indirect fuel external costs (€c/km)		**0.452**				**0.186**		

*Notes: Figures reflect electricity sourced using average UK energy mix (2015)

Indirect vehicle production emissions (electric average UK mix)*

Vehicle kerb weight = 1474 kg	CO2	CH4	N20	CO	HC	NO_x	PM10	SO_2
Vehicle production (g/tonne-km)	25.33	0.032	0.000	0.079	0.053	0.045	0.006	0.090
Indirect emissions (g/km)	37	0.047	0.000	0.116	0.078	0.066	0.009	0.133
External costs per g (€/g)	46	966	14260	0.3	1900	2600	8730	4500
External costs per km (€c/km)	0.170	0.005	0.000	0.000	0.015	0.017	0.008	0.060
Indirect veh external costs (€c/km)		**0.175**				**0.100**		

Total direct and indirect external costs

	Greenhouse Gases (GHG)	Air Quality (AQ)
Total external costs (€c/km)	**0.627**	**0.286**
Maximum external cost (€c/km)	**2.009**	**1.341**

From eqn. (2) GHG Rating = 100 × Q_{GHG} (vehicle) / Q_{GHG} (maximum)

GHG Rating = 100 × (0.627 / 2.009) = 31.2 (1 dec. pl.)

From eqn. (4) AQ Rating = 100 × Q_{AQ} (vehicle) / Q_{AQ} (maximum)

AQ Rating = 100 × (0.286 / 1.341) = 21.3 (1 dec. pl.)

From eqn. (6) NGC Rating = 100 × Q_{TOTAL} (vehicle) / Q_{TOTAL} (maximum)

NGC Rating = 100 × (0.627 + 0.286) / (2.009 + 1.341)

NGC Rating = 100 × (0.881 / 3.350) = 27.2 (1 dec. pl.)

Record published: http://www.nextgreencar.com/view-car/49677/nissan-leaf-electric-car-acenta-24kwh-auto-electric-(av-uk-mix)/