NGC Emissions Calculator Methodology (United Kingdom)

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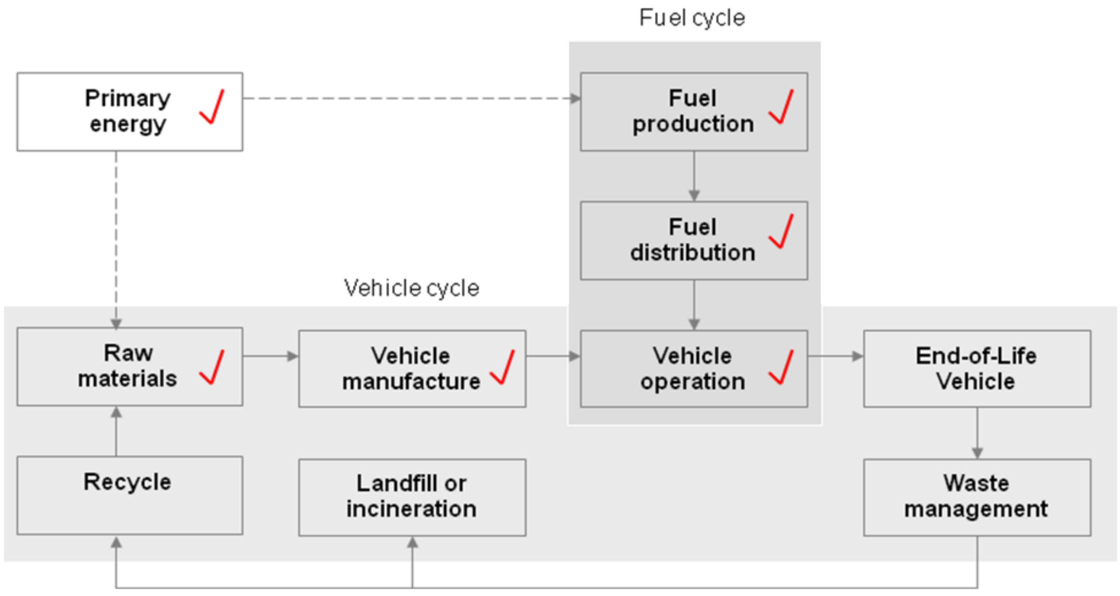
1 Methodology overview

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.

In addition to direct (tailpipe) emissions, the NGC Emissions Calculator also estimates indirect emissions, as these form 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 Emissions Calculator estimates the extent of direct and indirect air emissions arising from the fuel and vehicle cycles (see Figure 1).[1] The emissions estimated by the calculator include: oxides of nitrogen (NOx), particulates of up to 10 microns (PMs or PM10), and carbon dioxide (CO2). Note that these emissions are only three of the eight emissions assessed for the NGC Rating (http://www.nextgreencar.com/emissions/ngc-rating/).

Figure 1 Direct and indirect emissions assessed by the emissions calculator



By including both direct and indirect emissions, the NGC Emissions Calculator 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).

[1] Note that secondary impacts are not quantified – these include: impacts associated with the construction of energy generating, refinery, and process plants, road infrastructure, changes in land use, resource depletion and waste disposal.

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), nitrogen oxides (NOx), carbon dioxide (CO2), methane (CH4) and nitrous oxides (N2O), 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 (HFCVs), 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.

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)[2] 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, 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, NOx, PM_{10} and CO_2. For vehicles used in the UK, data is sourced from the Department for Environment Food & Rural Affairs (Defra), the European Joint Research Centre (JRC)[3] and, where no reliable UK data is available, information based on the North American GREET model adapted for a UK context.[4] 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.[5]

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 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).[6]

[2] Vehicle Certification Agency. URL: http://www.dft.gov.uk/vca/
[3] Joint Research Centre-EUCAR-CONCAWE collaboration. URL: http://iet.jrc.ec.europa.eu/about-jec/downloads
[4] The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. URL: https://greet.es.anl.gov
[5] Vehicle lifetime is assumed to be 150,000 km.
[6] Life Cycle Assessment of Vehicle Fuels and Technologies. Conducted by Ecolane for the London Borough of Camden, 2006.

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 Emissions Calculator 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 Emissions Calculator 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.[7]

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)[8] 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.

[7] 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.
[8] International Council on Clean Transportation. URL: http://www.theicct.org/

5 Emissions calculator methodology

The NGC Emissions Calculator estimates total emissions of carbon dioxide (CO_2), nitrogen oxides (NOx) and particulate (PM_{10}). The calculator also provides a breakdown of total emissions according to direct (tailpipe emissions at point-of-use) and indirect emissions (emissions generated during fuel and vehicle production).

For all vehicles types, **direct tailpipe emissions** are calculated by multiplying the official or real-world emissions figure (in grams per km) by the journey distance or mileage (in miles), and a factor representing driving style (‘Normal, ‘ Aggressive/Fast’, ‘Eco-driving’).

For **direct CO_2 emissions**, the factors that represent driving style reflect the evidence presented by the Energy Saving Trust (EST) that eco-driving can improve fuel consumption (and hence tailpipe CO2) by up to 15% for petrol and diesel cars. An eco-driving factor of 1.15 is therefore assumed for all vehicle types. Aggressive/Fast driving is assumed to worsen fuel economy (and hence tailpipe CO2) by a similar amount.

For **direct NOx emissions**, the factors that represent driving style reflect the evidence presented by the ICCT datasets that – using analysis by NGC – aggressive driving can increase tailpipe NOx by up to 22% (factor of 1.22) for diesel cars. The figures also suggest that eco-driving can reduce tailpipe NOx by around 10% (factor of 0.9).

For **direct PM emissions**, official emissions data is sourced using test-derived figures (‘official combined’ or ‘official weighted combined’) as published by the VCA and vehicle manufacturers. Given current evidence, real-world tailpipe PM emissions are assumed to be largely unaffected by road conditions, test cycle or driving style.

For all vehicle types, **indirect fuel production emissions** are based on published data quoted on an energy delivered basis (in grams per giga joule) for NOx, PMs, and CO2. These values are then multiplied by the vehicle’s official or real-world fuel economy (in litres or kWh per 100 km), the journey distance or mileage (in miles), and a factor representing driving style (‘Normal, ‘ Aggressive/Fast’, ‘Eco-driving’).

The driving style factors used to scale indirect fuel production emissions of CO_2, NOx and PMs are the same as used for tailpipe CO_2 (see above). These reflect the evidence presented by the Energy Saving Trust (EST) that eco-driving can improve fuel consumption (and hence reduce upstream emissions) by up to 15% for petrol and diesel cars. An eco-driving factor of 1.15 is therefore assumed for all vehicle types. Aggressive/Fast driving is assumed to worsen fuel economy (and hence upstream emissions) by a similar amount.

For all vehicle types, **indirect vehicle production emissions** are estimated which represent the NOx, PMs, and CO_2 emissions associated with the vehicle’s manufacture. The approach is based on a per kg emissions for each vehicle type (petrol, diesel, electric, etc) which is then multiplied by the mass of the model selected. The calculator expresses indirect emissions associated with vehicle production in terms of g/km over a vehicle’s whole lifetime (based on a total vehicle mileage of 150,000 km).

6 Worked examples

4.1 VW PASSAT SALOON 2.0 TDI GT 150PS BMT – Diesel (Official Test)

Direct vehicle emissions and adjustment factors

Description	Metric	Imperial	MPG Factor	NOx Factor
Official CO2 tailpipe emissions	109 g/km	-	-	-
Official combined fuel economy	4.1 litres/100km	68.9 MPG	-	-
Real-world fuel economy (estimate)	5.5 litres/100km	49.6 MPG	1.39	-
Driving style	Normal	-	1.0	1.0
Official NOx tailpipe emissions (Euro 6)	67 mg/km	-	-	5.5
Official PM10 tailpipe emissions	0 mg/km	-	-	-
Distance travelled (1 mile=1.61km)	16,100 km	10,000 miles	-	-

Indirect diesel fuel and vehicle emissions and scaling factors

Description	Emissions	Fuel / Vehicle data
CO2 fuel production	14200 g/GJ	Energy density 35.9 MJ/litre
NOx fuel production	36.1 g/GJ	
PM10 fuel production	1.1 g/GJ	
CO2 vehicle production	19.0 g/kg-km	Kerb Weight 1400 kg
NOx vehicle production	0.045 g/kg-km	
PM10 vehicle production	0.008 g/kg-km	

Data Type = ‘Real World’, Driving Style = ‘Normal’

Direct CO2 emissions (tailpipe) = (109 x 1.35 x 1.0 x 16,100) = 2.37 tonnes

Direct NOx emissions (tailpipe) = (67 x 5.5 x 1.0 x 16,100) = 5.93 kg

Direct PM emissions (tailpipe) = (0 x 1.0 x 1.0 x 16,100) = 0.00 kg

Indirect CO2 emissions (fuel) = (14200 x 5.5 x 35.9 x 1.0 x 16,100) = 0.45 tonnes

Indirect NOx emissions (fuel) = (36.1 x 5.5 x 35.9 x 1.0 x 16,100) = 1.15 kg

Indirect PM emissions (fuel) = (1.1 x 5.5 x 35.9 x 1.0 x 16,100) = 0.04 kg

Indirect CO2 emissions (vehicle) = (19.0 x 1400 x 1.0 x 16,100) = 0.43 tonnes

Indirect NOx emissions (vehicle) = (0.045 x 1400 x 1.0 x 16,100) = 1.01 kg

Indirect PM emissions (vehicle) = (0.008 x 1400 x 1.0 x 16,100) = 0.18 kg

Record published: http://www.nextgreencar.com/emissions-calculator/vw/passat-saloon/52911/

4.2 Nissan LEAF Acenta 24kWh – Battery Electric (Real World estimate)

Direct vehicle emissions and adjustment factors

Description	Metric	Imperial	EV Factor	NOx Factor
Official CO2 tailpipe emissions	0 g/km	-	-	-
Official combined fuel economy	15.0 litres/100km	-	-	-
Real-world fuel economy (estimate)	18.8 kWh/100km	-	1.25	-
Driving style	Aggressive/Fast	-	1.15	1.0
Official NOx tailpipe emissions	0 mg/km	-	-	1.0
Official PM10 tailpipe emissions	0 mg/km	-	-	-
Distance travelled (1 mile=1.61km)	16,100 km	10,000 miles	-	-

Indirect electricity and vehicle emissions and scaling factors

Description	Emissions	Fuel / Vehicle data
CO2 fuel production	139146 g/GJ	Energy density 3.6 MJ/kWh
NOx fuel production	301 g/GJ	
PM10 fuel production	7.94 g/GJ	
CO2 vehicle production	25.3 g/kg-km	Kerb Weight 1474 kg
NOx vehicle production	0.045 g/kg-km	
PM10 vehicle production	0.006 g/kg-km	

Data Type = 'Real World', Driving Style = 'Aggressive/Fast'

Direct CO2 emissions (tailpipe) = (0 x 1.25 x 1.15 x 16,100) = 0.00 tonnes

Direct NOx emissions (tailpipe) = (0 x 1.0 x 1.0 x 16,100) = 0.00 kg

Direct PM emissions (tailpipe) = (0 x 1.0 x 1.0 x 16,100) = 0.00 kg

Indirect CO2 emissions (electricity) = (139146 x 18.8 x 3.6 x 1.15 x 16,100) = 1.74 tonnes

Indirect NOx emissions (electricity) = (301 x 18.8 x 3.6 x 1.15 x 16,100) = 3.77 kg

Indirect PM emissions (electricity) = (7.94 x 18.8 x 3.6 x 1.15 x 16,100) = 0.10 kg

Indirect CO2 emissions (vehicle) = (25.3 x 1474 x 1.0 x 16,100) = 0.61 tonnes

Indirect NOx emissions (vehicle) = (0.045 x 1474 x 1.0 x 16,100) = 1.07 kg

Indirect PM emissions (vehicle) = (0.006 x 1474 x 1.0 x 16,100) = 0.14 kg

Record published: http://www.nextgreencar.com/emissions-calculator/nissan/leaf/49677

4.3 Mitsubishi Outlander 2.0 GX3h Auto PHEV – Plug-in Hybrid (Official Test)

Direct vehicle emissions and adjustment factors

Description	Metric	Imperial	MPG/EV Factor	NOx Factor
Official CO2 tailpipe emissions	44 g/km	-	-	-
Official fuel economy (petrol)	1.9 litres/100km	149 MPG	-	-
Official fuel economy (electricity)	13.6 kWh/100km	-	-	-
Official fuel economy (petrol only)	5.8 litres/100km	49.0 MPG	-	-
Real-world fuel economy (petrol only)	8.1 litres/100km	35.0 MPG	1.39	-
Real-world fuel economy (estimate)	17.0 kWh/100km	-	1.25	-
Driving style	Normal	-	1.0	1.0
Official NOx tailpipe emissions (Euro 5)	3 mg/km	-	-	3.6
Official PM10 tailpipe emissions	0 mg/km	-	-	
Distance travelled (1 mile=1.61km)	16,100 km	10,000 miles	-	

Indirect fuel and vehicle emissions and scaling factors

Description	Emissions (petrol)	Emissions (elec)	Pet. / Vehicle data	Elec / Vehicle data
CO2 fuel production	12500 g/GJ	139146 g/GJ	Energy density 32.2 MJ/litre	Energy density 3.6 MJ/kWh
NOx fuel production	42.4 g/GJ	301 g/GJ		
PM10 fuel production	2.4 g/GJ	7.94 g/GJ		
CO2 vehicle production	21.5 g/kg-km		Kerb Weight 1810 kg	
NOx vehicle production	0.046 g/kg-km			
PM10 vehicle production	0.007 g/kg-km			

Data Type = ‘Official Test’, Driving Style = ‘Normal’

Direct CO2 emissions (tailpipe) = (44 x 1.0 x 1.0 x 16,100) = 0.71 tonnes

Direct NOx emissions (tailpipe) = (3 x 1.0 x 1.0 x 16,100) = 0.05 kg

Direct PM emissions (tailpipe) = (0 x 1.0 x 1.0 x 16,100) = 0.00 kg

Indirect CO2 emissions (petrol + electric) = (12500 x 1.9 x 32.2 x 1.0 x 16,100) + (139146 x 13.6 x 3.6 x 1.0 x 16,100) = 1.22 tonnes

Indirect NOx emissions (petrol + electric) = (42.4 x 1.9 x 32.2 x 1.0 x 16,100) + (301 x 13.6 x 3.6 x 1.0 x 16,100) = 2.79 kg

Indirect PM emissions (petrol + electric) = (2.4 x 1.9 x 32.2 x 1.0 x 16,100) + (7.94 x 13.6 x 3.6 x 1.0 x 16,100) = 0.09 kg

Indirect CO2 emissions (vehicle) = (21.5 x 1810 x 1.0 x 16,100) = 0.63 tonnes

Indirect NOx emissions (vehicle) = (0.046 x 1810 x 1.0 x 16,100) = 1.34 kg

Indirect PM emissions (vehicle) = (0.007 x 1810 x 1.0 x 16,100) = 0.20 kg

Record published: http://www.nextgreencar.com/emissions-calculator/mitsubishi/outlander-phev/51537

4.4 Mitsubishi Outlander 2.0 GX3h Auto PHEV – Plug-in Hybrid (Real-World)

Direct vehicle emissions and adjustment factors

Description	Metric	Imperial	MPG/EV Factor	NOx Factor
Official CO2 tailpipe emissions	44 g/km	-	-	-
Official fuel economy (petrol)	1.9 litres/100km	149 MPG	-	-
Official fuel economy (electricity)	13.6 kWh/100km	-	-	-
Official fuel economy (petrol only)	5.8 litres/100km	49.0 MPG	-	-
Real-world fuel economy (petrol only)	8.1 litres/100km	35.0 MPG	1.39	-
Real-world fuel economy (estimate)	17.0 kWh/100km	-	1.25	-
Driving style	Normal	-	1.0	1.0
Official NOx tailpipe emissions (Euro 5)	3 mg/km	-	-	3.6
Official PM10 tailpipe emissions	0 mg/km	-	-	
Distance travelled (1 mile=1.61km)	16,100 km	10,000 miles	-	

Indirect fuel and vehicle emissions and scaling factors

Description	Emissions (petrol)	Emissions (elec)	Pet. / Vehicle data	Elec / Vehicle data
CO2 fuel production	12500 g/GJ	139146 g/GJ	Energy density 32.2 MJ/litre	Energy density 3.6 MJ/kWh
NOx fuel production	42.4 g/GJ	301 g/GJ		
PM10 fuel production	2.4 g/GJ	7.94 g/GJ		
CO2 vehicle production	21.5 g/kg-km		Kerb Weight 1810 kg	
NOx vehicle production	0.046 g/kg-km			
PM10 vehicle production	0.007 g/kg-km			

Data Type = 'Real-World', Proportion of miles on electric = 50%, Driving Style = 'Normal'

Direct CO2 emissions (tailpipe) = 0.5 x (44 x 3.05 x 1.39 x 1.0 x 16,100) = 1.50 tonnes

Direct NOx emissions (tailpipe) = 0.5 x (3 x 3.6 x 1.0 x 16,100) = 0.09 kg

Direct PM emissions (tailpipe) = 0.5 x (0 x 1.0 x 1.0 x 16,100) = 0.00 kg

Indirect CO2 emissions (petrol + electric) = 0.5 x (12500 x 8.1 x 32.2 x 1.0 x 16,100) + 0.5 x (139146 x 17.0 x 3.6 x 1.0 x 16,100) = 0.95 tonnes

Indirect NOx emissions (petrol + electric) = 0.5 x (42.4 x 8.1 x 32.2 x 1.0 x 16,100) + 0.5 x (301 x 17.0 x 3.6 x 1.0 x 16,100) = 2.37 kg

Indirect PM emissions (petrol + electric) = 0.5 x (2.4 x 8.1 x 32.2 x 1.0 x 16,100) + 0.5 x (7.94 x 17.0 x 3.6 x 1.0 x 16,100) = 0.09 kg

Indirect CO2 emissions (vehicle) = (21.5 x 1810 x 1.0 x 16,100) = 0.63 tonnes

Indirect NOx emissions (vehicle) = (0.046 x 1810 x 1.0 x 16,100) = 1.34 kg

Indirect PM emissions (vehicle) = (0.007 x 1810 x 1.0 x 16,100) = 0.20 kg

Record published: http://www.nextgreencar.com/emissions-calculator/mitsubishi/outlander-phev/51537