SUSTAINABLE ENERGY IRELAND

Hybrid Electric and Battery Electric Vehicles

Technology, Costs and Benefits

A study on the costs and benefits of hybrid electric and battery electric vehicles in Ireland

2007 Edition, Version 1

November 2007

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1 Introduction

Under the Kyoto Protocol, Ireland has agreed to limit its national carbon dioxide (CO_2) emissions during the period 2008 – 2012 to a maximum of 13% above 1990 levels. Ireland's CO_2 emissions peaked in 2001 at 31% above 1990 levels. The National Climate Change Strategy for Ireland identified transport as a fast growing source of greenhouse gas emissions. Due to the predicted continuing rise in CO_2 emissions from road transport, it has been decided that action is required to reduce emissions from this sector if Ireland is to meet its Kyoto commitment.

A measure that is of potential interest is increasing the use of hybrid electric vehicles (HEVs) and/or battery electric vehicles (BEVs). These options have the advantage of reducing average vehicle energy consumption, and hence reducing CO_2 emissions. However, before these proposals can be taken forward, further work is required to assess the potential energy and CO_2 savings, and the associated costs and benefits of HEVs and BEVs in vehicle fleets in Ireland. Sustainable Energy Ireland (SEI) has commissioned AEA Energy & Environment (AEA) and ILTP to undertake this work. This work consists of a "Cost of ownership calculator" which provides the energy efficiency, emissions and costs (capital, running and energy) for HEVs and BEVs by vehicle type on a per km basis, an easy to understand "Buyer's Guide" to these vehicle technologies and this report (Report 1) which presents more detailed information on technical developments in these technologies and assesses the most cost effective and lowest carbon dioxide options.

1.1 Scope of this report

This report, report 1, brings together the following pieces of research:

- A technical report – a detailed state of the art review of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicle (BEV) technology;
- A review of the life-cycle analyses (LCA) that have been undertaken on the environmental impacts of these vehicle types (manufacture, use and disposal), with a particular focus on battery types;
- A review of the primary potential owner groups and uses for HEVs, PHEVs and BEVs and the most cost effective and lowest carbon dioxide emission options;
- A review of vehicle battery charging options and patterns of energy use associated with this;
- Documentation on the data sources and assumptions used in the buyer's guide and cost of ownership calculator;
- Information on battery charge / discharge efficiencies.

This document should be read in conjunction with the "Buyer's guide" and the cost of ownership calculator.

The buyers guide provides an overview of information on HEV, PHEV and BEV technologies and concentrates primarily on the costs of ownership of these types of vehicles. This report provides more detailed information on technical developments for passenger cars, light utility vehicles (or vans), minibuses and full sized public transport buses. This information is presented in **Section 2**.

Previous life-cycle analyses of road vehicles have shown that the use phase of the vehicle dominates almost all environmental impact categories. However, the construction phase is not insignificant and there are also a number of potential environmental impacts surrounding the disposal phase. **Section 3** summarises a literature and web review of existing LCA studies on road vehicles, and on battery systems. In particular, the life-cycle impacts of HEVs and BEVs in comparison with conventional petrol and diesel vehicles have been examined.

Section 4 reviews and identifies the main potential candidate vehicle owner groups and uses (cars, vans, minibuses and buses) for HEVs, PHEVs and BEVs in Ireland. Fleet operation and vehicle use characteristics are considered and a ranking of vehicles in terms of potential emission and economic benefits is presented; **Section 5** identifies the technology options, which are available for vehicle battery charging and presents typical patterns of energy use data and lastly, Section 6 provides details with regard to the assumptions that have been made when compiling the cost of ownership calculator.

Appendix 1 contains detailed information on battery charge / discharge cycle efficiencies, Appendix 2 provides detailed emissions data for different vehicle types under alternative usage scenarios and Appendix 3 contains detailed cost of ownership data. Appendix 4 contains a glossary of the terms used in this report.

2 Technical Information

2.1 Introduction

The buyers guide provides an overview of BEV, HEV, and PHEVs technologies for passenger cars, light utility vehicles (vans), minibuses and full sized public transport buses. The emphasis was on these vehicle types because of their significant contribution to Ireland's carbon dioxide emissions

This section presents more detailed information on these technologies and further details, where applicable on:

- Battery types (Information on battery charge / discharge efficiencies can be found in Appendix1)
- Vehicle energy efficiency performance
- Vehicle availability
- Emissions performance
- Capital and operating costs

Detailed information regarding emissions performance and capital and operating costs is provided in Appendix 2 and 3 of this report.

2.2 Battery Electric Vehicles

2.2.1 Introduction

Battery electric vehicles (BEVs) are powered by electricity stored in large batteries within the vehicles. These batteries are used to power an electric motor, which drives the vehicle. This system allows BEVs to operate with zero emissions at their point of use. Most new BEVs also use 'regenerative braking', which allows the electric motor to act as a generator in order to re-capture energy that would normally be lost through heat dissipation and frictional losses – this improves energy efficiency and reduces brake wear.

BEVs benefit from the high levels of torque found in electrical motors as well as smooth gearless acceleration and deceleration. BEVs have no emissions at point of use and operate in almost complete silence, except for noise from the tyres. All of these factors make them ideal for inner city and urban usage.

Although BEVs produce zero emissions at point of use, the source of the electricity must be taken into account when considering the wider scale environmental benefits; if renewable energy is used then electric cars can offer a much reduced environmental impact over other vehicle technologies.

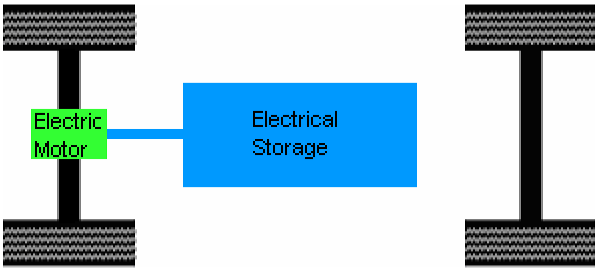
A short summary of the main advantages and disadvantages of BEV technology include:

Advantages	**Disadvantages**
• Zero emissions at point of use • Torque and smooth response suited to urban driving • Cheap to run • Quieter operation	• High capital cost • Generally small in size • Limited range • Limited speed • Slow recharge rate and limited dedicated quick recharge facilities • Emissions can simply be transferred to production sources

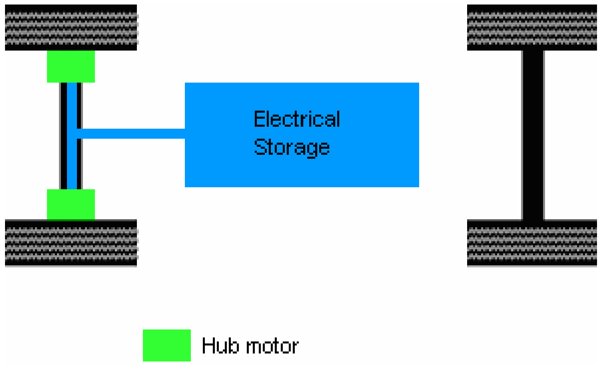
2.2.2 Technology details

Battery electric vehicles (BEVs) are powered by either a large electric motor connected to a transmission, or smaller electric motors housed within the wheel hubs. The energy used to power these motors comes exclusively from battery packs housed within the vehicles that must be charged from an external source of electricity (for smaller vehicles a household socket is a sufficient source).

BEV – Central motor



BEV – Hub motors



The two types of BEV are illustrated above. As can be seen the two types are very similar, the key difference is the positioning and size of the electric motors. The central motor type is currently more common as it works on tried and tested principles of car design. It is also more suited to larger vehicles in which the motor must be quite powerful. However, the requirement to transfer power from the motor to the wheels does involve some losses in efficiency through friction.

The hub motor type, however, can avoid many of the transmission losses experienced in the central motor type but, at the current time, is more suited to smaller vehicles due to the power requirements of larger vehicles and as such is a less regularly used technology.

BEVs also, usually, incorporate other technologies, which reduce energy consumption. For example regenerative braking, which allows energy that would otherwise be wasted as heat during braking to be recycled back into the electrical storage system. This improves the overall efficiency of the car and can significantly improve the range of the vehicle. Another example is that because of the nature of electric motors, no energy is consumed when the vehicle is at a standstill, thus conserving energy further.

There are a number of technologies in the pipeline that may improve efficiency even further and increase the viability of electrical motors as a power source. For example, super capacitors store energy for a short period of time much more efficiently than a dynamo recharging a battery. This technology could be used to further improve the regenerative braking system.

2.2.3 Battery types

Battery types

There are a number of rechargeable battery technologies that have been used or are likely to be used in the future for hybrid and electric vehicles. The principal technology types are described briefly below, with Table 2.2.3 providing a summary of their performance characteristics.

Box 2.2.3: Battery Technologies

Lead acid (Pb-acid)

Lead-acid batteries are the oldest type of rechargeable battery and have a very low energy-to-weight and energy-to-volume ratio. These factors mean that lead acid batteries take up significant amounts of space within vehicles and add significant amounts of weight. However, they can maintain a relatively large power-to-weight ratio and are low cost making them ideal for use in road vehicles.

Nickel Cadmium (NiCd)

Nickel Cadmium give the longest cycle life of any currently available battery (over 1,500 cycles) but has low energy density compared to some other battery types. Cadmium is also toxic – a hazard to both humans and animals, so its use (mainly in domestic applications), is being superseded by Li-ion and NiMH types, in part forced by EU legislation.

Nickel-Metal-Hydride (NiMH)

The Nickel Metal Hydride battery technology is similar to a NiCd battery in design, except cadmium is replaced making it less detrimental to the environment. NiMH batteries can also have 2-3 times the capacity of an equivalent size NiCd, with much less significant memory effect. Compared to lithium-ion batteries, energy capacity is lower and self-discharge is higher. Applications include hybrid vehicles such as the Toyota Prius, the Toyota RAV4-EV all-electric plug-in electric car, and consumer electronics.

Lithium-ion (Li-ion)

The relatively modern lithium-ion battery technology has a very high charge density (i.e. a light battery which stores a lot of energy). Current limitations include volatility, the potential for overheating, high cost, and limited shelf and cycle life. The technology currently has widespread use in consumer electronics (e.g. mobile phones) but has only recently begun to be used in transport applications (e.g. the Tesla Roadster electric car and in Prius conversions to a plug-in hybrid). General motors and Toyota are now also moving towards using more Lithium-ion batteries.

Li-ion polymer

This is a similar technology to Li-ion, but typically has slightly lower charge density, greater life cycle degradation rate and an ultra-slim design (as little as 1 mm thick). Disadvantages include the high instability (see the glossary (Appendix 4) for further information) of overcharged batteries and if the battery discharges below a certain voltage it may never be able to hold a charge again.

Sodium Nickel Chloride (NaNiCl)

Sodium Nickel Chloride, also known as the Zebra battery, belongs to the class of molten salt batteries. These use molten salts as an electrolyte, offering both a higher energy density, as well as a higher power density making rechargeable molten salt batteries a promising technology for powering electric vehicles. However, the normal operating temperature range is 270–350 °C, which places more stringent requirements on the rest of the battery components and can bring problems of thermal management and safety. Furthermore, there are also significant thermal losses when the battery is not in use.

Table 2.2.3: Properties of different types of rechargeable battery

Battery Type	Specific Energy (Wh/kg)	Energy/ Volume (Wh/litre)	Power/ Weight, W/kg	Number of cycles of 1 battery pack	Energy Efficiency	Energy Density % of Pb-acid	Self-discharge per 24h	Losses due to Heatin g
Pb-acid	40	60-75	180	500	82.5%	100%	1%	
NiCd	60	50-150	150	1,350	72.5%	150%	5%	
NiMH	70	140-300	250-1,000	1,350	70.0%	175%	2%	
Li-ion	125	270	1,800	1,000	90.0%	313%	1%	
Li-ion polymer	200	300	> 3,000			500%		
NaNiCl	125	300		1,000	92.5%	313%	0%	7.20%

Sources: LCE (2006)[1], Batteries in a portable world[2], Battery FAQ[3]

The higher the energy density the further the distance that vehicles can travel and therefore a breakthrough in the batteries' energy to weight ratio could increase the marketability of battery electric vehicles[4].

As Table 2.2.3 shows rechargeable batteries typically self-discharge more rapidly than disposable alkaline batteries (up to 5% a day depending on temperature and cell chemistry). Modern lithium based batteries however, show improvements in this respect.

Battery lifetime should be considered when calculating the cost of ownership as batteries wear out and need to be replaced. This rate depends on a number of factors such as how often the vehicle is used and how much it is charged and discharged. The vehicle manufacturer will be able to advise how best to look after the battery to extend its life.

Further information on battery characteristics and their efficiency is provided in Appendix 1.

2.2.4 Vehicle Energy Efficiency Performance

The distance that a battery electric vehicle can be driven before it needs recharging depends on the type and number of batteries installed and can range from 30 to 120 miles[4]. However, this is often more than sufficient for urban and city centre drivers. The reason for the short range that can be driven is due to the energy storage limitations of the types of batteries that are on the market today. For further details regarding battery types, please see section 2.2.3.

Battery electric cars typically use 0.2 to 0.5 kilowatt hours (kWh) of energy per mile[5] [6]. Therefore for a range of 100 miles at 200-watt hours per mile, a battery capacity of 20 kWh will be required. Nearly half of this energy consumption is due to inefficiencies in charging the batteries. For a typical conventional petrol vehicle that does 46 miles to the gallon , this is equivalent to 0.8 kWh per mile and therefore battery electric cars are more energy efficient than conventionally fuelled vehicles.

2.2.5 Vehicle availability

BEVs are generally limited to passenger cars and small vans due to the size and weight of batteries required to power the electric motors. However, there are some small sized buses in operation that utilise electrical power. For example, Ebus sell a shuttle size electric bus ideal for use in small towns or locations such as airports, as well as a heritage style trolley bus for use in historic areas, parks or seafronts. Larger electric buses are also on the market, but these tend to use their onboard electricity storage for short sections away from external sources such as overhead cables.

[1] "Comparison of the Environmental impact of 5 Electric Vehicle Battery technologies using LCA", Julien Matheys, Jean-Marc Timmermans, W out Van Autenboer, Joeri Van Mierlo, Gaston Maggetto, Sandrine Meyer, Arnaud De Groof, W alter Hecq, Peter Van den Bossche. Proceedings of the 13th CIRP International Conference on Life Cycle Engineering, 2006.
[2] http://www.buchmann.ca/
[3] http://www.battery-faq.com/
[4] UK Energy Saving Trust: http://www.energysavingtrust.org.uk/fleet/technology/lowcarbonvehicles/electricvehicles/
[5] Idaho National Laboratory, 2007. Full size electric vehicle reports at: http://avt.inel.gov/fsev.html Website accessed July 2007.
[6] http://www.mpoweruk.com/performance.htm#offset

Details regarding the BEVs that are currently on sale are shown below:

Passenger cars:
Examples of cars for sale in Ireland:

- The Reva G-wiz http://www.greenmachines.ie/
- Micro-Vett - Ydea city car http://www.micro-vett.it/english/ydeaing.html
- Micro-Vett - Doblo vehicle http://www.micro-vett.it/english/company.html

Other battery electric cars not currently available in Ireland but available in other parts of Europe include:

- The MEGA City car http://www.niceccarcompany.co.uk
- The Maranello 4cycle http://www.maranello4cycle.com/
- Th!ink City car. http://en.think.no/

High performance sports car (currently only available in the United States)

- Tesla Roadster www.teslamotors.com

Vans
Examples of vans for sale in Ireland:

- Modec: http://www.modec.co.uk/new5.html
- Micro-Vett: http://www.micro-vett.it/eng/indexing.html

For sale in other parts of Europe:

- Smith Electric Vehicles: http://www.smithelectricvehicles.com/index.asp
- Mega MultiTruck II: http://www.nicecarcompany.co.uk/megatruck/?gclid=CMe4-cT2s40CFQLilAodLXQptg
- Electric Berlingo: http://www.citroen.mb.ca/citroenet/passenger-cars/psa/berlingo/berlingo-electrique.html

Buses
For sale in Ireland:

- Ebus http://www.ebus.com/

2.2.6 Emissions performance

Battery electric vehicles produce no emissions at their point of use. They are therefore well suited to urban areas where vehicle emissions represent a large proportion of urban air pollutants. However, whilst battery electric vehicles produce no emissions at point of use, there are emissions associated with generating the electricity used to power them. The overall emissions performance will depend on the source of energy used to charge the battery. Electricity generated from fossil fuels such as coal will lead to higher carbon dioxide and air quality emissions compared to electricity sourced from renewable sources such as wind or hydroelectric power, which will have virtually zero emissions during vehicle operation. As with all vehicles, these vehicles will however have emissions associated with their manufacture, details of which can be found in Section 3.

Passenger cars
Figures 2.2.6a to 2.2.6c provide estimated CO_2 emissions as a result of owning and operating a battery electric car under an average, low and high use scenario. These figures are thought to be typical profiles for Ireland (see Section 6.7 for further information). For comparison purposes, emissions from a petrol and diesel car are also shown. The figures shown relate to the emissions arising *over the whole ownership period* and for the battery electric car are based on the projected electricity grid mix in Ireland. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	10,500	8,000	15,000
% of driving in city areas	25%	25%	25%

Figure 2.2.6a: "Low use of car"

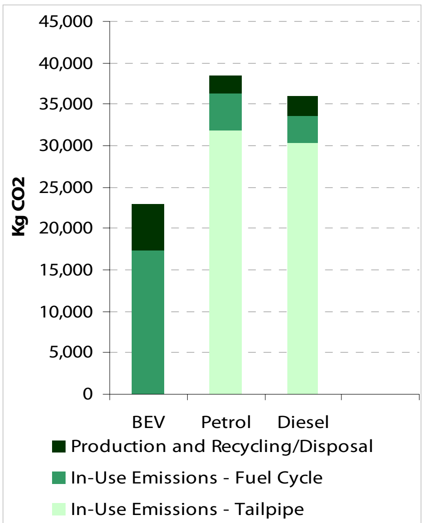


Figure 2.2.6b: "Average use of car"

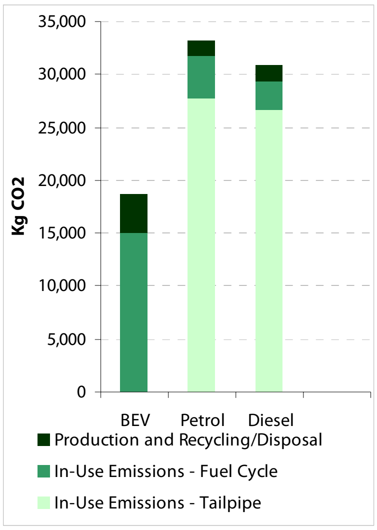
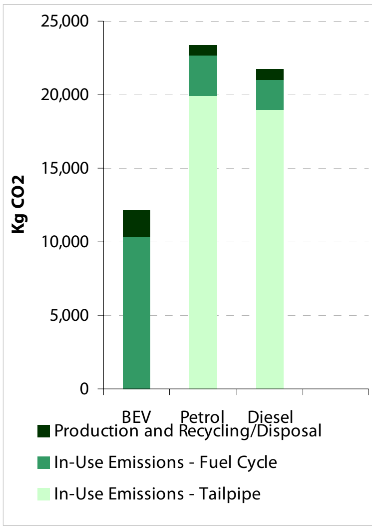


Figure 2.2.6c: "High use of car"



The data behind these graphs and data for air quality pollutants can be found in Appendix 2 and the Cost of Ownership Calculator.

Vans

Figures 2.2.5d to 2.2.5f provide estimated CO_2 emissions to air as a result of owning and operating a battery electric van under an average, low and high use scenario. For comparison purposes, those emissions arising from a petrol and diesel van are also shown. The figures shown relate to the emissions arising *over the whole ownership period* and for the battery electric van are based on the projected electricity grid mix in Ireland. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%

Figure 2.2.5d: ""Low use" of van

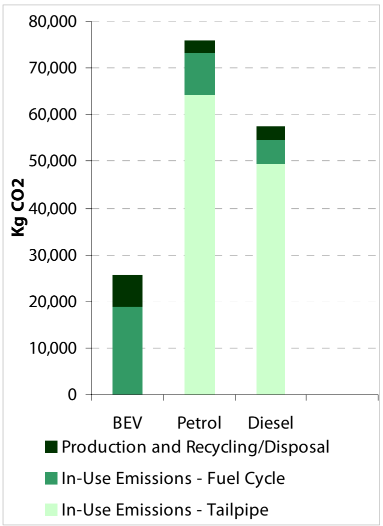


Figure 2.2.5e: "Average use" of van

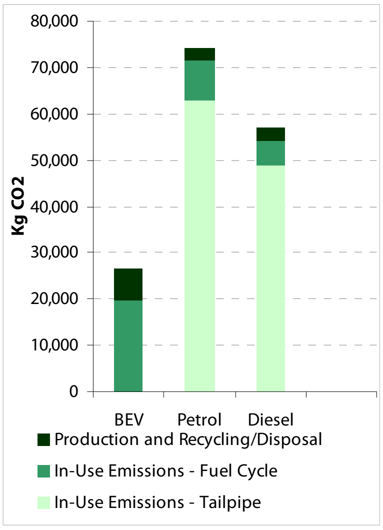
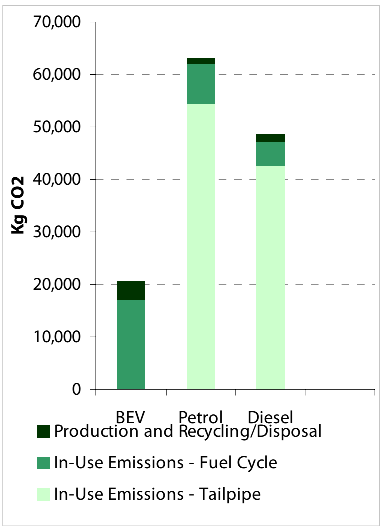


Figure 2.2.5f: "High use" of van



Minibuses

Figures 2.2.5g to 2.2.5i provide estimated emissions to air as a result of owning and operating a battery electric minibus under an average, low and high use scenario. For comparison purposes, those emissions arising from a diesel minibus are also shown. The figures shown relate to the emissions arising *over the whole ownership period* and for the battery electric bus are based on the projected electricity grid mix in Ireland. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Minibus assumptions:

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	17,000	12,000	25,000
% of driving in city areas	40%	40%	40%

Figure 2.2.5g: ""Low use"

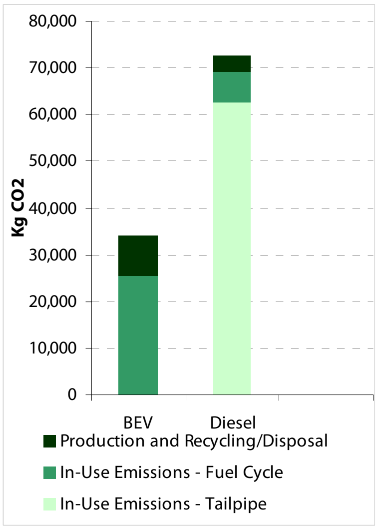


Figure 2.2.5h: "Average use"

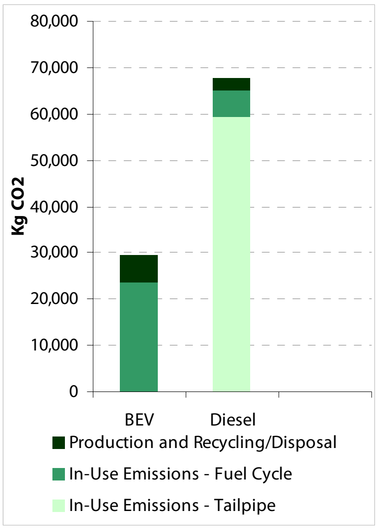
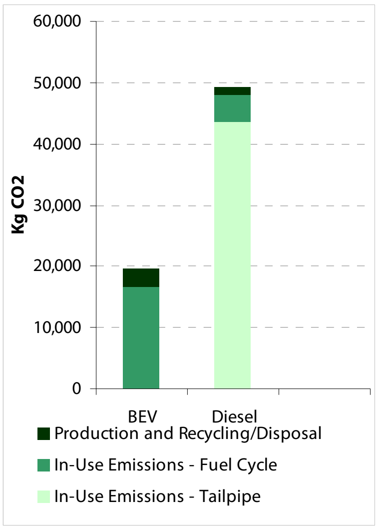


Figure 2.2.5i: ""High use"



Midi bus (a single decker bus in between a minibus and full size bus)
Figures 2.2.5j to 2.2.5l provide estimated emissions to air as a result of owning and operating a battery electric midi bus under urban, inter-urban and express scenarios. For comparison purposes, those emissions arising from a diesel midi bus are also shown. The figures shown relate to the emissions arising *over the whole ownership period* and for the battery electric bus are based on the projected electricity grid mix in Ireland.

Midi bus assumptions:

Assumption:	**Urban**	**Inter-urban**	**Express**
Ownership period (years)	10	10	10
Annual vehicle mileage	30,000	50,000	70,000
% of driving in city areas	90%	40%	10%

Figure 2.2.5j: ""Urban use" of a midibus

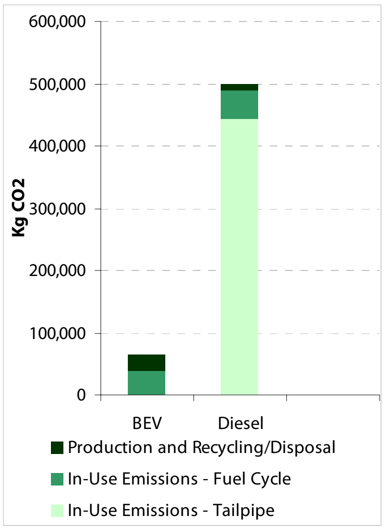


Figure 2.2.5k: "Inter-urban use" of a midibus

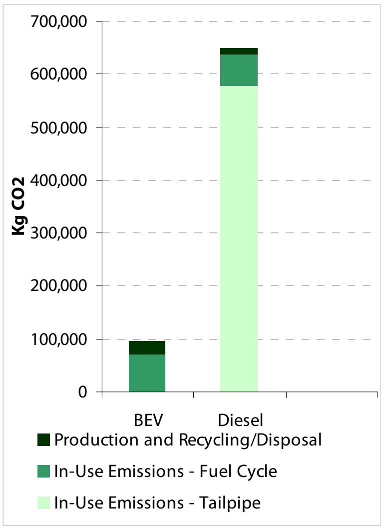
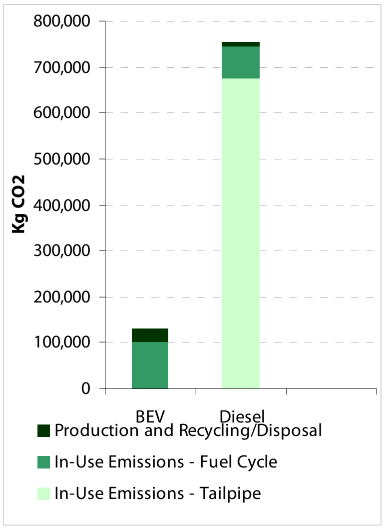


Figure 2.2.5k: "Express use" of a midibus



Further information relating to the life-cycle emissions of battery electric vehicles and how this has been estimated can be found in Section 3 and Section 6.

Further details regarding emissions of other pollutants can be found in Appendix 1 and the Cost of Ownership Calculator.

2.2.7 Capital and operating costs

The cost of ownership of a BEV primarily depends on the cost of the battery. Battery costs make up a significant proportion of the overall capital cost of BEVs. The type and capacity of the battery will determine the maximum speed, travel range, battery lifetime and re-charging time.

Prices have fallen in recent years and are expected to continue to fall with increasing demand.

Due to the potentially high costs involved, some manufacturers offer the opportunity of leasing or renting the battery from them rather than having to buy it (for example, Th!ink City Car).

The high purchase costs for BEVs are partially offset through reduced energy costs; fuel-running costs are low due to the competitive price of electricity and due to the high efficiency of the vehicle. It can cost as little as 1.5 cents to run a car on electricity for a mile compared to approximately 15 cents per mile with petrol[7]. Non-energy running costs (tax and maintenance) are however higher than for conventional petrol and diesel equivalents. This leads to the overall ownership costs (covering purchase, energy, and operational costs) for BEVs being higher than for petrol and diesel equivalents.

Figures 2.2.6a to 2.2.6d provide indicative cost information for owning a battery electric car, van, mini-bus and midi-bus under the "average" scenario. The financial information shown relates to costs incurred over the ownership period. Note that this information does not include the treatment of business vehicles for tax purposes.

Figure 2.2.6a: Average car use

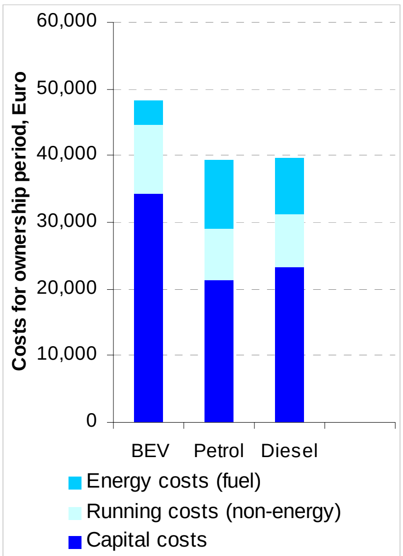
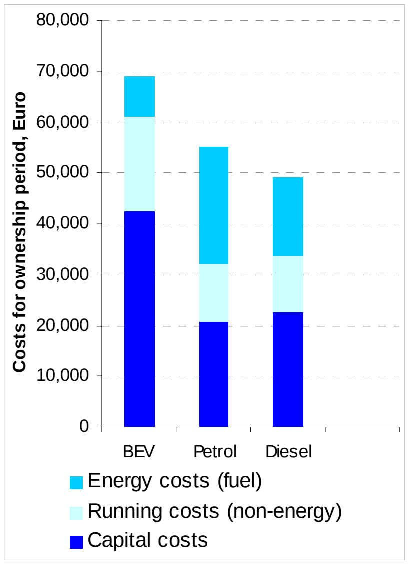


Figure 2.2.6b: Average van use



[7] Adapted from 'Pathways to Future Vehicles – a 2020 strategy', UK Energy Saving Trust, April 2002.

Figure 2.2.5c: Urban full size / midi-bus use

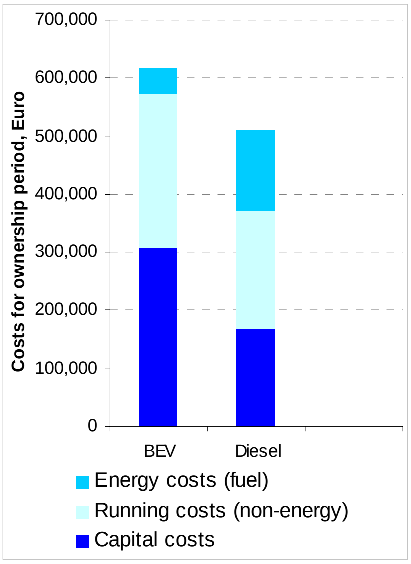
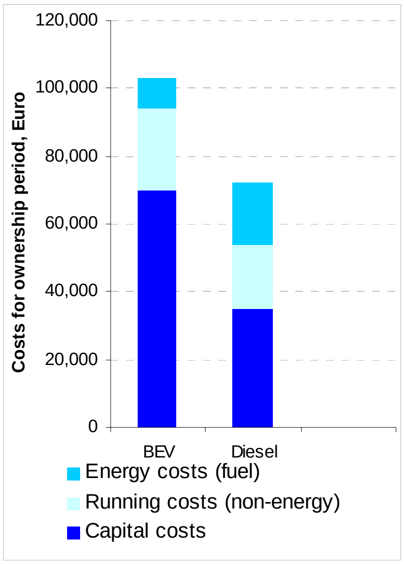


Figure 2.2.5d: Average minibus use



The data behind these figures can be found in Appendix 2. Indicative costs of alternative scenarios can be obtained from the Cost of Ownership calculator.

2.3 Hybrid Electric Vehicles

2.3.1 Introduction

Hybrid electric vehicles (HEVs) are powered by a combination of electricity and either petrol or diesel. The electricity is used only as an intermediate energy storage medium to improve the overall efficiency of the vehicle. They therefore DO NOT need to be plugged in to recharge the battery. This cuts down on the amount of fuel needed, producing fewer emissions and lowering overall fuel costs. As with BEVs, most hybrids also use 'regenerative braking', which captures energy from braking to be put back into the battery - this improves energy efficiency and reduces brake wear.

Manufacturers are currently developing plug-in hybrid electric vehicles (PHEVs), with much bigger batteries, representing a bridge between HEV and BEV technology

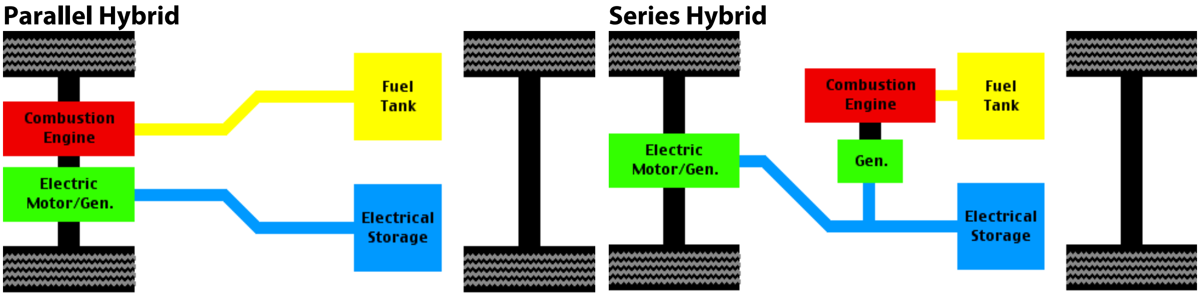
A short summary of the main advantages and disadvantages of hybrid technology include:

Advantages	Disadvantages
• Significantly improved fuel consumption and reduced running costs • Reduced in-use carbon dioxide and other harmful emissions, particularly in urban driving conditions	• Significantly higher capital cost due to additional components and currently expensive battery technology • Higher production and disposal emissions than conventional vehicles

2.3.2 Technology details

Hybrid technology operates to improve the overall efficiency of the use of petrol or diesel fuel. It does this by operating a smaller (more efficient) internal combustion engine within a narrower, more efficient operational speed/power band and using an electric engine and electrical storage to balance the vehicle's energy requirements. There are essentially two types of hybrid configurations, illustrated in the figure below.

Figure 2.3.1: Parallel and series hybrid configurations



In a *parallel* hybrid, both the electric and combustion engines can provide power directly to the wheels of the vehicle. When the power supplied by the combustion engine is surplus to requirements, the electric engine is used in reverse as a generator to store additional energy in the electrical storage. The electric engine can provide additional power when the load is greater than can be provided by the smaller combustion engine alone. In full/strong hybrids such as the Toyota Prius, the vehicle can be powered for short distances by the electric engine alone. Mild hybrids such as the Honda Civic IMA have smaller electric engines and have to operate the regular engine continuously to provide power to the wheels.

A *series* hybrid has a much bigger and more powerful electric engine that provides all the power to the wheels of the vehicle. The combustion engine provides energy indirectly, operating continuously at peak efficiency to provide electrical power via a generator to the electric energy and to the electrical storage.

In both types of hybrid, the electric motor assists in acceleration, which allows for a smaller and more efficient internal combustion engine. In addition, the engine can be stopped and started quickly to reduce stationary engine idling which reduces fuel consumption and the electric motor can recover and store energy from braking that would otherwise be lost as heat – this is referred to as regenerative braking. The energy flow in hybrid vehicles is managed by advanced control systems to optimise the efficiency of operation. Current hybrids utilise batteries (which should last the lifetime of the car) as the electrical storage, however future vehicles are likely to also utilise super capacitors. Super capacitors can store and release smaller amounts of energy much more quickly and efficiently, so offering improved regenerative braking efficiency and increased power delivery for acceleration.

In terms of durability, there is a reduced load on the internal combustion engine due to less idling taking place and reduced break wear due to the regenerative breaking system in use.

Regular HEVs operate completely on petrol or diesel fuel and therefore <u>do not</u> require plugging in to charge the battery.

Vehicles operating in urban areas, such as delivery vans, trucks and buses, can suffer from very large energy losses due to the high proportion of deceleration and braking. These types of vehicles often require engines that can perform across a relatively wide range of operating conditions, and such engines are usually less efficient and bigger than engines designed to operate over a more restricted range. For urban areas, hybrid powertrains may offer significant reductions in greenhouse gas emissions. Whilst there are several light duty passenger hybrid vehicles already available on the market, hybrid powertrains are in an advanced demonstration stage/early market introduction phase for light commercial and urban transit bus applications, but still further away from market implementation for heavy goods vehicles

2.3.3 Vehicle availability

The following hybrid electric cars are currently available for purchase in Ireland:

- Toyota Prius www.toyota.ie
- Lexus RX 400h and the Lexus GS 450h www.lexus.ie/
- Honda Civic IMA www.honda.ie

These vehicles may be particularly suited for use by taxis. This is because they are primarily used in urban locations, have intensive operating schedules thereby maximising fuel savings over the lifetime of the vehicle and they may spend considerable amounts of time idling.

Current hybrid van manufacturers include:

- XGEM: http://www.xgem.net/
- DaimlerChrysler: http://www.daimlerchrysler.com/
- Azure Dynamics: http://www.azuredynamics.com/index.htm
- Micro-Vett: http://www.micro-vett.it/english/bimodaleing.html

WrightBus based in Northern Ireland are one of the largest hybrid bus manufacturers and they offer single and double-decker versions. Currently there are six test buses in London and the operational evaluation of a prototype double-decker bus equipped with hybrid propulsion technology is set to begin in Dublin later this year. The double-decker buses use a 1.9 litre diesel engine rather than a 7-litre diesel engine, which leads to substantial fuel savings[8].

2.3.4 Emissions performance

Although hybrid vehicles do not offer zero emissions at point of use, they can offer substantial reductions in emissions of carbon dioxide and air pollutants compared with conventionally fuelled petrol and diesel vehicles. This is shown in Figures 2.3.3a to 2.3.3l below.

Passenger car

Figures 2.3.3a to 2.3.3c provide estimated CO_2 emissions to air as a result of owning and operating a petrol and diesel hybrid car under an average, low and high use scenario. For comparison purposes, those emissions arising from a conventional petrol and diesel car are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%

[8] www.wrightbus.com

Figure 2.3.3a: ""Low car use"

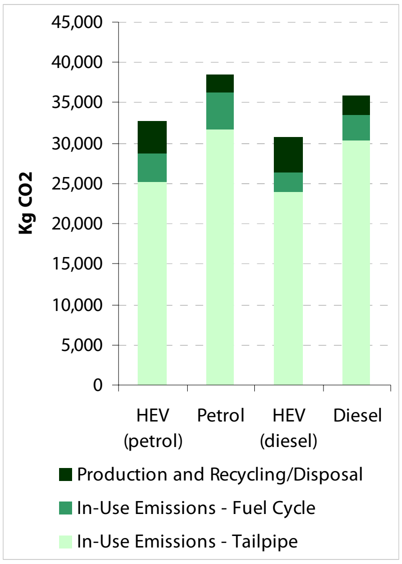


Figure 2.3.3b: "Average car use"

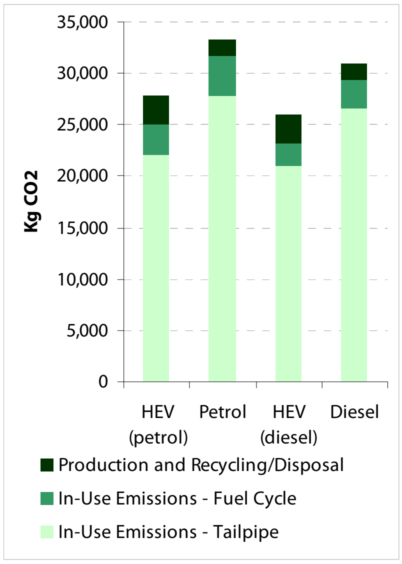
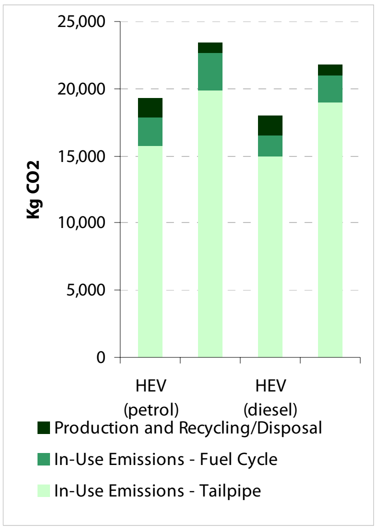


Figure 2.3.3c: "High car use"



The data behind these graphs and data for air quality pollutants can be found in Appendix 2 and the cost of ownership calculator.

2.3.4.1 Vans

Figures 2.3.3d to 2.3.3f provide estimated CO_2 emissions to air as a result of owning and operating a petrol and diesel hybrid van under an average, low and high use scenario. For comparison purposes, those emissions arising from a conventional petrol and diesel van are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%

Figure 2.3.3d: ""Low van use"

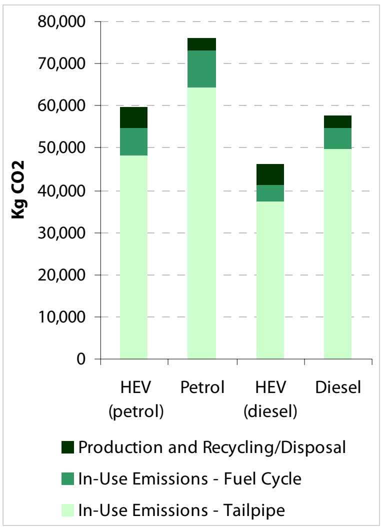


Figure 2.3.3e: "Average van use"

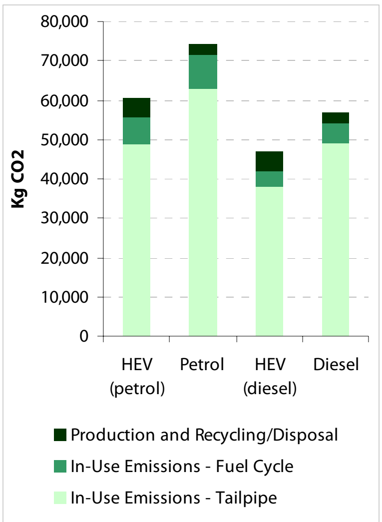
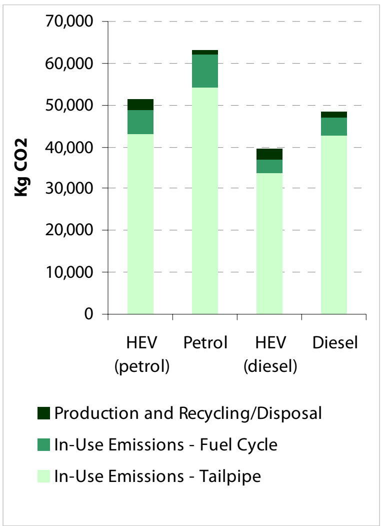


Figure 2.3.3f: "High van use"



Minibus

Figures 2.3.3g to 2.3.3i provide estimated emissions to air as a result of owning and operating a diesel hybrid minibus under an average, low and high use scenario. For comparison purposes, those emissions arising from a diesel minibus are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Minibus assumptions:

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	17,000	12,000	25,000
% of driving in city areas	40%	40%	40%

Figure 2.3.3g: ""Low minibus use"

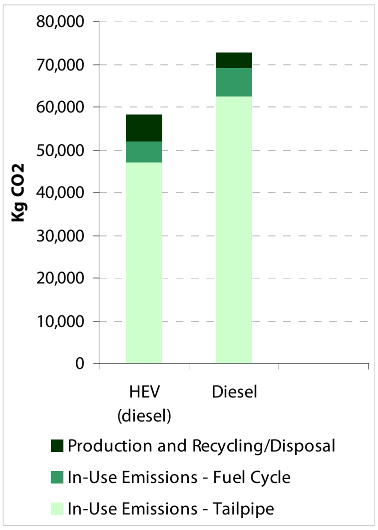


Figure 2.3.3h: "Average minibus use"

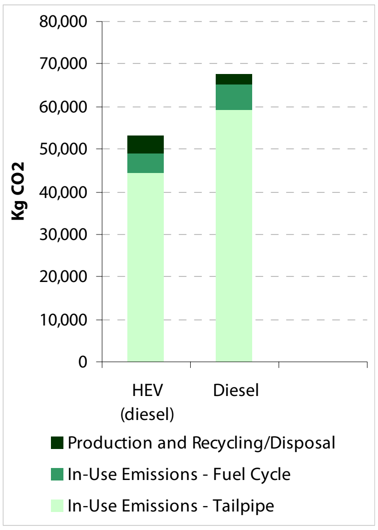
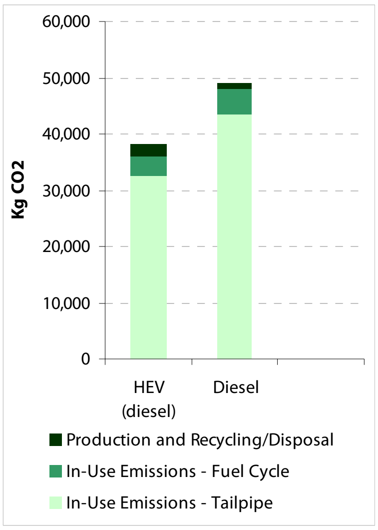


Figure 2.3.3i: "High minibus use"



Midi bus

Figures 2.3.3j to 2.3.3l provide estimated emissions to air as a result of owning an operating a diesel hybrid midi bus under an urban, inter-urban and express scenario. For comparison purposes, those emissions arising from a diesel midi bus are also shown. The figures shown relate to the emissions arising *over the whole ownership period*.

Midi bus assumptions:

Assumption:	**Urban**	**Inter-urban**	**Express**
Ownership period (years)	10	10	10
Annual vehicle mileage	30,000	50,000	70,000
% of driving in city areas	90%	40%	10%

Figure 2.3.3j: ""Urban midi bus use"

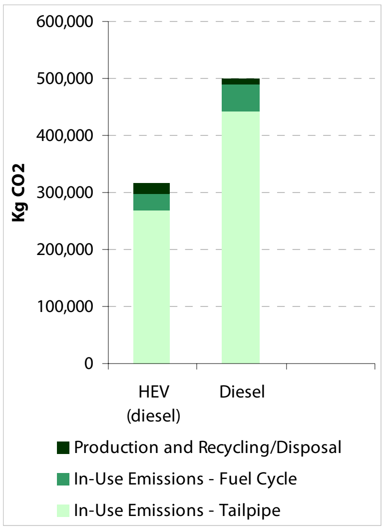


Figure 2.3.3k: "Inter-urban midi bus use"

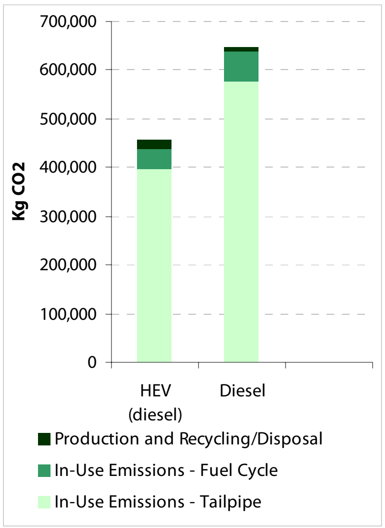
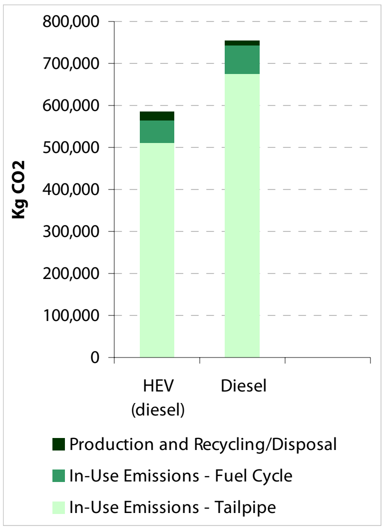


Figure 2.3.3l: "Express bus"



Further information relating to the life-cycle emissions of battery electric vehicles and how this has been estimated can be found in Section 3 and Section 6. Further details regarding emission of other pollutants can be found in Appendix 2 and the Cost of Ownership Calculator.

2.3.5 Capital and operating costs

Hybrid electric vehicles are more expensive to buy than conventionally fuelled vehicles due to the extra batteries and electronics required. The payback period will depend on the mileage driven, the hours of operation, fuel costs, electricity costs and government subsidies. The results from the cost of ownership calculator show that hybrid cars have higher ownership costs than their conventional alternatives under the low, average and high use scenarios. This is in contrast with a January 2007 analysis by Intellichoice showing that all 22 currently available HEVs in the United States will save their owners money over a five year period. In that study, the largest savings obtained were for the Toyota Prius, which had a five year cost of ownership 40.3% lower than the cost of comparable non-hybrid vehicles[9].The different findings between these two studies is as a result of the difference in

[9] Hybrids cost-efficient over long haul, 9th January 2007. http://www.businessweek.com/autos/content/jan2007/bw20070108_774581.htm?chan=top+news_top+news+index_autos

mileage assumed. This can be seen by entering higher mileage in the “custom” box in the Cost of Ownership calculator as with increased mileage, hybrid cars become economically attractive.

Diesel hybrid vehicles, minibuses and midi-buses show a similar trend in that the overall ownership costs are higher than their conventional counterparts under the low, average and high use scenarios. Again, **the ownership costs are highly dependent on the assumptions regarding annual average mileage and the proportion of city use.**

The exception to hybrid vehicles being more expensive than their conventional alternatives (in the scenarios that have been assessed in the cost of ownership calculator) is petrol hybrid vans. In the examples provided, the relatively small increase in capital cost is more than outweighed by the reduced energy costs.

Note that the costs shown do not include the treatment of business vehicles for tax purposes.

Figure 2.3.4a: Costs arising from average car use

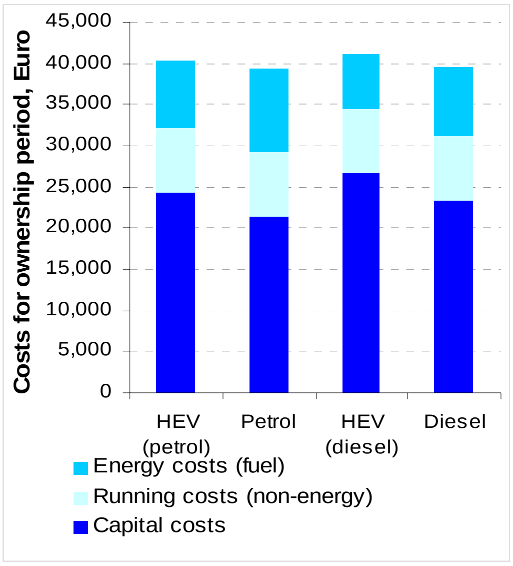


Figure 2.3.4b: Costs arising from average van use

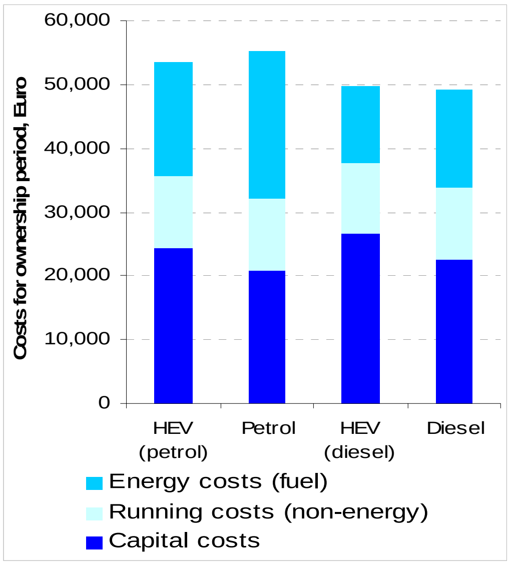


Figure 2.3.4c: Costs arising from average mini-bus use

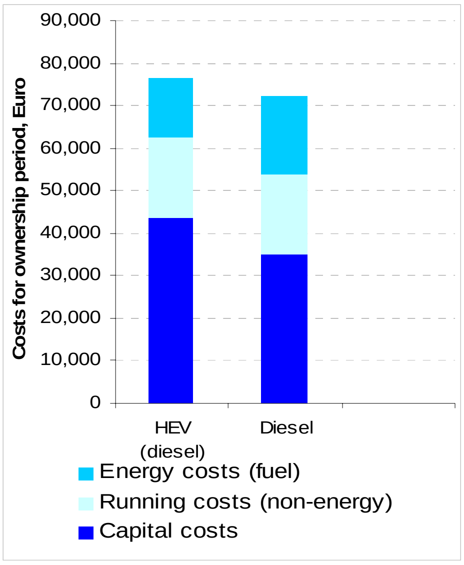
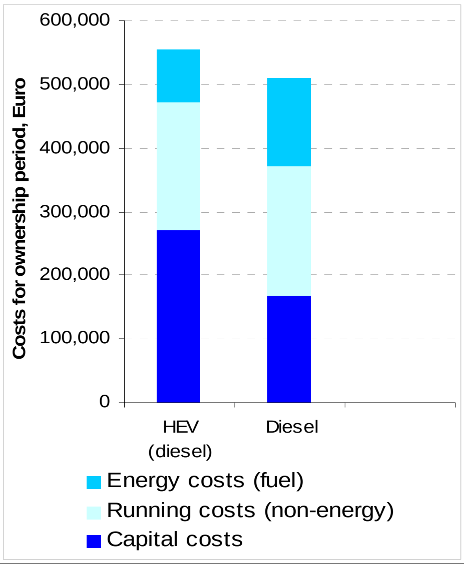


Figure 2.3.4d: Costs arising from full size / midi-bus use in urban areas



2.4 Plug-in Hybrid Electric Vehicles (PHEVs)

2.4.1 Introduction

Plug in hybrid electric vehicles (PHEVs) work similarly to conventional hybrid vehicles in that they can operate using their petrol or diesel engine as well as stored electricity for an electric motor. However, they have much larger batteries than conventional HEV and can also be charged from the mains when not in use in order to maximise the range available to the electric motor. As such, they act as a halfway ground between hybrid electric vehicles and battery electric vehicles.

In addition, most PHEVs (like BEVs and HEVs) would run a regenerative braking system that puts power from braking back into the battery system. All of this allows PHEVs to be very efficient, and if driven for relatively short distances, they could have zero emissions at the point of use.

The benefits of PHEVs are largely similar to those of electric vehicles in that they can, if kept at a high level of charge, operate the majority of the time on electric power, thus reducing their emissions to zero at the point of use. They also have the additional benefits related to electric motors of quiet operation and rapid acceleration. Because of the additional weight of the battery packs, PHEVs tend to be smaller vehicles, usually in the car and small van sector.

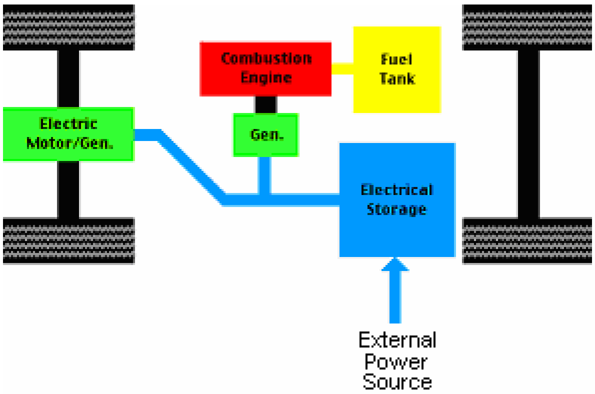
There are two key types of PHEV. The first can run indefinitely with the petrol/diesel motor providing the car with the energy required for motion. The second is effectively a battery electric vehicle with a small onboard generator to allow the range of the vehicle to be extended.

Advantages	**Disadvantages**
• Improvements in fuel consumption • Reduction of in-use emissions – potentially to zero • Cheap to run	• High capital cost • Lack of availability • Limited range in some types • Emissions can simply be transferred to production sources

2.4.2 Technology details

At the current time there are very few PHEVs available directly from manufacturers. However, these are in development and are likely to be available on a bigger scale shortly. There are a number of companies offering conversions from regular hybrid vehicles such as the Toyota Prius to allow external charging, although these conversions are not generally approved by the original vehicle manufacturers as yet.

Plug-in Hybrid Electric Vehicle



The illustration above shows the general layout of the power system within a PHEV. It is very similar to that of a series hybrid but with a larger electrical storage capacity. This enables the greater range available to these types of vehicles before the combustion engine has to kick in. The type of PHEV which cannot operate independently of recharging would have a very similar layout, the only difference being the combustion engine and generator would be insufficient to keep the electrical storage topped up under normal driving conditions but would slow the rate of depletion of the power stored in the batteries.

PHEVs also usually incorporate other technologies to aid their day-to-day operation. For example, regenerative braking allows energy that would otherwise be wasted as heat during braking to be recycled back into the electrical storage system. This improves the overall efficiency of the vehicle and can significantly improve the range. In addition to this, because of the nature of electric motors, no energy is consumed when the vehicle is at a standstill, thus conserving energy further.

There are also a number of technologies in the pipeline that may improve efficiency even further and increase the viability of electrical motors as a power source. Super capacitors store energy for a short period of time much more efficiently than a dynamo recharging a battery. This technology could be used to further improve the regenerative braking system. There are also technologies such as high-speed flywheels, which are designed to store energy more efficiently than charging batteries.

2.4.3 Battery charging

PHEVs typically require deeper charging and discharging than conventional hybrids. As the number of full cycles affects battery lifetime, battery life may be less than for conventional hybrids which do not deplete their batteries as often. For further information on battery types and charging/discharging, please see Appendix 1.

2.4.4 Vehicle availability

There are no plug-in hybrid electric cars or buses currently available for sale in Ireland. It is envisaged that they will be available for purchase in the next few years.

A variety of companies are currently producing Plug-in hybrid vans such as Mercedes-Benz/DaimlerChrysler (Germany/USA), UQM Technologies, Inc. (USA), Azure Dynamics (USA), XGEM (USA), MICRO-VETT (Italy) and Citroen (France).

2.4.5 Emissions performance

The combination of the internal combustion engine and the electric motor helps hybrid cars perform more efficiently, cutting down on fuel use. Plug-in hybrids have the additional advantage that they can operate purely on electricity from the grid for short distances, so reducing net emissions significantly over regular hybrids.

Passenger car

Figures 2.4.4a to 2.4.4c provide indicative CO_2 emissions to air as a result of owning and operating a petrol and diesel plug-in hybrid car under an average, low and high use scenario. The results are 'indicative' because there are no plug-in hybrids currently for sale in Ireland. For comparison purposes, those emissions arising from a conventional petrol and diesel car are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%

Figure 2.4.4a: "Low car use"

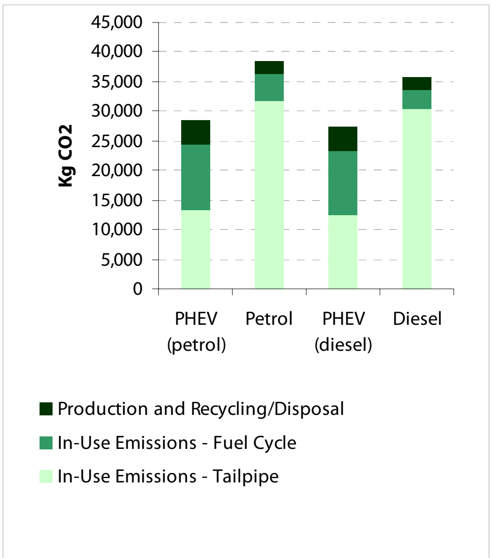


Figure 2.4.4b: "Average car use"

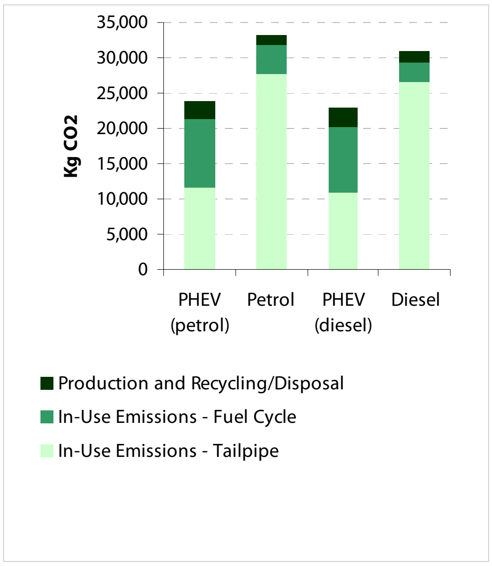
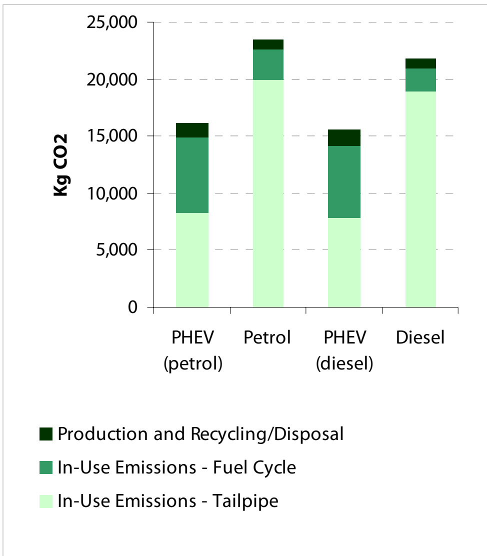


Figure 2.4.4c: "High car use"



Vans

Figures 2.4.4d to 2.4.4f provide estimated CO_2 emissions to air as a result of owning and operating a petrol and diesel plug-in hybrid van under average, low and high use scenarios. For comparison purposes, those emissions arising from a conventional petrol and diesel van are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%

Figure 2.4.4d: "Low van use"

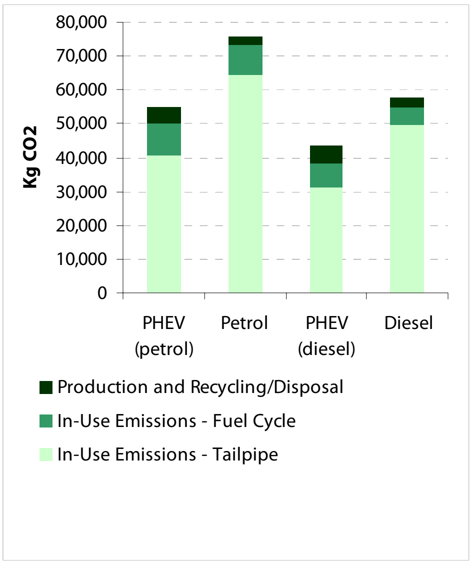


Figure 2.4.4e: "Average van use"

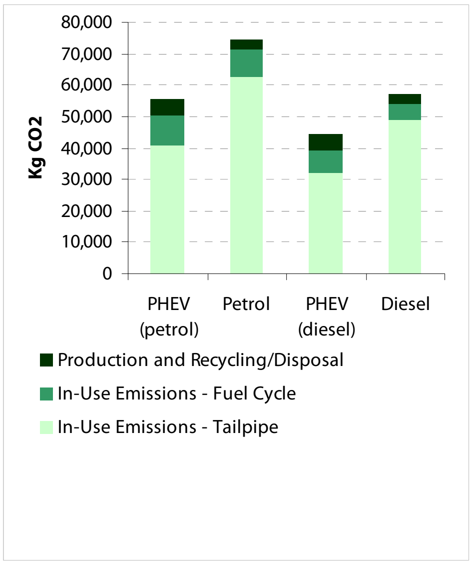
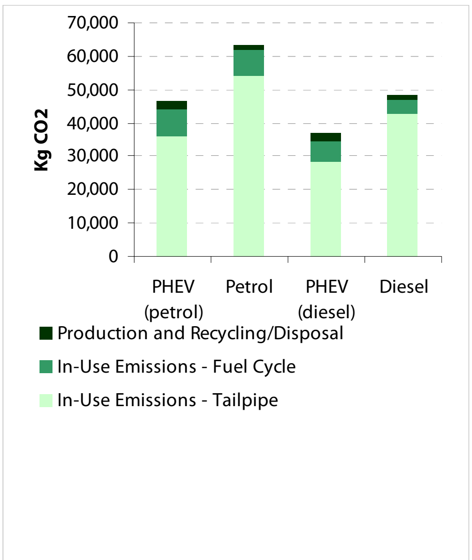


Figure 2.4.4f: "High van use"



Minibus
Figures 2.4.4g to 2.4.4i provide estimated emissions to air as a result of owning and operating a diesel plug-in hybrid minibus under an average, low and high use scenario. For comparison purposes, those emissions arising from a diesel minibus are also shown. The figures shown relate to the emissions arising *over the whole ownership period*. It is worth noting that the graphs should not be compared as they relate to different periods of ownership.

Minibus assumptions:

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	17,000	12,000	25,000
% of driving in city areas	40%	40%	40%

Figure 2.4.4g: "Low minibus use"

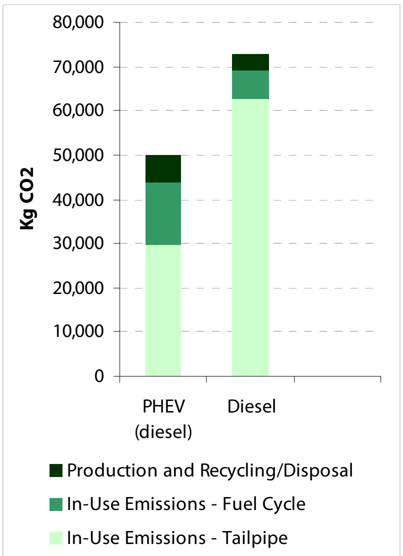
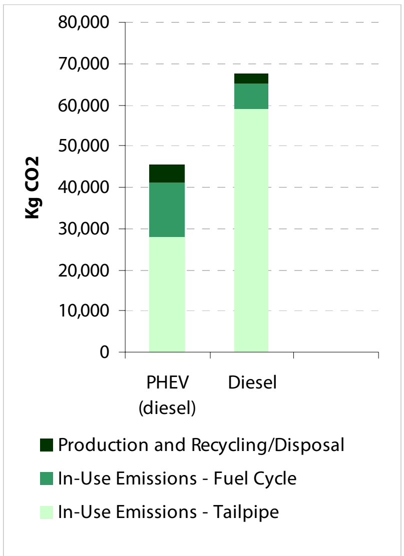
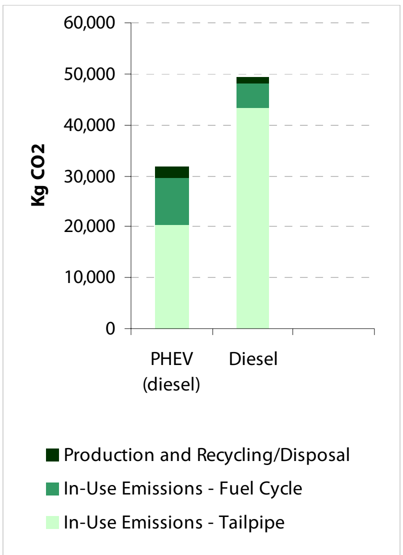


Figure 2.4.4h: "Average minibus use"



2.4.5.1 Figure 2.4.4i: "High minibus use"



Midi bus

Figures 2.2.4j to 2.2.4l provide estimated emissions to air as a result of owning and operating a diesel plug-in hybrid midi bus under urban, inter-urban and express (i.e. long distance) scenarios. For comparison purposes, those emissions arising from a diesel midi bus are also shown. The figures shown relate to the emissions arising *over the whole ownership period.*

Midi bus assumptions:

Assumption:	**Urban**	**Inter-urban**	**Express**
Ownership period (years)	10	10	10
Annual vehicle mileage	30,000	50,000	70,000
% of driving in city areas	90%	40%	10%

Figure 2.4.4j: "Urban midi bus use"

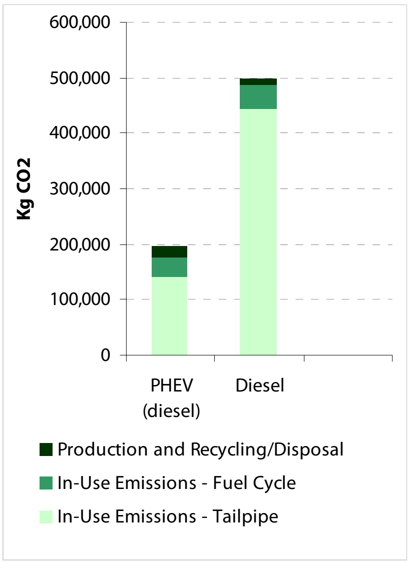


Figure 2.4.4k: "Inter-urban midi bus use"

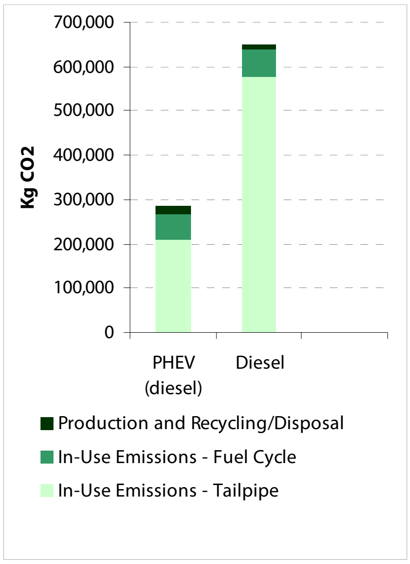
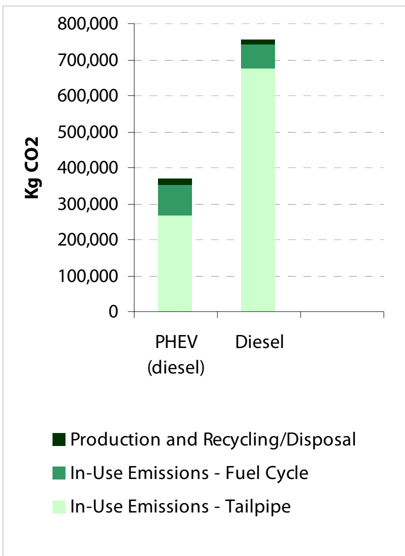


Figure 2.4.4l: "Express midi bus use"



Further information relating to the life-cycle emissions of battery electric vehicles and how this has been estimated can be found in Section 3.

Further details regarding emissions of other pollutants can be found in Appendix 1 and the Cost of Ownership Calculator.

2.4.6 Capital and operating costs

As with regular hybrid electric vehicles, the introduction by manufacturers of more mass-market plug-in hybrid electric vehicles is expected to rapidly drive down the cost of electric drive components. At present however, plug-in hybrids have greater total ownership costs than conventional vehicles. This is due to the much greater capital costs involved when purchasing plug-in hybrids.

Figure 2.4.5a: Costs of ownership under average car use

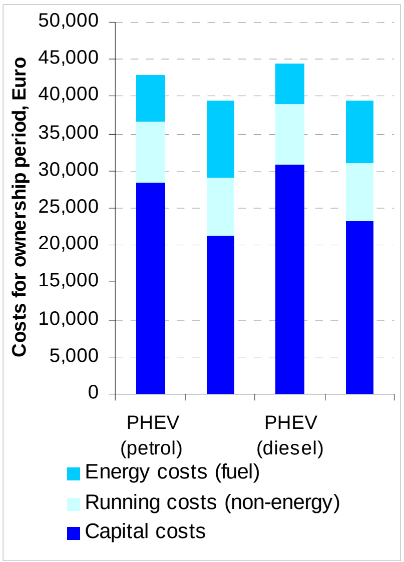


Figure 2.4.5b: Costs of ownership under average van use

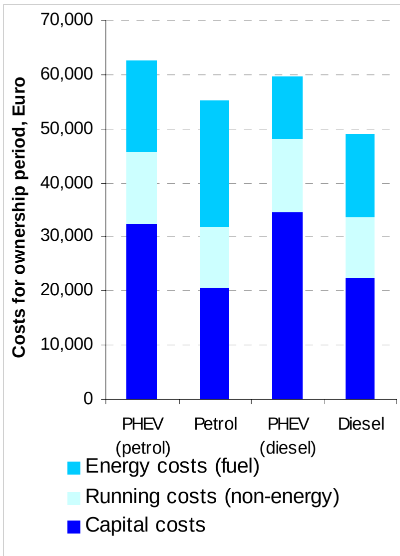


Figure 2.4.5c: Costs of ownership under average mini-bus use

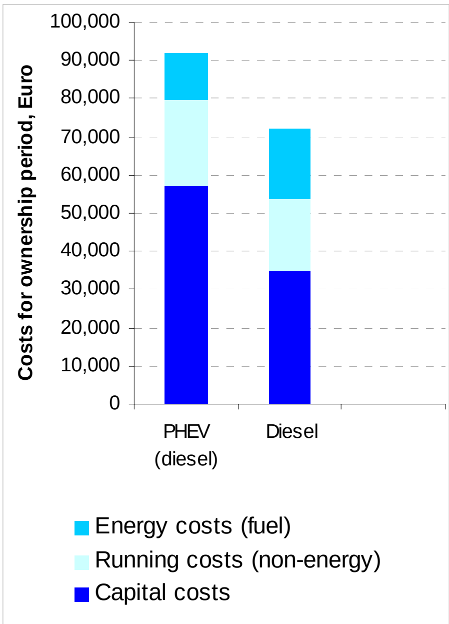
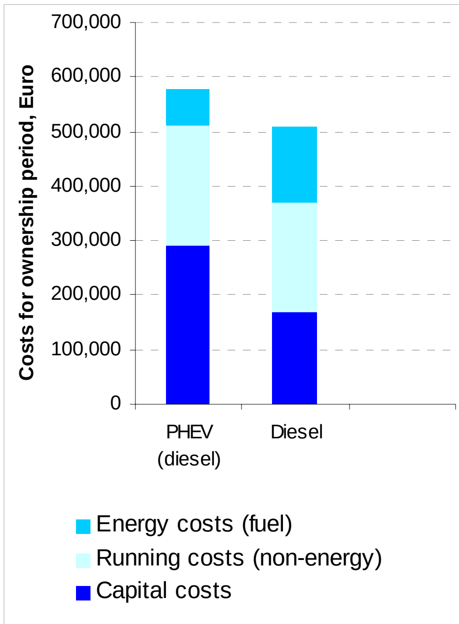


Figure 2.4.5d: Costs of ownership under urban full size / midi-bus use



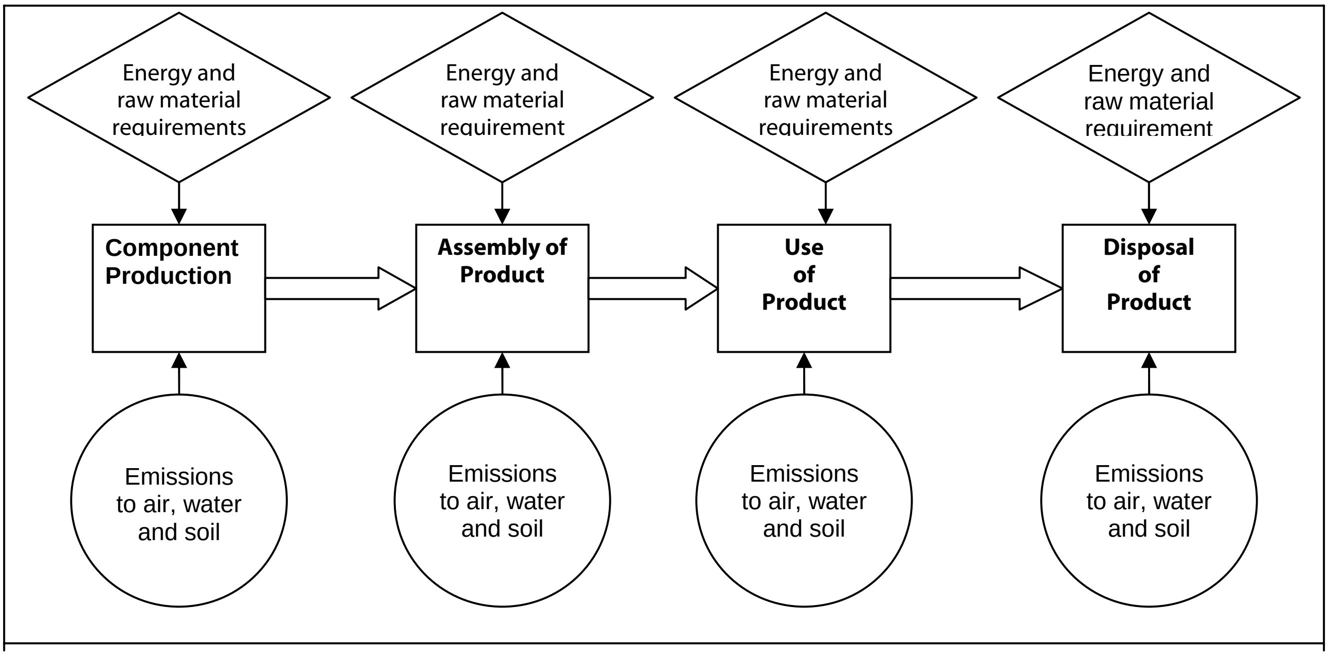
Further information on the costs of ownership and the emissions performance of the vehicles mentioned in this study can be found in Appendix 1 & 2 and in the "Cost of Ownership" calculator.

3 Life cycle analysis

3.1 Introduction

Lifecycle analysis (LCA) is a generic technique for estimating the inputs and impacts associated with a product or system throughout its lifetime. It can be thought of as environmental accounting – the summing of all the energy and materials inputs, emissions to air and water, and the solid waste streams associated with the production, use and disposal of a product or system. This is illustrated in Figure 3.1a below.

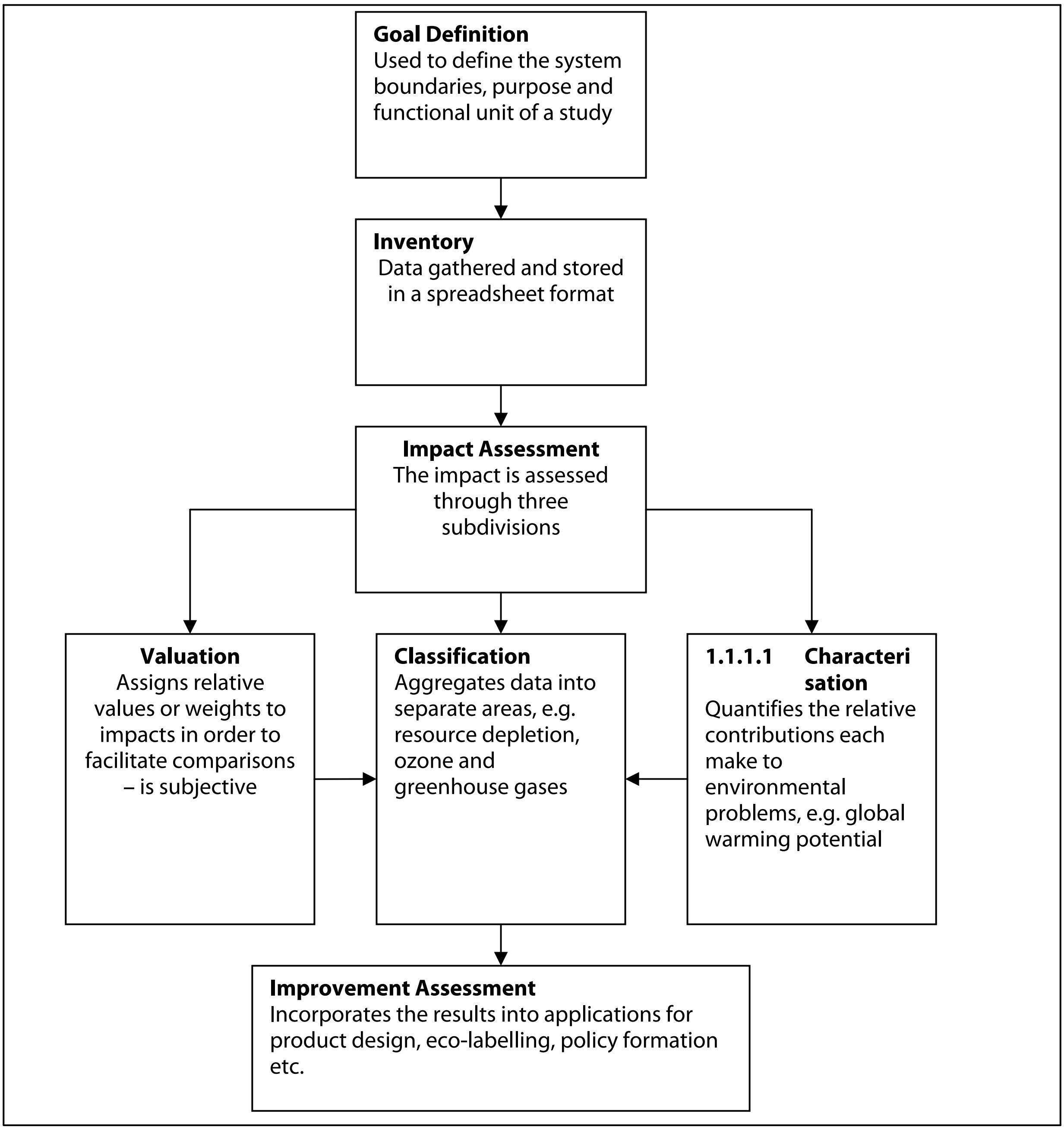
Figure 3.1a: Inputs and outputs that should be considered in a LCA study.[10]



Several standards have been developed for undertaking an LCA in an effort to allow studies carried out by different organisations to be comparable. These standards differ slightly according to the boundaries they place on the emissions sources that should be included in the analysis. For example, whether credits are given for recycling of materials - so avoiding a proportion of the emissions that would otherwise be emitted to produce the raw materials (this can be significant, for example, up to 90% energy savings are achievable for aluminium recycling). The following elements are common to most LCA's as illustrated in Figure 3.1b

[10] House of Lords Select Committee on Science & Technology, 1999 – 2000.

Figure 3.1b: Stages in a LCA as Defined by SETAC (ISO 14040)[10]



3.1.1 Lifecycle analysis definition

The environmental impacts of vehicles can be divided into two categories: those impacts associated with the production, processing and use of the fuel; and those impacts that arise during the manufacture, maintenance and disposal of the vehicle. Respectively, these are termed the *fuel cycle* and the *vehicle cycle*. If these cycles are taken to include all the product processes from cradle-to-grave, the terms used are *fuel life cycle* and *vehicle life cycle*.

In the case of fossil fuels the fuel life cycle includes the following processes during which energy is consumed and emissions are generated[11]:

1. Fuel production – refining/processing of the raw materials into standard fuel;
2. Fuel distribution – distribution of the fuels to fuel stations;
3. Fuel use – consumption of fuel during *vehicle operation* (sometimes assessed as part of vehicle cycle).

In the case of electricity production a similar approach to above is used. Activities associated with fuel production and preparation and fuel distribution to power stations (which involves losses) will occur and the emissions arising from these activities will need to be taken into account. In addition, emissions occurring from fuel use will also occur but these will be from the combustion of fuel at power stations to produce electricity rather than being generated from the vehicle itself.

The vehicle life cycle includes the following processes during which energy is consumed and emissions and waste are generated:

a) Raw material extraction and material production – the materials used include steel, plastics, non-ferrous metals such as aluminium, glass, rubber and composites such as glass fibre;
b) Vehicle assembly – energy is required to assemble components and operate manufacturing plant;
c) Vehicle distribution – transport of a vehicle from the assembly line to the dealerships;
d) Vehicle use – energy consumed during vehicle operation (sometimes assessed as part of the fuel life-cycle)
e) Vehicle maintenance – maintenance and repair over the lifetime of the vehicle;
f) Vehicle disposal – end-of-life vehicles (ELVs) are shredded and a proportion of some materials are recycled for further use.

However, some studies simply refer to the "lifecycle" emissions, which can be taken to mean the fuel lifecycle emissions + the vehicle lifecycle emissions. Lifecycle analysis (LCA) studies also frequently refer to 'well-to-tank' or 'well-to-wheel' impacts/emissions. 'Well to tank' is normally used in the context of the fuel lifecycle and can be defined as the inputs, impacts and emissions associated with extracting, refining and delivering the fuel to the refuelling station. It does not include the emissions associated with powering the vehicle. In contrast, well to wheels includes all the inputs, impacts and emissions covered by 'well to tank' as well as the emissions associated with powering the vehicle.

3.2 Lifecycle emissions – case studies

The following section considers outcomes from relevant lifecycle analysis case studies that have been reviewed. Information on whole lifecycle analysis is provided first, followed by specific further information that has been obtained on certain aspects of the lifecycle. These are:

- Use – fuel cycle
- Materials
- Disposal of vehicles

[11] Ecolane, 2006. Lifecycle assessment of vehicle fuels and technologies. A study carried out for the London Borough of Camden.

3.2.1 Overview

Case study – Life Cycle Analysis of Honda Accord Hybrid Vehicles[12]

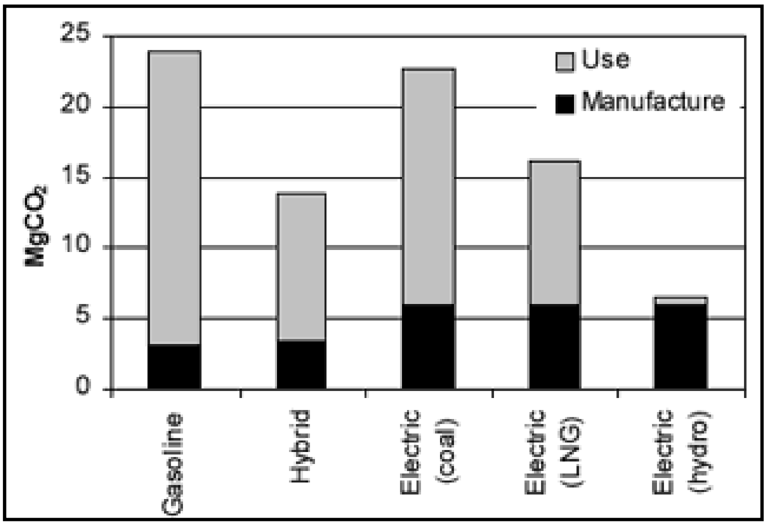
Whole life cycle analysis included the fuel efficiency during use, the production emissions and the final disposal impact of hybrid and conventional vehicles. The study concluded that:

- Hybrid electric vehicles have higher production and disposal impacts but improved vehicle efficiencies can lead to overall reductions in emissions;
- The use of a hybrid engine leads to approximately a 25% reduction in CO_2 emissions during the vehicle use phase.

Case study – Electric vs gasoline[13]

The study looked at the CO_2 emissions that can be attributed to use and manufacture. The results are presented in Figure 3.2.1a below.

Figure 3.2.1a: Lifecycle CO_2 emissions for a gasoline, hybrid and electric powered vehicles.



The study concluded that:

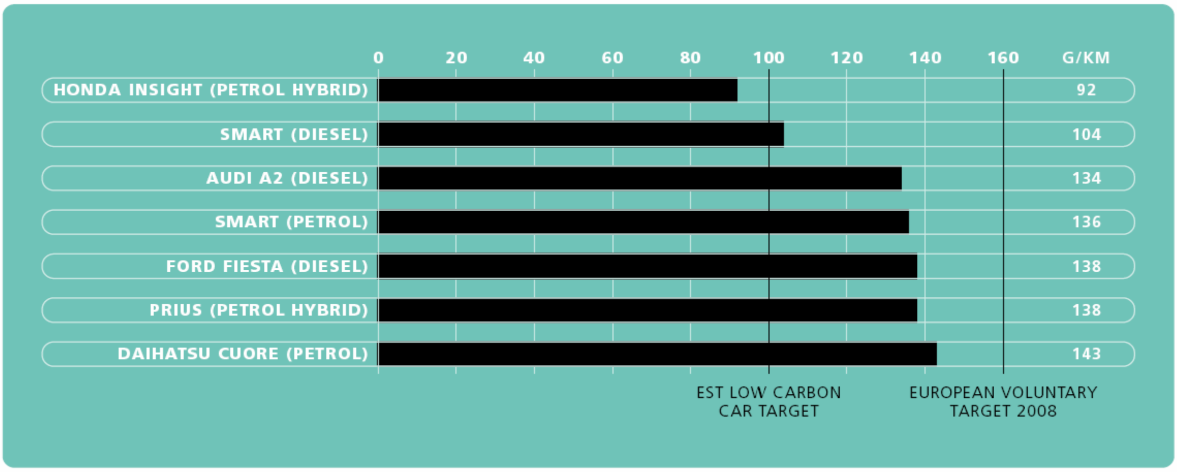
- Gasoline powered vehicles release the lowest levels of CO_2 emissions during manufacture.
- Gasoline powered vehicles have high in use emissions which leads to them having the highest life cycle emissions overall.
- Hybrids and electric vehicles have higher manufacturing emissions than conventional gasoline vehicles.
- Life cycle emissions from electric vehicles are highly dependent on the source of electricity used to power them.

[12] Shekar Viswanathan and Luz Stella Bradley National University, California 2006
[13] Tahara et al Seikei University Tokyo (2001)

Case study - Pathways to Future Vehicles[14]

The strategy examined three key pathways to achieving low carbon vehicle fuels and technologies. The study recommended that the UK government worked in partnership with vehicle manufacturers and fuel suppliers to strive for 10% of new car sales in the UK being low carbon by 2010. They definition of a low carbon car was less than or equal to 100g/km of CO_2 measured on a well to wheels basis. The Honda Insight achieves 92 grams/km well to wheel CO_2 emissions, which demonstrates that there are already hybrid technologies on the market that could be classified as low carbon.

Figure 3.2.1b: The well to wheel CO_2 performance of current car technologies



Case Study – Ecolane Transport and the London Borough of Camden[15]

The London Borough of Camden commissioned Ecolane Ltd to conduct a research project to assess the lifecycle environmental impacts of commercially available road vehicles and technologies in the UK. This research was driven by the need to have clear information on the emission profiles of each of the options as it was felt that there was difficulty for the fleet operator or policy maker to make informed decisions as to which vehicle technology or fuel was most appropriate for a given application. The outputs of the research were to be used to compare the lifecycle environmental performance of cleaner vehicles with each other and against conventional vehicle fuels / technologies to inform future transport policy developments within the London Borough of Camden.

Greenhouse gas emissions

The results of the study conducted by Ecolane for the London Borough of Camden show a number of trends in the life cycle greenhouse gas emissions. The vehicle types analysed were petrol (PET), diesel (DSL), bioethanol (BioE), biodiesel (BioD), compressed natural gas (CNG), liquid petroleum gas (LPG), average mix battery electric (AvBEV), renewable energy battery electric (ReBEV) and hybrid electric (HEV) vehicle technologies. For each fuel type, 5 sizes of vehicle have been assessed ranging from a small city car to a large sports utility vehicle.

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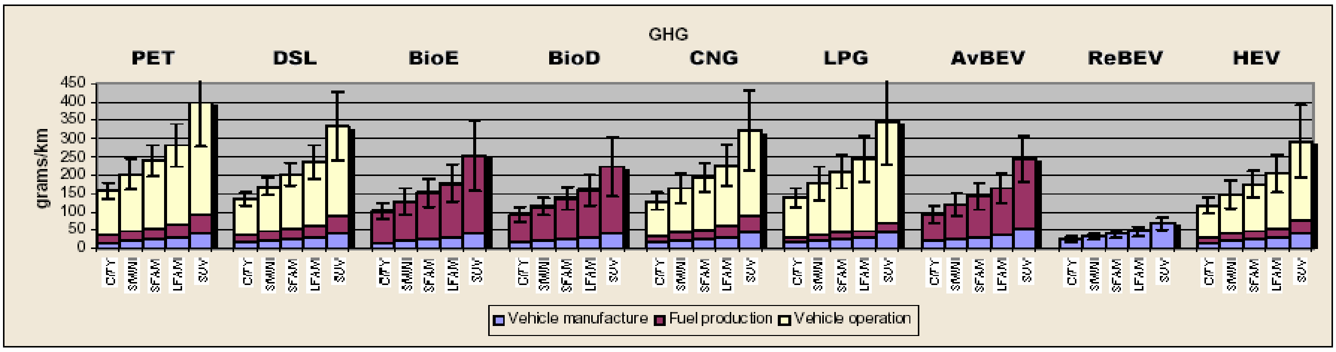
[14] Pathways to future vehicles – A 2020 strategy. Energy Savings Trust, April 2002
http://www.energysavingtrust.org.uk/fleet/usefulresources/strategicpolicydocuments/

[15] Lifecycle assessment of vehicle fuels and technologies. Final report, London Borough of Camden, Ecolane, March 2006

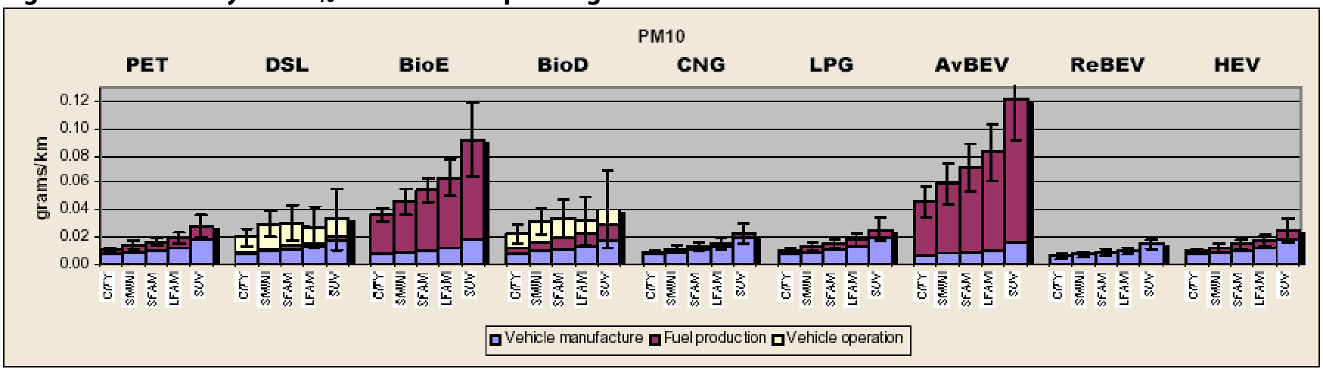
Figure 3.2.1c: Lifecycle CO_2 emissions for passenger cars.
The following conclusions on CO_2 emissions were made by the study:



- Petrol vehicles have the highest levels of CO_2 emissions across their life cycle
- Hybrids offer a reduction compared to petrol of 27%
- Battery electric vehicles offer a reduction of 43% for those using average mix electricity and at least 80% for those using a renewable energy source.
- CO_2 emissions from battery electric vehicles occur during the fuel and vehicle production stages. There are no emissions associated with the vehicle use phase.
- The study highlighted that battery electric vehicles have high levels of operational efficiency

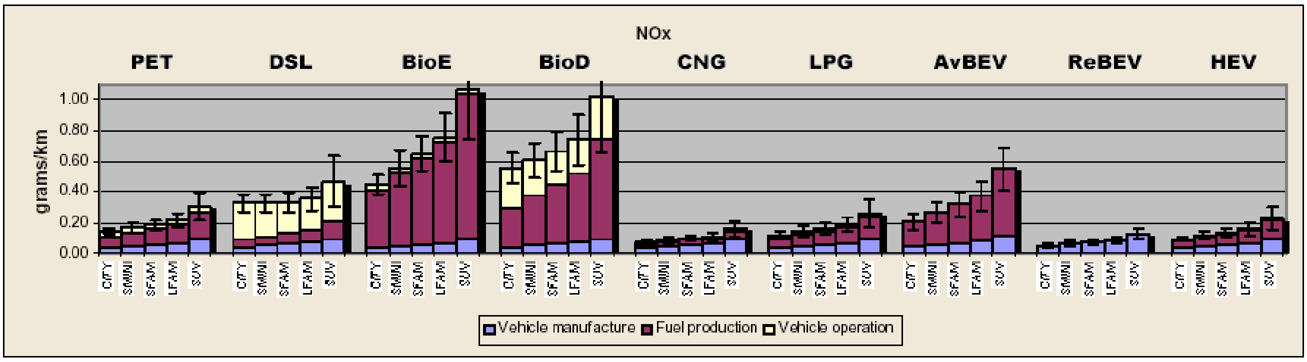
Air Quality
The air quality impacts of different vehicles were also tested. The results together with the main findings of the study for particulates (PM_{10}), nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons (HCs) are shown below:

Figure 3.2.1d: Lifecycle PM_{10} emissions for passenger cars.



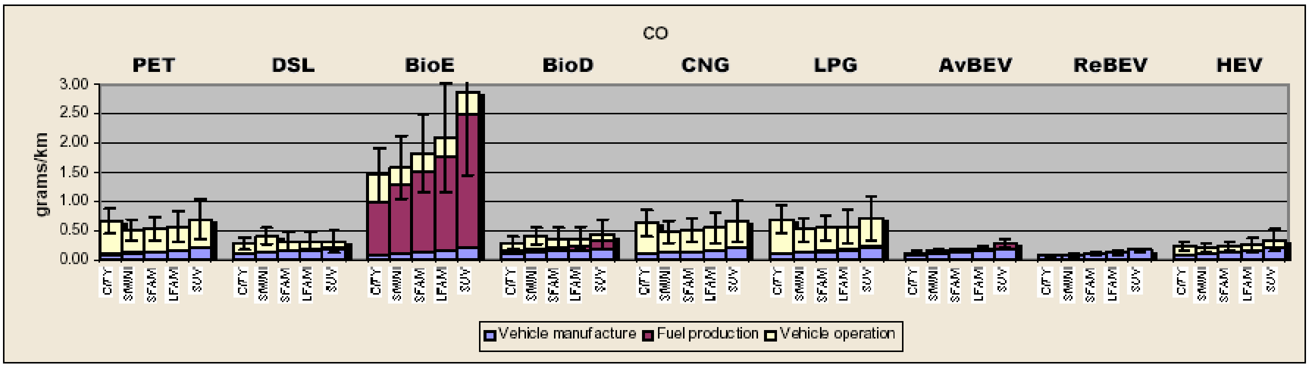
- Battery electric vehicles using average mix electricity for their battery charging were found to be the highest emitters of PM_{10}. This is most likely due to the high levels of particulate emissions that are inherent with the central power generation system in the UK. It must be noted that this situation would differ greatly depending on the energy mix being used to generate electricity and therefore the results may differ if an Ireland specific study was conducted.
- Hybrid electric vehicles release low levels of PM_{10} emissions.
- Of the conventionally fuelled vehicles, diesel has the highest 'in use' PM_{10}

Figure 3.2.1e: Lifecycle NOx emissions for passenger cars



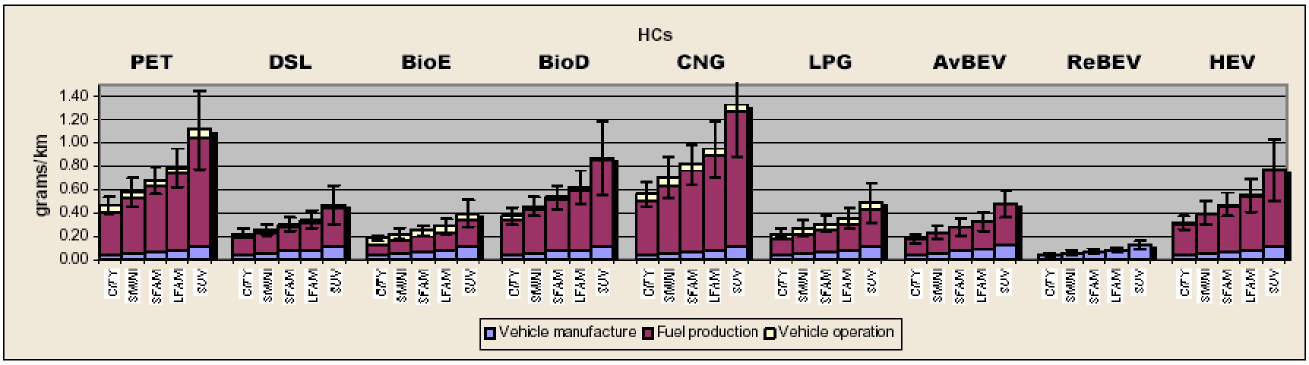
- Life-cycle NO_x emissions vary widely between the vehicle types.
- Battery electric vehicles charged with the average electricity mix perform worse than HEVs with regard to NOx emissions.
- Battery electric cars charged from renewable sources have the lowest life cycle NOx emissions.
- Hybrid electric cars also have low lifecycle NOx emissions.
- If compared by vehicle size, life cycle NOx emissions are significantly greater for diesel cars than for petrol. The majority of emissions occurring during fuel production for petrol models and during operation for diesel models.

Figure 3.2.1f: Lifecycle carbon monoxide (CO) emissions for passenger cars



- Carbon monoxide emissions are similar across many of the different vehicle technologies available, with the exception of bioethanol.
- Electric and hybrid electric vehicles do show improvements over their conventionally fuelled counterparts.
- The majority of CO emissions for battery and hybrid electric vehicles occur during the vehicle manufacturing stage of the life cycle.
- Of the conventionally powered vehicles, petrol cars are responsible for higher levels of life-cycle CO emissions than diesel cars, most of which occur during the vehicle operation phase of the life cycle. Diesel fuelled vehicles show levels of CO emissions that are comparable to those of the hybrid electric cars.

Figure 3.2.1g: Lifecycle hydrocarbon (HC) emissions for passenger cars



- The vast majority of HC emissions occur during the fuel production stage of the life cycle.
- Emissions of HCs for battery electric vehicles charged from renewable sources are therefore significantly lower than those for any other technology.
- Battery electric vehicles charged from average mix electricity also perform well.
- It should be noted that due to the fact that the majority of HC emissions occur during the fuel and vehicle production stages, the majority of these emissions are likely to occur away from dense urban populations, though this depends on the location of manufacturing and refining facilities.

3.2.2 Fuel life-cycle

Case study – Ecolane Transport Consultancy and London Borough of Camden[15]

For further information on the Ecolane study please see Section 3.2.1 This study suggested that fuel life cycle emissions for the use of petrol HEV compared with a typical petrol vehicle can offer:

- 75% reductions in HC, CO and NOx emissions
- 30% reduction in CO_2 emissions and fuel use

Case Studies – University of Liege

Two case studies have been conducted by the University of Liege on the lifecycle emissions of vehicles. These are discussed below.

Study 1[16]

The study looked at the energy consumed and exhaust gases emitted during the operational phase of the vehicle, including the whole supply chain from cradle (extraction of primary energy) to gate (moving vehicle). The four vehicles studied are described in Table 3.2.2a below.

Table 3.2.2a: The main technical characteristics of the four vehicles studied.

	Mitsubishi 2000 cm^3	Seat Ibiza TDI	Peugeot 206	Toyota Prius
Energy supply	Petrol	Diesel	Electricity	Petrol + electricity
Max. power (Kw)	106	81	20	75
EGR	Yes	Yes	-	Yes
Catalyst	3-way catalyst	Oxidation	-	3-way catalyst
Battery type	Lead-acid	Lead-acid	Ni-Cd	Ni-MH

Note: EGR = exhaust gas re-circulation technology

[16] A simplified LCA for automotive sector – comparison of ICE (diesel and petrol), electric and hybrid vehicles. Sophie Nicolay, University of Liege, Belgium, 2000 http://www.ulg.ac.be/cior-fsa/publicat/8lca_ve.pdf

Two assumptions have been considered for the electric vehicle. In the first, electricity is obtained from the average Belgium power station mix; the second scenario is where electricity is consumed from the average Belgium mix but excluding nuclear power. As the results are derived from the average energy mix for Belgium, different conclusions may be obtained if based on Ireland specific data. The results are presented in Table 3.2.2b below.

Table 3.2.2b: Fuel cycle emissions according to the first University of Liege study

	CO_2 (g/km)	CH_4 (g/km)	N_2O (g/km)	PM_{10} (g/km)	CO (g/km)	NO_x (g/km)	SO_2 (g/km)	HC (g/km)
Petrol Vehicle	217	0.021	0.050	0.008	3.020	0.478	0.157	0.783
Diesel Vehicle	170	0.006	0.010	0.106	0.860	0.927	0.118	0.229
Electric Vehicle (average energy mix for electricity generation)	73	0.139	5.6E-5	0.017	0.050	0.145	0.186	0.002
Electric Vehicle (excluding nuclear power from the energy mix)	163	0.311	1.0E-4	0.33	0.126	0.323	0.416	0.004
Hybrid Vehicle	104	0.010	0.024	0.004	0.556	0.121	0.076	0.156

The study found that:

- Hybrid vehicles offer a significant carbon reduction compared to petrol and diesel. This is in agreement with other studies.
- The reduction of emissions offered by electric vehicles depends strongly on the source of electricity.
- The PM_{10} emissions released during the use phase of the diesel vehicle are high.
- The high CH_4 emissions obtained from electric vehicles are as a result of high CH_4 emissions from the extraction of coal.
- As expected NOx emissions are highest from the diesel vehicle. The hybrid vehicle results in the lowest NOx emissions.
- The SO_2 emissions resulting from the electric vehicle excluding nuclear power are high. This is as a result of the sulphur contained in the coal and oil used to fuel Belgium's power stations.

Study 2[17]

The aim of the second University of Liege study was to show how two different methods of environmental impact assessment could be used in order to determine the advantages and disadvantages of a particular vehicle type. Six vehicles were assessed in the study but only the results of four, which are directly applicable to this study, are presented here. Characteristics of the four vehicles are provided in Table 3.2.2c below.

Table 3.2.2c: The main technical characteristics of the four vehicles studied.

	Honda Civic 1.6 i	VW Golf 1.9 TDI	Peugeot 106	Toyota Prius
Energy supply	Petrol	Diesel	Electricity	Hybrid: Petrol
Max. power (Kw)	80.9	66	20	75
Catalyst	3-way catalyst	Oxidation	-	3-way catalyst
Battery type	Lead-acid	Lead-acid	Ni-Cd	Ni-MH

[17] Comparison of 2 models of environmental evaluation – application to a particular case study (alternative vehicles) B Gerkens, University of Liege, Belgium http://www.ulg.ac.be/cior-fsa/publicat/9lca-av.pdf

This study assessed the fuel cycle emissions from cradle (extraction of primary energy) to grate (moving vehicle) and vehicle construction emissions. As with the first study, two assumptions have been considered for the electric vehicle. In the first one, an electric car is powered using the average Belgian fuel mix and in the second scenario an electric car is powered using the average Belgium fuel mix but excluding nuclear power. Again the results for electric vehicles are based on the average Belgium fuel mix and therefore different results may be obtained if the study was repeated using Ireland specific data.

Table 3.2.2d: Fuel cycle emissions according to the second University of Liege study

	CO_2 (g/km)	CH_4 (g/km)	N_2O (g/km)	PM_{10} (g/km)	CO (g/km)	NO_x (g/km)	SO_2 (g/km)	HC (g/km)
Petrol Vehicle	249	0.215	0.003	0.031	1.320	0.244	0.218	0.497
Diesel Vehicle	178	0.131	0.004	0.055	0.149	0.480	0.159	0.065
Electric Vehicle (average production)	94	0.160	0.002	0.050	0.027	0.211	0.212	0.011
Electric Vehicle (without nuclear production)	183	0.378	0.003	0.090	0.035	0.366	0.384	0.025
Hybrid Vehicle	135	0.099	0.003	0.023	0.581	0.162	0.149	0.242

The conclusions from this second study were the same in that:

- Hybrid vehicles were shown to offer low CO_2 emissions; however the lowest CO_2 emissions are obtained by operating an electric vehicle powered by the average electricity mix;
- The reduction of emissions achieved by using electric vehicles depends strongly on the source of electricity;
- Higher emissions were obtained in the second study for the Toyota Prius as a result of emissions associated with the construction of the vehicle being taken into account.

Case study: Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars[18]

This study, conducted for the European Commission looked into a wide range of potential methods (both technical and non-technical) for reducing the CO_2 emissions arising from passenger cars and their associated costs. Hybrid electric drive transmissions were amongst the different technologies considered. The study reviewed two California Air Resources Board (CARB) studies[19] and an International Energy Agency (IEA) Study[20].

The Californian Environmental Protection Agency and Air Resources Board have announced regulations aimed at reducing CO_2 emissions from road vehicles. In support of this they have developed an inventory, the results of which are presented in [CARB 2004a] and [CARB 2004d] and are provided in Table 3.2.2e. The data is based on in house expertise and consultation of external experts.

Table 3.2.2f provides CO_2 reduction potentials as presented in IEA, 2005 for a list of technologies that provides a CO_2 emission reduction on the type approval test. Unfortunately the sources of data are not documented in the original source.

[18] TNO/IEEP/LAT, 2006 Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2 emissions from passenger cars.

[19] [CARB 2004a] Staff proposal regarding the maximum feasible and cost-effective reduction of greenhouse gas emissions from passenger cars, California Environmental Protection Agency and Air Resources Board, June 2004.
[CARB 2004d] Staff Report: Initial Statement of reasons for proposed Rulemaking, Public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles, California Environmental Protection Agency and Air Resources Board, August 2004.

[20] IEA 2005] Making cars more fuel efficient: Technology for Real Improvements on the Road, International Energy Agency and European Conference of Ministers of Transport Joint Report, 2005

Table 3.2.2e: CO_2 emissions reduction potential and manufacture costs. (Data derived from CARB 2004a and CARB 2004d[19])

	Technology options	Petrol small CO2-red. [%]	Petrol small Costs [Euro]	Petrol Large CO2-red. [%]	Petrol Large Costs [Euro]
Engine	Reduced engine friction losses	0,4	3	0,4	9
	DI / homogeneous charge (stoichiometric)		115	0,7	157
	DI / Stratified charge (stoichiometric)				
	DI / Stratified charge (lean burn / complex strategies)	4,3	441	6,4	581
	Mild downsizing (≈ 10%) with turbocharging	4,3	339	5,7	127
	Medium downsizing (≈ 20%) with turbocharging				
	Strong downsizing (≥ 30%) with turbocharging				
	Variable Valve Timing	2,1	106	2,9	195
	Variable valve control	7,9	342	11,4	386
	Cylinder deactivation	2,1		4,3	68
	Variable Compression Ratio	5,0		5,0	
Trans-mission	Optimised gearbox ratios				
	Piloted gearbox				
	Continuous Variable Transmission	2,9	127	2,1	148
	Dual-Clutch				
Hybrid	Start-stop function		119		119
	Regenerative braking				
	Mild hybrid (motor assist)	20,7	1543	20,7	1543
	Full hybrid (electric drive)	38,6	2429	38,6	2429
Body	Improved aerodynamic efficiency	1,1	0 - 76	1,4	0 - 76
	Mild weight reduction (≈ 10%)				
	Medium weight reduction (≈ 25%)				
	Strong weight reduction (≈ 40%)				
Other	Low rolling resistance tyres	1,4	12 - 54	1,4	12 - 54
	Advanced aftertreatment				

The CARB research suggests that the use of a hybrid drive system can lead to anywhere between a 20% and nearly 40% reduction in CO_2 emissions when compared to a petrol fuelled vehicle, depending on whether the hybrid system used is a mild hybrid or full hybrid. Table 3.2.2f, which has been taken from the IEA report, shows a similar set of results to that of Table 3.2.2e. However, the reductions achievable with a mild hybrid are much lower at only 5-7% of the petrol engine. However, the full hybrid potential reduction of 30-50% is similar to those shown in Table 3.2.2e. This set of figures also shows potential reduction rates of 3-5% for the use of a stop-start function.

		petrol		
		CO2-red. [%]		Costs
Technology options		min.	max.	[Euro]
Engine	Reduced engine friction losses	2.0	4.0	
	DI / homogeneous charge (stoichiometric)	12.0 (both DI rows)	15.0 (both DI rows)	
	DI / Stratified charge (lean burn / complex strategies)			
	Mild downsizing (≈ 10%) with turbocharging	2.0 (both downsizing rows)	4.0 (both downsizing rows)	
	Medium downsizing (≈ 20%) with turbocharging			
	Variable Valve Timing	1.5	2.5	
	Variable valve control	5.0	7.0	
	Cylinder deactivation	6.0	8.0	
	Continuous Variable Transmission	5.0	7.0	
Hybrid	Start-stop function	3.0	5.0	150 - 200
	Mild hybrid (motor assist)	5.0	7.0	
	Full hybrid (electric drive)	30.0	50.0	
Body	Improved aerodynamic efficiency	2.0	4.0	
	Medium weight reduction	3.5	7.0	
Other	Low rolling resistance tyres	2.0	4.0	25 - 40
	Low friction engine lubricants	0.5	1.0	20 - 30

Table 3.2.2f: Type approval CO_2 reduction data from [IEA, 2005] for various technologies

3.2.3 Materials

Case study – Ecolane Transport and the London Borough of Camden, 2006

The Ecolane report contains information regarding the average material content of a number of different vehicles and ties this to the emissions attributable to the production of that material. In this way it is possible to produce some more detailed results as to the lifecycle impacts that can be attributed to different types of vehicle. Table 3.2.3a below shows the material composition for a number of different vehicle types. Petrol, diesel and biofuel internal combustion engine (ICE) vehicles are included along with a nickel metal hydride hybrid electric vehicle, a conversion battery electric vehicle and a dedicated battery electric vehicle. It is important to note that due to overall size differences the absolute quantity of materials often differs between vehicles but the proportions of materials may remain similar.

Table 3.2.3a : Material composition of six normalised vehicle types[21]

Normalised composition	ICE Petrol		ICE Diesel		HEV Petrol-NiMH		ICE bi-fuel		Conversion BEV Pb-Ad		Dedicated BEV Pb-Ad	
	kg		kg		kg		kg		kg			
Ferrous	599.2	59.9%	611.3	61.1%	597.7	59.8%	620.0	62.0%	475.6	47.6%	340.01	34.0%
Composites	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	18.337	1.8%
Aluminium	48.9	4.9%	42.3	4.2%	128.7	12.9%	46.4	4.6%	12.4	1.2%	33.619	3.4%
Copper	3.2	0.3%	4.1	0.4%	31.6	3.2%	3.1	0.3%	9.9	1.0%	55.471	5.5%
Zinc	3.2	0.3%	4.1	0.4%	3.0	0.3%	3.1	0.3%	5.8	0.6%	0	0.0%
Lead	8.6	0.9%	10.7	1.1%	5.0	0.5%	8.1	0.8%	154.3	15.4%	283.47	28.3%
Magnesium	3.2	0.3%	4.1	0.4%	8.5	0.9%	3.1	0.3%	5.8	0.6%	0	0.0%
Nickel	0.0	0.0%	0.0	0.0%	9.2	0.9%	0.0	0.0%	0.0	0.0%	0	0.0%
Plastics	158.2	15.8%	154.4	15.4%	119.2	11.9%	150.0	15.0%	140.4	14.0%	108.19	10.8%
Fluids	60.4	6.0%	60.6	6.1%	27.3	2.7%	57.3	5.7%	26.8	2.7%	89.089	8.9%
Rubber	41.7	4.2%	42.8	4.3%	30.5	3.1%	39.5	3.9%	37.0	3.7%	30.562	3.1%
Glass	28.4	2.8%	25.5	2.5%	26.7	2.7%	27.0	2.7%	25.2	2.5%	30.562	3.1%
Others	44.9	4.5%	40.4	4.0%	12.5	1.2%	42.5	4.3%	106.9	10.7%	10.697	1.1%
Total	**1000**	**100.0%**	**1000**	**100.0%**	**1000**	**100.0%**	**1000**	**100.0%**	**1000**	**100.0%**	**1000**	**100.0%**

Table 3.2.3a shows that the majority of the vehicle types being considered contain very similar materials on a percentage basis. However, exceptions to this do exist. One of the key differences is in the use of lead. Conventionally fuelled vehicles contain very little, with lead only making up around 1% of the total vehicle mass. However, for the two electric vehicles considered this proportion is much higher at 15% and 28% for the conversion and the dedicated BEV respectively. This can be attributed to the presence of large lead acid battery packs to power the vehicle. The small amount of lead in the hybrid drive model is explained by the use of nickel metal hydride batteries rather than lead acid batteries. Likewise, an electric vehicle using different battery technologies would not have such a high proportion of lead in the content of the vehicle.

Lighter weight materials also represent a greater proportion of the mass of alternatively fuelled vehicles. This is most likely in an effort to save mass and thus extend the range by improving the fuel consumption of these types of vehicle. The dedicated battery electric vehicle contains more composite material than all the other vehicle types and both the conversion and dedicated battery electric vehicle contain less ferrous materials. Similarly the hybrid electric contains much higher quantities of aluminium, a much lighter material for bodywork than ferrous materials.

The above Ecolane study however presents values on a normalised basis. This can be misleading when looking at the overall amount of material used in a vehicle. This is because hybrid vehicles are heavier than their conventional petrol / diesel alternative. Some illustrative equivalent weights of vehicles are show in Table 3.2.3b below.

Table 3.2.3b: Vehicle weight differences between 2007 model year HEVs and their Internal Combustion Engine Vehicle (ICEV) counterparts[22]

Hybrid electric vehicles	Equivalent ICEV vehicles	Increased weight of the HEV compared to the ICEV (Kg)
Toyota Prius, 2nd generation	Toyota Matrix	61
Toyota Camry	Toyota Camry	169
Honda Civic	Honda Civic	84
Honda Accord	Honda Accord	110
Lexus GS450h	Lexus GS430	175
Nissan Altima	Nissan Altima	150

For an accurate picture of the amount of materials used in different technology types, the data is Table 3.2.3a should be combined with that in Table 3.2.3b.

Table 3.2.3c shows the quantities of emissions that can be attributed to the use of various materials used in vehicle production (quoted in terms of grams of pollutant per kilogram of material produced). This data can be applied to the proportions of the materials in Table 3.2.3a to get an overall picture of

[21] Ecolane, 2006. Lifecycle assessment of vehicle fuels and technologies. A study carried out for the London Borough of Camden.

[22] Reynolds & Kandikar, 2007. How hybrid electric vehicles are different from conventional vehicles: the effect of weight and power on fuel consumption, Environmental Research letters. http://www.iop.org/EJ/article/1748-9326/2/1/014003/erl7_1_014003.html

the quantity of emissions produced during the production life cycle analysis for different vehicle types.

Table 3.2.3c: Emissions attributable to materials production[21,23]

gms/kg	PMs	NOx	CO	HCs	SO2	CO2	CH4	N20	Reference
Ferrous	1.85	3.33	29.02	1.40	3.77	2352	1.23	0.12	IISI 2002
Composites		36.00		12.00	23.00	12000	12.00		Rydh and Sun 2005
Aluminium	8.25	12.00	1.65	15.45	33.15	6049 (i)			IPAI 2000; IAI 2003
Copper		10.00		1.40	658.00	20000	1.40		Rydh and Sun 2005
Zinc		20.00		9.70	65.00	10000	9.70		Rydh and Sun 2005
Lead		2.60	0.34	0.16	7.40	1680	0.06		DeLucci 2004
Magnesium		20.00		9.70	65.00	10000	9.70		Rydh and Sun 2005
Nickel		10.00		1.40	658.00	20000	1.40		Rydh and Sun 2005
Plastics		20.70		19.00	26.70	3800	19.00		Rydh and Sun 2005
Rubber		10.00		5.00	15.00	1700	5.00		Rydh and Sun 2005
Glass		2.30		0.79	2.30	760	0.79		Rydh and Sun 2005
	Note: no entry denotes that no data is available - the model therefore assumes no emissions of this type. (i) CO2 equivalent (inlcudes all greenhouse gas emissions).								

3.2.4 Disposal

Disposal of vehicles is a stage that must be included in any full life cycle analysis . Disposal impacts vary widely from country to country depending on the level of recycling and recovery of materials that occurs there. End of life vehicles (ELVs) are generally stripped of any materials that could be of use as spare parts or could be reconditioned for reuse as well as many materials that pose a particular environmental hazard such as oil from the engine and fuel remaining in the tank and fuel lines. This removal of parts makes it very difficult to make any exact assumptions as to the recycling rate as different vehicles will have different quantities of materials removed before the recycling stage depending on age, type of vehicle, how well it has been designed for dismantling and the reason it has been scrapped.

The Waste Management (end of life vehicles) Regulations came into effect in June 2006. This places obligations on producers and vehicle importers to:

- Establish national collection systems for the recovery and treatment of end of life vehicles. From the 1st January 2007, owners of intact end of life cars and vans could deposit them free of charge at authorised treatment facilities.
- Producers must ensure that vehicles do not contain lead, mercury, cadmium or hexavalent chromium other than in cases specified in the fourth schedule of the regulations.
- Keep records of the aggregate weight of materials for re-use, recycling, recovery and disposal arising from end of life vehicles and report to Local Authorities on an annual basis.
- Producers are obliged to make available to authorised treatment facilities dismantling information for each type of new specific vehicle put on the market in Ireland within six months of the vehicle being on the market.

The Regulations also introduce new environmental standards to ensure that when a vehicle is scrapped as much material as possible is recovered and recycled and that it takes place in a way that does not harm the environment. These targets are in accordance with the provisions of Directive 2000/53/EC.

In the UK around 98% of (ferrous and non-ferrous) metals from ELVs are currently recovered for re-use[24]. These metals are used by the steel industry and in smelting plants. It is thought that this figure is similar to that achieved in Ireland. The proportions of plastics and other materials is much lower, in

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[23] IISI 2002. World Steel lifecycle inventory methodology report, International Iron & Steel Institute, Committee of Environmental Affairs, Brussels, 2002. Rydh & Sun, 2005. Lifecycle inventory data for materials grouped according to environmental and material properties. Journal of cleaner production (13) pp1258 – 1268. IAI 2003 – Lifecycle assessment of aluminium, International Aluminium Institute, 2003. IPAI 2000, Lifecycle inventory of the worldwide aluminium industry with regard to energy consumption and emissions of greenhouse gases. Paper 1 – automotive International Primary Aluminium Institute, 2000.

[24] Wasteonline, 2004. http://www.wasteonline.org.uk End of life vehicle and tyre recycling information sheet.

part due to the variety of materials used and the subsequent difficulty encountered with sorting and recycling.

Credits rather than costs may be given for recycling of some materials – particularly aluminium, glass and ferrous metals, as these are produced from raw material in a very energy intensive way. Recycling can therefore lead to significant reductions in some emissions when incorporated into the overall balance of vehicle lifecycle emissions. Similarly, reuse of components can also be counted as a credit as it can lead to the reduction in new parts manufacture. With the rates of reuse and recycling set to increase under the ELV Directive the overall lifecycle impact of vehicles may be expected to reduce in the future.

EC directive 91/157/EEC requires the collection of batteries containing lead. This directive has led to the development of a very well established system for collection of lead acid batteries. Because of this recycling rates are estimated to be in excess of 90%. Similarly high levels of recycling are anticipated for newer batteries used in hybrid and electric vehicles, such as NiMH and particularly Li-ion (where valuable materials can be recovered).

Review of primary potential candidate owner groups and uses for HEVs, PHEVs & BEVs

3.3 Introduction

This section reviews and identifies the main potential candidate vehicle owner groups and uses for HEVs, PHEVs and BEVs in Ireland. This information has been used in the "Cost of ownership calculator". The following vehicles have been considered in this study:

- Passenger cars,
- Light utility vehicles (or vans),
- Minibuses, and
- Full sized public transport buses.

It has been decided to concentrate on these vehicle types due to their significant contribution to Ireland's CO_2 emissions.

3.4 Fleet operation statistics.

Tables' 4.2a to 4.2c provide information on the number of vehicles currently in operation in Ireland. A vehicle under 3.5 tonnes is classified as a light duty vehicle and is therefore of interest to this study. Table 4.2c shows that light duty vehicles comprise around 87% of the total number of goods vehicles in Ireland. The information shown is the most recent year for which this information was available.

Table 4.2a: Total Number of Vehicles in Ireland in 2005 by Vehicle Category[25]

Passenger cars	Goods vehicles	PSV (small)	PSV (large)	School buses	Other buses	Total
1,662,157	286,548	21,888	7,625	1,018	537	1,979,773

Table 4.2b: Total number of passenger cars and vans by fuel type

Vehicle type	Petrol	Diesel	LPG
Car	1,415,400	246,082	48
Van	1,928	247,343	-

Table 4.2c: Number of goods vehicles by unladen weight in 2005.

Weight category (Kg)	**Number of vehicles**
Not exceeding 610	1,145
611 – 813	507
814 – 1016	7,852
1017 – 1270	60,733
1271 – 1524	40,489
1525 - 1778	51,643
1779 - 2032	59,734
2033 - 2286	14,901
2287 - 2540	5,636
2541 - 2794	2,548
2795 - 3048	2,200
3049 - 3302	1,366
3303 - 3500	517
TOTAL	**249,271**

[25] Irish bulletin of vehicle and driver statistics 2005 (vehicle registration unit)

3.5 Predicted CO_2 emissions from road transport

Predicted CO_2 emissions for Ireland have been taken from the GAINS model. GAINS (the Greenhouse gas and Air Pollution, Interactions and Synergies model) [26] provides a consistent framework for the analysis of reduction strategies for air pollutants across Europe and beyond. The model considers those pollutants covered by the National Emission Ceilings Directive (NECD) as well as particulate matter and greenhouse gases. The model estimates historic emissions of these pollutants based on information collected from international inventories and provides forecasts up until 2030.

Various major emission projection scenarios incorporating current legislation have been developed using the GAINS model. The results presented in the following text and against which possible reductions in CO_2 emissions arising from the use of BEVs, HEVs and PHEVs have been assessed have been taken from the NEC_NAT_CLEV4 scenario. This scenario incorporates data provided by Ireland and assumes the introduction of Euro V and VI for light duty vehicles and Euro VI for heavy-duty vehicles.

Table 4.3a provides GAINS' estimated CO_2 emissions arising from road transport activity. The data shows that CO_2 emissions are expected to increase from this sector by over 20% between 2005 and 2020. Table 4.3b provides a breakdown of CO_2 emissions by vehicle type. When considering the promotion of BEVs, HEVs and PHEVs, priority should be given to those vehicles that contribute the most emissions, as it is likely that this is where the largest gains can be made. The exception to this maybe buses where local governments may subsidise their use and therefore may have an influence over the technologies in use. In the case of CO_2, cars comprise the majority of emissions followed by light duty vehicles; buses on the other hand only contribute ~6% of emissions. It is interesting to note that the contribution that each of the vehicle types make to total road transport emissions stays roughly the same in all years presented.

Table 4.3a: Estimated CO_2 from road transport as predicted by the GAINS model (Mtonnes).

	2005	2010	2015	2020
Total RT	12.7	15.3	16.7	18.1
Total (all sectors)	48.4	52.3	56.1	58.8
RT as a % of total emissions	26%	29%	30%	31%

Table 4.3b: Estimated CO_2 emissions by vehicle class as predicted by the GAINS model (Mtonnes).

Vehicle type	2005	2005 (%)	2010	2010 (%)	2015	2015 (%)	2020	2020 (%)
Buses	0.7	6%	0.9	6%	1.0	6%	1.0	6%
HGVs	1.6	13%	2.0	13%	2.2	13%	2.4	13%
Motorcycles	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Cars	6.6	52%	7.8	51%	8.7	52%	9.4	52%
LDVs	3.7	29%	4.6	30%	4.9	29%	5.3	29%
Total RT	**12.7**	**100%**	**15.3**	**100%**	**16.7**	**100%**	**18.1**	**100%**

[26] http://www.iiasa.ac.at/web-apps/apd/RainsWeb/

3.6 Ranking of owner and usage categories in terms of potential emissions and economic benefits

This section compares the different vehicle types in terms of their greenhouse gas emission benefits. The approach taken in this analysis has been to first rank the different options in terms of their CO_2 emission abatement performance and then to assess the economic benefits associated with the reduction in emissions. The data presented relates to the "average" scenario for cars, vans and minibuses and the "urban" scenario for full size / midi-buses as provided in the Buyer's Guide and the Cost of Ownership Calculator. *Significantly different results may be obtained if assumptions made with regard to the annual average mileage for these vehicles were changed.*

3.6.1 Ranking of options based on CO_2 emission reductions

Table 4.4.1a ranks the different options in terms of CO_2 emission reductions per vehicle and Table 4.4.1b ranks the different options in terms of CO_2 emission reductions if 10% of the fleet was switched to the newer technologies (See Section 4.2 for fleet details). The change in CO_2 emissions refers to reductions achieved over the ownership period.

Table 4.4.1a: Rank ordering of options in terms of CO_2 reductions on a per vehicle basis

Conversion	Change in CO_2 emissions (Kg)
Diesel full size/midi bus → battery electric full size/midi bus	-435,439
Diesel full size/midi bus → plug-in-diesel hybrid full size/midi bus	-304,635
Diesel full size/midi bus → diesel hybrid full size/midi bus	-182,929
Petrol van → battery electric van	-47,515
Diesel minibus → battery electric minibus	-38,174
Diesel van → battery electric van	-30,104
Petrol van → diesel plug-in-hybrid van	-29,981
Petrol van → diesel hybrid van	-27,289
Diesel minibus → diesel plug-in-hybrid minibus	-22,346
Petrol van → petrol plug-in-hybrid van	-18,852
Petrol car → battery electric car	-14,507
Diesel minibus → diesel hybrid minibus	-14,349
Petrol van → petrol hybrid van	-13,801
Diesel van → diesel plug-in-hybrid van	-12,570
Diesel car → battery electric car	-12,199
Petrol car → diesel plug-in-hybrid car	-10,159
Diesel van → diesel hybrid van	-9,878
Petrol car → petrol plug-in-hybrid car	-9,239
Diesel car → diesel plug-in-hybrid car	-7,851
Petrol car → diesel hybrid car	-7,275
Diesel car → petrol plug-in-hybrid car	-6,931
Petrol car → petrol hybrid car	-5,403
Diesel car → diesel hybrid car	-4,967
Diesel car → petrol hybrid car	-3,095
Diesel van → Petrol – plug in hybrid van	-1,441
Diesel van → Petrol hybrid van	+3610

Table 4.4.1b: Rank ordering of options in terms of CO_2 reductions based on 10% of the fleet switching

Conversion	Change in CO_2 emissions (Mtonnes)
Petrol car → battery electric car	-2.05
Petrol car → diesel plug-in-hybrid car	-1.44
Petrol car → petrol plug-in-hybrid car	-1.31
Petrol car → diesel hybrid car	-1.03
Petrol car → petrol hybrid car	-0.76
Diesel van → battery electric van	-0.74
Diesel full size/midi bus → battery electric full size/midi bus	-0.33
Diesel van → diesel plug-in-hybrid van	-0.31
Diesel car → battery electric car	-0.30
Diesel van → diesel hybrid van	-0.24
Diesel full size/midi bus → Diesel plug-in-hybrid full size/midi bus	-0.23
Diesel car → diesel plug-in-hybrid car	-0.19
Diesel full size/midi bus → diesel hybrid full size/midi bus	-0.14
Diesel car → petrol hybrid car	-0.08
Diesel car → diesel hybrid car	-0.12
Diesel car → petrol plug-in-hybrid car	-0.17
Diesel van → petrol plug-in-hybrid van	-0.04
Diesel minibus → battery electric minibus	-0.04
Diesel minibus → Diesel plug-in-hybrid minibus	-0.03
Diesel minibus → diesel hybrid minibus	-0.02
Petrol van → battery electric van	-0.01
Petrol van → diesel plug-in-hybrid van	-0.01
Petrol van → diesel hybrid van	-0.01
Petrol van → petrol plug-in-hybrid van	-0.00
Petrol van → petrol hybrid van	-0.00
Diesel van → petrol hybrid van	+0.09

Note: the results are independent of each other. For example the first row refers to 10% of the petrol car fleet switching to battery cars and the second row refers to the impact of 10% of petrol cars switching to diesel plug-in-hybrids.

As can be seen from the tables, the ranking of options varies depending on whether the analysis is undertaken on a per vehicle basis or assuming that 10% of the fleet are switched to these newer technologies. On a per vehicle basis the largest CO_2 reductions are achieved by switching full size/midi buses to battery electric, plug-in-hybrids and diesel hybrids. Cars rank lower using this approach because of their relatively small contribution to CO_2 emissions on a per vehicle basis. If the second approach is followed and vehicles are ranked on the emission reductions achievable by switching 10% of the fleet, then petrol cars switching to battery electric cars are ranked first. This is due to the large number of cars in operation. In both cases, switching a diesel van to a petrol hybrid van ranks last and in fact leads to an increase in emissions over the ownership period.
In the best case scenario presented in Table 4.4.1b above, a reduction of 2.05 million tonnes of CO_2 could be achieved over a ten-year period. On an annual basis, this amounts to a reduction in road transport CO_2 emissions of approximately 1.3% and a reduction in total CO_2 emissions of approximately 0.4% if assessed against the GAINS' model predictions in 2010.

3.6.2 Ranking of options based on benefit to cost ratio

In addition to ranking the CO_2 emission benefits associated with BEVs, HEVs and PHEVs, the options have been ranked using the benefit to cost ratio (BCR) methodology. The benefits are based on the damage costs of climate change. These are usually referred to as the social cost of carbon (SCC) and can be used to assess the economic benefits of climate change policy or the economic impacts of greenhouse gas emissions[27]. Again, the data presented relates to the "average" scenario as provided

[27] For further information on the SCC, please see Section 6.6 on pollutant damage costs.

in the Buyer's Guide and the Cost of Ownership Calculator. The result of this analysis is presented in Table 4.4.2 below. It should be noted that because there are no net implementation costs associated with some options (i.e. total capital and operating costs are lower than the conventional petrol or diesel equivalent), the BCR couldn't be quantified. In effect, there are no costs and only benefits for these options and hence a ratio cannot be defined.

Table 4.4.2: Rank ordering of options based on the benefit to cost ratio

Conversion	Benefit to cost ratio
Petrol van → petrol hybrid van	Unquantifiable but high *
Petrol van → diesel hybrid van	Unquantifiable but high *
Diesel van → diesel hybrid van	0.77
Petrol van → diesel plug-in-hybrid van	0.22
Petrol car → petrol hybrid car	0.17
Diesel full size/midi bus → diesel hybrid full size/midi bus	0.15
Diesel full size/midi bus → diesel plug-in-hybrid full size/midi bus	0.15
Diesel full size/midi bus → battery electric full size/midi bus	0.14
Petrol car → diesel hybrid car	0.13
Diesel minibus → diesel hybrid minibus	0.13
Petrol van → battery electric van	0.11
Diesel car → petrol hybrid car	0.10
Diesel car → diesel hybrid car	0.09
Petrol van → petrol plug-in-hybrid van	0.08
Petrol car → petrol plug-in-hybrid car	0.07
Petrol car → diesel plug-in-hybrid car	0.06
Diesel car → petrol plug-in-hybrid car	0.05
Diesel van → battery electric van	0.05
Diesel car → diesel plug-in-hybrid car	0.04
Petrol car → battery electric car	0.04
Diesel car → battery electric car	0.04
Diesel van → diesel plug-in-hybrid van	0.04
Diesel minibus → battery electric minibus	0.04
Diesel minibus → diesel plug-in-hybrid	0.04
Diesel van → petrol plug-in-hybrid van	0.01
Diesel van → petrol hybrid van	-0.02

* No additional implementation costs therefore there are only monetary benefits and a BCR cannot be quantified

The table shows that under the "average" scenario, by switching petrol vans to the hybrid options, there are no additional costs involved in achieving the CO_2 emission benefits. Switching from a diesel van to a petrol hybrid van has a negative BCR as under this scenario, CO_2 emissions actually increase. For other options, the implementation costs significantly outweigh the monetary value of the CO_2 emissions benefits that could be achieved.

3.7 Summary of findings

The ranking of CO_2 reductions and the benefit to cost ratio carried out for this study has allowed the different options to be assessed. Based on the results obtained from this work, the following conclusions have been made:

- On a per vehicle basis, the largest CO_2 emission reductions can be achieved by switching full size / midi buses to battery electric, plug-in-hybrid or hybrid vehicles. However, at the current time, there are few large size / midi electric buses in operation and no plug-in-hybrid buses available for sale in Ireland. Therefore, switching full size/midi buses to hybrids is the most appropriate substitute to make (if costs are disregarded) at the present time.
- If 10% of either the car, van or bus fleet was going to be switched, then the most beneficial in terms of CO_2 emission reductions is to switch petrol cars to battery electric cars. The second most beneficial switch is from petrol cars to diesel hybrid cars. However, these would both have cost implications.
- The most cost-effective options are to switch conventional petrol vans to either petrol or diesel hybrids. These switches lead to cost savings and CO_2 savings and hence lead to a high benefit to cost ratio.

4 Battery charging and patterns of energy use

This section is split into two parts: an identification of the technology options available for vehicle battery recharging and associated charging regimes and costs and the patterns of energy use as required by fleet operators.

4.1 Technology options available for battery recharging

There are two methods in which a vehicle can be charged[28].

1) Conductive coupling – this is a direct electrical connection and might be as simple as plugging a mains lead into a weatherproof socket through special high capacity cables with connectors to protect the user from high voltages.
2) Inductive coupling. A special 'paddle' is inserted into a slot on the car. The paddle is one winding of a transformer, while the other is built into the car. When the paddle is inserted it completes a magnetic circuit which provides power to the battery pack.

The major advantage of the inductive approach is that there is no possibility of electrocution as there are no exposed conductors, although interlocks can make conductive coupling nearly as safe. The advantage of conductive coupling equipment is that it is lower in cost and much more efficient due to the lower number of components that are required.

Once plugged in, electricity from the grid is supplied in the form of an alternating current (AC). However, a battery can only store direct current (DC). Therefore, when the battery is charged the charger converts the AC to a DC and supplies it to the battery at the correct voltage so that the motor and wheels receive the correct amount of power. An electronic device called a "controller" does this[29]. AC motors power some electric vehicles and in this case the DC from the battery must be re-converted to AC by an "inverter".

4.2 Charging regime and costs

The current electricity price in Ireland is approximately 14.5 cents/kWh for general domestic usage and 7 cents per kWh for night saver rate. This is based on the average tariff of ESB Customer Supply, Energia and Airtricity. Electricity prices at present vary by provider, however this will change from the 1st November 2007 when there will be one price for all providers. The Commission for Energy Regulation (CER) and the Northern Ireland Authority for Energy Regulation (NIAER) are working together to provide a single electricity market (SEM) for the island of Ireland. The SEM will be a gross pool market into which all electricity generated or imported onto the island of Ireland must be sold and from which all wholesale electricity for consumption on or export from the island of Ireland must be purchased.

The difference in costs between day and night usage show that there are substantial savings that can be made by recharging battery electric vehicles over night.

Details from the cost of ownership calculator show that over a one-year period for a battery-electric car travelling approximately 10,500 miles (assuming that 80% of the time the battery is charged overnight), the electricity costs for recharging the battery amount to approximately €760. In this scenario, running a petrol and diesel car the same distance would cost around €2,600 and €2,100 respectively in fuel costs. Further information on the costs of battery charging can be obtained from the Cost of Ownership calculator.

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[28] Wikipedia http://en.wikipedia.org/wiki/Battery_electric_vehicle
[29] IEA – hybrid and electric vehicle implementing agreement http://www.ieahev.org/electric.html

4.3 Patterns of energy usage data

Energy usage data is required so that further work can be conducted in the future on the electricity supply implications and the associated patterns of energy demand.

Twenty-two vehicle fleet operators were contacted to ascertain operational statistics so that an assessment could be made as to whether BEVs and PHEVs would be suitable. Responses were received from eight fleet operators, although in some cases these were limited in nature. The operators that provided information were: Dublin City Council, Eircom, Dublin Bus, Cork City Council, JJ Kavanagh, Cork County Council, Bus Eireann and Fingal County Council. A summary of the information provided is presented in the following sections.

4.3.1 Range driven from base:

Vehicle type	Total number of vehicles in responses from fleet operators	Range of mileage for distance driven from base
Car	1,007	10 - 40
Vans	3,480	10 - 40
Mini-buses	6	12 – 250
Large buses	2,620	5 - 250

4.3.2 Average daily mileage

Vehicle type	Total number of vehicles in responses from fleet operators	Average daily mileage
Car	1,007	40 – 460
Vans	3,480	40 - 460
Mini-buses	6	40
Large buses	2,620	5 - 250

4.3.3 Average time away from base

Vehicle type	Total number of vehicles in responses from fleet operators	Hours away from base
Car	1,007	6 – 8 hours
Vans	3,480	2 – 8 hours
Mini-buses	6	Varies
Large buses	2,620	2.5 – 18 hours

4.3.4 Do vehicles operate to predictable routes?

Vehicle type	Total number of vehicles in responses from fleet operators	Yes, No or Some of the fleet operates to predictable routes
Car	1,007	Some
Vans	3,480	Some
Mini-buses	6	Some
Large buses	2,620	Predominately yes.

4.3.5 Are vehicles used during the day or night?

Vehicle type	Total number of vehicles in responses from fleet operators	Day or night
Car	1,007	Day
Vans	3,480	Day
Mini-buses	6	Day
Large buses	2,620	Predominately day

The survey responses showed that buses operate to the most predictable routes and in some instances only travel short distances (5 miles) before returning to base where in theory they could have their batteries re-charged. The Ebus transit shuttle, manufactured in California has an operational range of 60 – 90 miles and therefore it appears from the data collected, that this distance is beyond that often required by operators. Although only a small sample of operators responded to the questionnaire, the bus movement data collected is thought to be representative of the Irish bus fleet due to obtaining responses from large bus operators such as Dublin bus, JJ Kavanagh and Bus Eireann. The bus operators surveyed operate predominately during the day meaning that recharging could take place during the night leading to cheaper operational costs.

The average mileage driven from base for passenger cars and vans was found to be around 10 to 40 miles. Many of the smaller BEVs such as the Reva G-Wiz have a range of around 30 to 60 miles whilst the Micro-Vett Porter and Modec vans have a range of between 45 and 100 miles. From this it can be inferred that battery electric cars/vans or plug-in hybrid electric cars/vans could also be used in some cases. It is anticipated that fast charging would need to be utilised as the total daily distance exceeds the distance driven from base by a large amount implying that many trips are undertaken in a day.

The small number of minibuses that were included in the survey showed that distances travelled tended to be similar to large buses but that they operated on less defined routes and therefore battery recharging may pose more of a problem. However, in this instance the survey undertaken was very limited, so this may not be representative of the average fleet in Ireland.

5 Data Sources and Assumptions

This section examines data sources and assumptions used in the buyer's guide and the cost of ownership calculator

The Buyer's guide and cost of ownership calculator provides information on:

- In-use emissions – tailpipe (CO_2 + air quality pollutants)
- In-use emissions – fuel cycle (CO_2 + air quality pollutants)
- Vehicle production – recycling and disposal (CO_2 + air quality pollutants)
- Capital costs (after discount and including resale)
- Running costs (non-energy i.e. tax and maintenance)
- Running costs (energy)
- Total cost (over ownership period)
- Increased cost compared to petrol car
- Cost per tonne of CO_2 saved

We consider these in turn below

5.1 In-Use Emissions - Tailpipe

5.1.1 CO_2

The vehicle technology efficiencies (base combined cycle average) in MJ/km (and costs) for cars, vans and buses are based on the dataset developed in 2006 to update the transport module of the UK MARKAL energy model[30]. This was used in policy analysis for the UK's 2006 Energy Review and 2007 Energy White Paper (EWP). This dataset was verified with government and industry stakeholders. Because minibuses were not explicitly covered in the MARKAL model dataset, values were estimated for the purposes of this work by scaling van data to the difference between buses and HGVs. The dataset was also cross-checked for consistency with more recent information gathered on hybrid and electric vehicles for this study.

For petrol, diesel and HEV technologies, the corresponding urban and extra-urban vehicle efficiencies were estimated from their average relative deviations from the combined cycle figures for the respective technologies contained in the UK's Vehicle Certification Agency (VCA) dataset of car fuel consumption and CO_2 for all new car models available in the UK[31]. For BEVs the relative efficiencies of urban and extra-urban cycles were estimated based on information from a study by TNO (2002)[32].

Table 5.1.1 Fuel properties and emission factors for petrol and diesel

Fuel	Energy density (Net CV)	Physical density	Carbon intensity ($kgCO_2/GJ$)		Fuel Cycle emissions, kg[pollutant]/GJ				
	GJ/tonne	Litres/tonne	Tailpipe	Fuel Cycle	CO	VOC	NOx	PM	SOx
Diesel	43.39	1203	72.93	7.50	0.0047	0.0904	0.0392	0.00143	0.0811
Petrol	44.69	1354	70.15	9.60	0.0053	0.2137	0.0448	0.00188	0.0978

5.1.2 Air quality pollutants

Emissions of air quality pollutants (CO, VOCs, NO_x and PM) have been estimated for conventional petrol and diesel vehicles using data from the UK National Atmospheric Emissions Inventory (NAEI)

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[30] The MARKAL (standing for MARKet ALlocation) energy model is a bottom-up model consisting of detailed datasets on current and future technologies (with costs and efficiency and other performance parameters), and a set of end-user energy demands. The model essentially calculates the least-cost way across the entire energy system of achieving the end-user demands. The model is supported by the IEA and has widespread international use.

[31] The VCA database of new car CO_2 and fuel consumption is available online at: http://www.vcacarfueldata.org.uk/downloads/

[32] Comparative Assessment of Fuel Consumption for Conventional and Hybrid Vehicles, Rob Winkel, Erik van den Tillaart, Jacob Eelkema and Richard Smokers from TNO Automotive. Proceedings 19th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium (EVS 19), Korea, 2002 (TNO-paper VM 0208). Available at: http://www.automotive.tno.nl/VM/EST/publicaties/Comparison%20Conventional%20and%20hybrid%20Vehicles.pdf

for new Euro IV compliant cars, vans and buses. For HEVs and PHEVs running on petrol and diesel we have assumed a reduction in emissions of NO_x and PM for the urban drive cycle only – summarised in Table 5.1.2. Tailpipe emissions of SO_2 were estimated on the basis of fuel consumption and sulphur-free fuel (<10ppm sulphur) for simplicity, as this fuel already accounts for more than 30% of Irelands current supply and will be mandatory for all road vehicles from 2009.

Table 5.1.2: Assumptions on reductions of urban tailpipe emissions of NO_x and Particulate Matter (PM) for hybrid electric vehicles

	NOx	**PM**
Petrol hybrid	37.5%	0%
Diesel hybrid	80%	92%

5.2 In-Use Emissions - Fuel Cycle

In-use fuel cycle emissions are directly dependent on the quantity of fuel/energy used. This section summarises the data sources used to derive emission factors per unit of energy for the different fuels (electricity, petrol, diesel). Emissions per kilometre are then calculated from the fuel consumption of different vehicles.

Electricity

The future electricity mix was taken from AEA's analysis of projected emissions from the power generation sector[33]. This study provided both fuel consumption and estimated emissions from power sources (taking into account new abatement technologies) annually from 2006 to 2010, and then for 2015 and 2020. This allowed the grams of a pollutant per KWh of energy supplied to be estimated for the years identified above. For the individual years post 2010, where data was not available from this study, the estimated emissions have been interpolated from the data provided.

Petrol and diesel

Greenhouse gas emissions (in kg CO_2 equivalents) were taken from the JRC (2007) Well-to-Wheels study[34]. In the absence of other data sources, fuel cycle emissions of air quality pollutants (CO, VOC, NO_x, SO_x and PM) were taken from the European Commission funded project "Methodologies for estimating air pollutant emissions from transport (MEET 1997)[35]. The emission factors are summarised in Table 6.1.1

5.3 Vehicle Production and Recycling and Disposal

For the life-cycle analysis, we have estimated the normalised material composition for the different vehicle types, based on the figures from Ecolane (2006), as presented in Table 5.3a. For BEVs we have recalculated values based on a Lithium ion battery pack, as these are more commonly the battery of choice for new BEVs. The recalculation was made on the basis of information on the relative specific energies of the different battery types compared to lead-acid batteries (in **Error! Reference source not found.**2.2.2) and on the material composition of the different battery types (in Table 6.3a).

Table 5.3a: Material composition of the seven normalised vehicle technology types

Composition (kg)	**Petrol**	Diesel	HEV Petrol (NiMH)	HEV Diesel (NiMH)	PHEV Petrol (Li-ion)	PHEV Diesel (Li-ion)	Dedicated BEV (Li-ion)
Ferrous	599.2	611.3	597.7	609.8	597.7	609.8	340.0
Composites	0.0	0.0	0.0	0.0	0.0	0.0	18.3
Aluminium	48.9	42.3	126.7	120.1	126.7	120.1	126.7
Copper	3.2	4.1	31.6	32.5	31.6	32.5	55.5
Zinc	3.2	4.1	3	3.9	3.0	3.9	0.0
Lead	8.6	10.7	5	7.1	5.0	7.1	5.0
Magnesium	3.2	4.1	8.5	9.4	8.5	9.4	0.0

33 Analysis of emissions from the power generation sector. Report for the Dept of Environment, Heritage and Local Government. AEA Energy & Environment, May 2007.
34 Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context, Well-To-Wheels Report, Version 2c, Feb 2007; EC JRC, CONCAWE, EUCAR. Available at: http://ies.jrc.cec.eu.int/WTW
35 EC MEET Project Deliverable 20, 'Fuel and Energy Production Emission Factors' (C.A. Lewis, ETSU, AEA Technology, 1997).

Composition (kg)	**Petrol**	Diesel	HEV Petrol (NiMH)	HEV Diesel (NiMH)	PHEV Petrol (Li-ion)	PHEV Diesel (Li-ion)	Dedicated BEV (Li-ion)
Nickel	0	0	9.2	9.2	0.0	0.0	0.0
Li-ion	0.0	0.0	0.0	0.0	74.4	74.4	148.7
Plastics	158.2	154.4	119.2	115.4	119.2	115.4	119.2
Rubber	60.4	60.6	27.3	27.5	27.3	27.5	89.1
Glass	41.7	42.8	30.5	31.6	30.5	31.6	30.6
Fluids	28.4	25.5	26.7	23.8	26.7	23.8	30.6
Other	44.9	40.4	12.5	8.0	12.5	8.0	10.7
Ferrous	59.9%	61.1%	59.9%	61.1%	56.2%	57.3%	34.9%
Composites	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
Aluminium	4.9%	4.2%	12.7%	12.0%	11.9%	11.3%	13.0%
Copper	0.3%	0.4%	3.2%	3.3%	3.0%	3.1%	5.7%
Zinc	0.3%	0.4%	0.3%	0.4%	0.3%	0.4%	0.0%
Lead	0.9%	1.1%	0.5%	0.7%	0.5%	0.7%	0.5%
Magnesium	0.3%	0.4%	0.9%	0.9%	0.8%	0.9%	0.0%
Nickel	0.0%	0.0%	0.9%	0.9%	0.0%	0.0%	0.0%
Li-ion	0.0%	0.0%	0.0%	0.0%	7.0%	7.0%	15.3%
Plastics	15.8%	15.4%	11.9%	11.6%	11.2%	10.9%	12.2%
Rubber	6.0%	6.1%	2.7%	2.8%	2.6%	2.6%	9.1%
Glass	4.2%	4.3%	3.1%	3.2%	2.9%	3.0%	3.1%
Fluids	2.8%	2.5%	2.7%	2.4%	2.5%	2.2%	3.1%
Other	4.5%	4.0%	1.3%	0.8%	1.2%	0.8%	1.1%

The data from Ecolane (2006) on production emissions per kg of the different materials was supplemented with additional data from the SimaPro® lifecycle analysis software tool[36] (with the exception of glass and batteries, discussed below). This additional data helped fill gaps for some of the pollutants and materials for production emissions as well as providing additional data on the emissions/savings due to recycling of different materials. These can be quite substantial (up to 95% saving for Aluminium) and therefore can significantly reduce the overall impact.

Glass

Because data on the energy used to produce or recycle toughened or laminated glass were not available, data for flat glass from the Ecoinvent database was used as a proxy. According to Berryman,[37] a glass recycling company, laminated and toughened glass can be recycled, though separating the laminate from the glass does add an extra step (and cost) to the process. After the glass is recovered, it is crushed and sold to the glass making industry. The glass would be used for making bottles and glasses as opposed to being used for flat glass again. At this point the process of recycling is the same as that for non-laminated flat glass; thus, emissions for recycling flat glass have been used as a proxy.

Batteries

The SimaPro® tool only contained data on the production of small consumer size batteries. Data on recycling for Nickel-Metal Hydride (Ni-MH) batteries, was therefore based on a life cycle assessment report on batteries for electric vehicles[38]. The work focused on one specific battery from each of the systems and the results were representative of these particular batteries and not of the battery systems to which they belong.

For Ni-MH batteries, the report provided data on the energy requirements for manufacturing the battery (in MJ/kg battery), the energy required for recycling the battery (MJ/kg battery), the emissions from manufacturing the battery (kg/kg battery), and the emissions from recycling the battery (kg/kg battery). The data was entered into SimaPro® to obtain total emissions from manufacturing and recycling the batteries.

Data for lithium ion batteries in SimaPro® is for a small 'AA' size battery and only for production emissions, but this was the best data which could be found. The emissions from production and recycling/disposal of Li-ion batteries were therefore also estimated from their component materials

[36] http://www.pre.nl/simapro
[37] Berryman (www.berryman-uk.co.uk).
[38] Rantik, M. (1999), "Life cycle assessment of five batteries for electric vehicles under different charging regimes," Chalmers University of Technology.

according to Table 5.3b and used to generate emission factors for recycling/disposal consistent with the production data already in SimaPro®.

See Box 1 in Section 2.2 for further information on battery types.

Environmental impact

A study presented at the 2006 International Conference on Life Cycle Engineering (LCE, 2006) evaluated the relative life cycle environmental impact of a range of rechargeable battery technologies, using the SimaPro® LCA software and the life cycle impact assessment (LCIA) method Eco-indicator 99. A summary of the results of this analysis is presented in Figure 6.3. The results clearly show that Li-ion and NaNiCl (Zebra) batteries offer significant environmental benefits over conventional Pb-acid, NiCd and NiMH technologies. Another principal conclusion of the LCE (2006) study was that the impacts of the assembly and production phases are compensated to a significant extent when collection and recycling of the batteries is efficient and performed on a large scale.

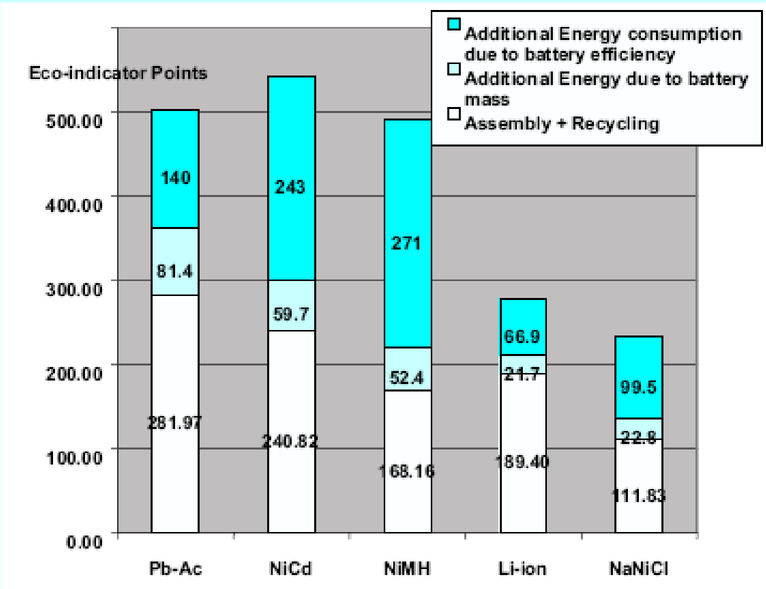


Figure 6.3: Environmental impact (in Eco-indicator points) of the assessed technologies, including the losses due to battery masses and to battery efficiencies during use. [From LCE2006 (2006)]

Table 5.3b: Material content of different types of rechargeable battery

Material	Pb-acid	NiMH	Li-ion
Lead	61.0%		
Nickel		26.5%	
Lithium			1.0%
Copper			13.0%
Cobalt or Manganese			15.0%
Aluminium			28.0%
Steel		43.5%	8.5%
Plastic	8.5%	5.0%	8.5%
Water, acid/alkali	27.0%	9.0%	
Other	3.5%	16.0%	26.0%
Total	**100%**	**100%**	**100%**

Sources: **Based on information from CUT (1999)[39] and Schexnayder et al[40]**

The 'End of Life Vehicles Directive' (or ELV Directive) - 2000/53/EC – has required since 2006 that a minimum of 80% of vehicles should be reused or recycled. The percentage of recycling of different materials in end of life vehicles was estimated primarily based on information from the Ecolane (2006) report on the degree of recycling so that the total rate complied with the minimum of 80%. It was assumed these percentages for the different materials were roughly consistent across the different vehicle technology types.

Table 5.3c: Assumed recycling rates of different materials and the resulting total rate of recycling for the different vehicle technology types

Material	
Ferrous	98%
Composites	90%
Aluminium	98%
Copper	98%
Zinc	98%
Lead	98%
Magnesium	98%
Nickel	98%
Li-ion	80%
Plastics	60%
Rubber	60%
Glass	40%

Vehicle type	
Petrol	80%
Diesel	81%
HEV Petrol	87%
HEV Diesel	88%
PHEV Petrol	86%
PHEV Diesel	87%
Dedicated BEV	81%

It was assumed the total emissions for different vehicle body types scaled up directly according to the average vehicle's unladen weight in the absence of more specific information on the variation in proportions of different materials between cars, vans and minibuses and buses. The average vehicle weights in Table 5.3d were used to estimate the total production and disposal emissions (in kg) of different pollutants for the different vehicle technologies and body types – the results for cars are presented in Table 5.3e. In reality there will be variation in the relative proportions of different materials for different vehicles, however there is no quantitative information available to make an adjustment. For the purposes of this work it is believed the current approximation is reasonable.

[39] Life cycle assessment of five batteries for electric vehicles under different charging regimes, Michail Rantik, Chalmers University of Technology, 1999.
[40] "Environmental Evaluation of New Generation Vehicles and Vehicle Components", Prepared by Susan M. Schexnayder1, Sujit Das2, Rajive Dhingra1, Jonathan G. Overly1, Bruce E. Tonn2, Jean H. Peretz1, Greg Waidley1, Gary A. Davis1, December 2001. 1 = University of Tennessee—Knoxville. 2 = Oak Ridge National Laboratory

Note, the Recycling/disposal emissions in Table 5.3e are net emissions, i.e. the emissions resulting from recycling minus the emissions from using new raw materials. In most cases the figures are therefore negative as recycling of the materials results in fewer emissions than the production of raw materials.

Table 5.3d: Assumed average weights of different vehicle types

	Car	Van	Minibus	Bus
Vehicle average unladen weight, kg	1,400	1,700	2,200	10,000

Table 5.3e: Emissions attributable to production and recycling of materials in a typical passenger car

Production emissions

Kg	CO_2 equivalent	CO	HC	NOx	PM	SO_2	CO_2	CH_4	N_2O
Petrol	3800	49.18	7.00	9.43	2.85	16.37	3616	6.80	0.129
Diesel	3817	49.75	6.81	9.35	2.83	17.01	3637	6.61	0.130
HEV Petrol	5291	36.14	7.54	9.76	4.64	52.85	5088	7.23	0.162
HEV Diesel	5308	36.71	7.35	9.67	4.62	53.48	5109	7.05	0.162
PHEV Petrol	5937	37.65	7.59	10.63	4.94	49.97	5729	7.39	0.164
PHEV Diesel	5954	38.21	7.40	10.54	4.92	50.61	5750	7.21	0.165
Dedicated BEV	6951	54.06	7.77	12.22	5.76	77.04	6742	7.75	0.145

Recycling/disposal emissions

Kg	CO_2 equivalent	CO	HC	NOx	PM	SO_2	CO_2	CH_4	N_2O
Petrol	-1564	-28.05	-2.05	-3.30	-2.32	-4.96	-1496	-2.82	-0.025
Diesel	-1495	-28.59	-1.89	-3.19	-2.28	-4.55	-1432	-2.68	-0.022
HEV Petrol	-1189	-27.98	-3.31	-4.04	-2.91	-4.18	-1092	-3.90	-0.049
HEV Diesel	-1120	-28.52	-3.14	-3.92	-2.87	-3.77	-1027	-3.75	-0.046
PHEV Petrol	-1908	-28.80	-3.31	-4.41	-3.17	-5.29	-1807	-4.03	-0.052
PHEV Diesel	-1839	-29.35	-3.14	-4.30	-3.13	-4.87	-1742	-3.88	-0.049
Dedicated BEV	-1389	-17.49	-3.39	-4.17	-2.52	-2.66	-1294	-3.81	-0.045

Net emissions

Kg	CO_2 equivalent	CO	HC	NOx	PM	SO_2	CO_2	CH_4	N_2O
Petrol	2237	21.13	4.95	6.13	0.53	11.40	2120	3.97	0.104
Diesel	2322	21.15	4.93	6.16	0.55	12.46	2205	3.93	0.108
HEV Petrol	4102	8.17	4.24	5.73	1.73	48.66	3996	3.34	0.112
HEV Diesel	4188	8.19	4.22	5.76	1.75	49.72	4082	3.30	0.116
PHEV Petrol	4029	8.85	4.28	6.21	1.76	44.68	3922	3.36	0.113
PHEV Diesel	4115	8.87	4.26	6.24	1.79	45.74	4008	3.32	0.116
Dedicated BEV	5562	36.57	4.38	8.05	3.24	74.38	5448	3.94	0.099

5.4 Capital Costs

The base capital cost (no taxes) by vehicle type and technology for cars, vans and buses are based on the dataset developed in 2006 to update the transport module of the UK MARKAL energy model used in policy analysis for the UK's 2006 Energy Review and 2007 Energy White Paper (EWP). This dataset was verified with government and industry stakeholders. Minibuses were not explicitly covered in the MARKAL model dataset and therefore new values had to be estimated for the purposes of this work. These minibus capital costs were calculated to be 75% higher than the values used for vans. This increase was estimated on the basis of a comparison of van and minibus model prices from Ford, Renault and Toyota. The dataset was also cross-checked for consistency with more recent information gathered for this study.

Value added tax (VAT at 21% in Ireland) and Vehicle Registration Tax (VRT) are added to the ex-tax capital costs to give the final price. VRT in Ireland is chargeable upon registration of a motor vehicle. All motor vehicles in the Republic of Ireland, other than those brought in temporarily by visitors, must be registered with the revenue commissioners. This is calculated as a percentage of the expected retail price (which would already include VAT). The current rates of VRT are:

23% for cars with an engine capacity below 1400cc
25% for cars with an engine capacity between 1400cc and 1900cc
30% for cars with an engine capacity above 1900cc
13% for commercial vehicles with a gross vehicle weight below 3.5 tonnes
€ 50 for other vehicles

For the average car we have assumed the 25% rate applies; for vans the 13% rate applies and for buses and minibuses the € 50 rate. We have also assumed that the current incentive for hybrid electric cars and vans applies for all HEV, PHEV and BEV cars and vans – this is a 50% reduction in VRT.

5.4.1 Depreciation

In order to make estimates of the cost of ownership for periods shorter than the vehicle lifetime it was necessary to construct a rudimentary depreciation model based on vehicle age and mileage. Since hybrid and electric vehicles are new to the marketplace and the technology is changing rapidly, it is difficult to accurately predict what resale values will be several years in the future. A comparison of the rates of depreciation for hybrid vehicles and conventional equivalents from the US DoE's online 'HEV Cost Calculator Tool'[41] revealed no significant differences in the relative depreciation rates.

The rudimentary depreciation model constructed for this study was based on the US DoE online calculator tool, taking into account small differences in the depreciation rates for the European market (where cars can depreciate by 60% first 3 years). The resulting period depreciation rates (undiscounted) presented in Table 5.4.1a are assumed to be consistent across all vehicle types in the absence of other information. In addition, an adjustment factor of 0.5% is applied for every 1,000 miles deviation from the average annual mileage for the vehicle model type – presented in Table 5.4.1b. The Irish government's test discount rate of 5% has been applied to the depreciation calculations, although this rate can be varied by the user in the calculation input assumptions. The discounting model results were also compared/calibrated with figures on the second hand prices of vans from Parkers website [42] and found to have a reasonable level of consistency.

Table 5.4.1a: Assumed basic (undiscounted) capital depreciation per period since new

Years since initiation	1	2	3	4	5	6	7	8	9	10	11+
Period reduction (basic)	30%	26%	22%	19%	16%	14%	12%	11%	10%	9.5%	9%
Cumulative depreciation	30%	48.2%	59.6%	67.3%	72.5%	76.4%	79.2%	81.5%	83.3%	84.9%	86.3%

Table 5.4.1b: Assumed average annual mileage by vehicle type

Vehicle type	Car	Van	Minibus	Bus
Average annual mileage	9,000	14,000	17,000	40,000

US DoE Energy Efficiency and Renewable Energy website, 2007. The 'HEV Cost Calculator Tool' is available at: http://www.eere.energy.gov/cleancities/hev/calculator/single.php

[42] Information is available online on second hand van prices at: http://www.parkers.co.uk/vans/

5.5 Non-Fuel Running Costs

The non-fuel running costs were defined to include maintenance, annual motor tax and annualised battery replacement costs. The base battery and maintenance costs (excluding VAT) by vehicle type and technology for cars, vans and buses were again based on the MARKAL dataset. Minibuses were assumed to have double the operating/maintenance cost of vans for the purposes of this study. The assumed rates of annual motor tax in Ireland presented in Table 5.5a are based on data from the Department of Environment, Heritage and Local Government.

Table 5.5a: Assumed Rates of Duty on Motor Vehicles

	Annual motor tax, €	Notes
Car	391	The rate for cars with engine size 1.5 to 1.6 litres; taken to represent the intermediate value for the range of engine sizes
Van	253	The rate for goods vehicles not over 3 tonnes
Minibus	117	The rate for buses with 9 to 20 seats
Bus	307	The rate for buses with 41 to 60 seats

Fuel Prices

In the absence of official long-term projections on prices for electricity, petrol and diesel, these have been estimated based upon assumptions in the future costs of oil, coal, natural gas, and on the variation in the electricity mix together with the costs of different types of power generation. These price projections are consistent with the assumptions for emission factor projections outlined in an earlier section. An outline of the methodology and assumptions made is provided in the following paragraphs.

In developing the electricity price projections we have used the projections data in GWh from different generation types taken from AEA's recent analysis of emissions from the Irish power generation sector (May 2007) – a report compiled for the Department of the Environment, heritage and local government (DEHLG), Ireland. These were used together with recent projected fossil fuel price assumptions provided in the UK's Department of Trade and Industry (DTI's) Updated Energy Projections from UEP 26 (UK Energy and CO_2 Emissions Projections, July 2006)[43], to produce estimated price projections. In doing so the following additional assumptions have been made:

For petrol and diesel:

a) Base year 2005 price for petrol and diesel fuel (including duty, VAT) are taken as 1.02 €/litre and 1 €/litre respectively.
b) UEP 26 provides price assumptions for crude oil (price/bbl) and natural gas (price/therm) for 2005, 2010, 2015, 2020 and 2050. We have assumed linear interpolation between the values for these years.
c) Projections in future petrol and diesel price were estimated based on 80% of the relative change in crude oil prices (the proportion of the cost of diesel production that is refining cost is 20%).

For electricity:

d) 2005 electricity prices are based on data from ILTP, and are taken to be 14.5 €cents/kWh and 7 €cents/kWh respectively for general domestic and night saver rate.
e) Projected electricity prices have been estimated by scaling to be consistent with the assumptions on fuel generation mix used to calculate the emission factors (discussed in an earlier section).

[43] UEP 26: UK Energy and CO2 Emissions Projections, July 2006, available on DTI's website at: http://www.dti.gov.uk/energy/environment/projections/recent/page26391.html

f) The assumed 2005 and 2010 electricity generation costs for the different types are provided in Table 5.5b. Future cost components for coal and gas generation were scaled relative to the projected change in coal and natural gas. Assumptions for renewables are based on figures from the UK DTI Renewables Innovation Review[44].

Table 5.5b: Initial assumptions on the costs of different generation types

Cents / KWh	Coal	Gas	Nuclear	Onshore Wind	Offshore Wind	Biomass
Base	3.1	3.3	4.1	4.2	5.5	6.4
Low	2.9	3.2	2.9	3.7	4.4	5.3
High	3.2	3.4	5.3	4.7	6.7	7.4

5.6 Pollutant Damage Costs

The following paragraphs summarise the development/source of the damage costs used in the environment module calculations for Air Quality (AQ) and Greenhouse Gas (GHG) pollutants.

5.6.1 Greenhouse Gas (GHG) Emissions and the Social Cost of Carbon:

The effects of global climate change are diverse and potentially very large. Traditionally the policy debate has focused on the costs of mitigation, but there is an increasing interest in the economic costs (social costs) of climate change. These are usually referred to as the Social Cost of Carbon (SCC), and can be used to assess the economic benefits of climate change policy, or the economic impacts of greenhouse gas emissions. The Social Cost of Carbon is usually estimated as the net present value of climate change impacts over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. It is the marginal global damage costs of carbon emissions.

The SCC values currently used in the cost of ownership calculator are based on those for use in policy appraisal across the UK Government. The central value assumed in the starting year of 2005 is £85/tC (= €33.8/tCO_2), with an increase of £1/tC (=1.5€/tC) per year according to recommended guidance[45]. Note the UK Government Economic Service (GES) also recommended that these values should be subject to periodic review. A recent review was undertaken (Watkiss et al, 2006[46]) and it is likely that a revised set of values will emerge later in 2007.

5.6.2 Air Quality (AQ) Externalities

Recent European work in the area of air quality externalities by AEA includes work for DG Environment on the Clean Air For Europe (CAFE) Programme and on assessing the environmental, social and economic impacts of the thematic strategy on the urban environment. In the CBA for this study, we follow the European Commission's Impact Assessment Guidelines, and make use of the air pollutant damage cost values for specific pollutants (e.g. SO_2, NOx, VOCs, PM_{10}) from the CAFE programme. These damage cost values take into account the environmental impacts of air pollution including damage to human health, damage to crops, and damage to buildings. We have based the specific values for each pollutant used in the cost of ownership calculator on those from the BeTa-Method*Ex* Excel tool[47] (developed under the Method*Ex* Project for EC DG Research).

Previous studies[48] have shown that the damage costs associated with primary PM_{10} emissions vary very significantly with location. This reflects the importance of PM_{10} as a local pollutant, and areas of

[44] More information is available from DTI's website at : http://www.dti.gov.uk/energy/sources/renewables/policy/government-renewable-energy-policy/renewables-innovation-review/page15308.html

[45] UK Government Economic Service (GES) paper *Estimating the Social Cost of Carbon Emissions* http://www.hm-treasury.gov.uk/documents/taxation_work_and_welfare/taxation_and_the_environment/tax_env_GESWP140.cfm

[46] Paul Watkiss, with contributions from David Anthoff, Tom Downing, Cameron Hepburn, Chris Hope, Alistair Hunt, and Richard Tol. The Social Costs of Carbon (SCC) Review – Methodological Approaches for Using SCC Estimates in Policy Assessment. Final Report to Defra. Published January 2006. http://www.defra.gov.uk/environment/climatechange/carboncost/aeat-scc.htm

[47] BeTa-Method*Ex* version 2, February 2007, available at: http://www.methodex.org/BeTa-Methodex%20v2.xls

[48] Watkiss, 2005. Evaluation of the air quality strategy. Published by Defra, January 2005. AEA, Metroeconomica and the Institute of Occupational Medicine. www.defra.gov.uk/environment/airquality/strategy/index.htm

high population density (e.g. urban areas) have higher damage costs, due to higher population weighted exposure per tonne of pollutant emitted. Hence vehicles operating in urban areas are likely to have higher PM_{10} damage costs associated with them than the equivalent vehicles operating in rural areas. A series of location specific PM_{10} emission factors were developed under the UK Government (Defra) analysis of air quality externalities in the UK and is presented in the Air Quality Strategy Review (AQSR). For the analysis here, we have scaled the UK location specific PM_{10} damage cost values to the difference between the average PM_{10} values for UK and Ireland from BeTa, to estimate location specific Irish PM_{10} damage costs. Whilst this does not explicitly take into account variations in damage costs due to location, it is a good approximate approach for the purposes of the model.

The other air pollutants included in this analysis (SO_2, NO_x, etc) are precursors to secondary pollutants that form in the atmosphere over time. For these pollutants, location is less important in determining the damage costs, and hence it is accepted practice to use single, uniform damage costs that do not vary with location.

CO is also potentially important for transport, but it was not considered in the CAFE Guidelines so for this pollutant, unit pollution values have been taken from a previous Defra Air Quality Evaluation[48].

The pollutant damage cost values are given in 2005 prices and the values for future years include an uplift for health of 2% (annual constant uplift), consistent with the latest UK IGCB guidance for appraisal. This reflects the assumption that willingness to pay will rise in line with economic growth. A summary of the base 2005 year pollutant damage costs used for this study is provided in Table 5.6.2.

Table 5.6.2: Base 2005 pollutant damage costs used in the cost of ownership calculator

	CO	NMVOCs	NOx	SOx	PM (diesel ICE urban)	PM (diesel ICE extra-urban)	PM (electricity)	PM (industrial production)	PM (waste and recycling)	CO_2 equivalent
2005 damage costs in €/tonne	2.26	679	3764	4842	25356	5154	5154	13671	11321	33.79

5.7 Vehicle use categories

From the information presented plus a literature review of current trends, the following vehicle use categories were constructed and used in the *Cost of Ownership calculator*.

Table 6.7: Vehicle use characteristics

	Cars			Vans			Minibuses			Buses		
User categories	Average	Low	High	Average	Low	High	Average	Low	High	Average	Low	High
Years of use	10	15	5	10	15	5	10	15	5	10	10	10
Discount rate for calculations (%)	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Annual mileage	10,500	8,000	15,000	14,000	9,000	25,000	17,000	12,000	25,000	30,000	50,000	70,000
% City driving miles	25%	25%	25%	30%	40%	25%	40%	40%	40%	90%	40%	10%
% Biofuel	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
% Recharge at night	80%	80%	80%	60%	60%	60%	60%	60%	60%	30%	30%	30%
% distance running off grid electricity (for PHEV only)	50%	60%	30%	40%	50%	30%	40%	50%	30%	30%	20%	10%

Notes: % recharge at night – this relates to BEV and PHEVs and is an estimate of the proportion of the electricity used from overnight charging of the vehicle (as opposed to regular / fast charging during the day).

% of distance running off grid electricity – this relates to PHEV only. PHEVs will probably have an all-electric range limited to 25–50 kilometres (with remaining journey running on petrol / diesel), so this figure represents an estimate of the proportion of total mileage that doesn't go beyond this daily range.

Appendix 1

Introduction

Batteries in BEVs must be periodically recharged using electricity either in the home or at business premises, where applicable. An alternative to recharging batteries is to exchange drained batteries with fully charged batteries, where this facility exists. The time taken to charge a battery is limited primarily by the capacity of the connection, rather than the battery characteristics. In Ireland, the average household outlet is around 3 kilowatts. The main connection to a house might be able to sustain 10 kilowatts if modifications are made. Assuming no energy loss in the charger, a ten-hour charge from an average household outlet will put a maximum of 30 KWh of energy into a battery.

The charger has three key functions[49]:

- Getting the charge into the battery (charging)
- Optimising the charging rate (stabilising)
- Knowing when to stop (terminating)

Once a battery is fully charged, the charging current has to be dissipated. This results in heat and gases, which are bad for batteries. The aim is to detect when the battery is fully charged and to stop the charging process before any damage is done. Detecting this cut off point and terminating the charge is critical in preserving battery life. In simple chargers, this is when a predetermined upper voltage limit is reached. This is particularly important for fast chargers where the danger of overcharging is greater.

Charge efficiency
Charge efficiency is the ratio (expressed as a percentage) of the energy removed from a battery during discharge compared to the energy used during charging to restore the original capacity.

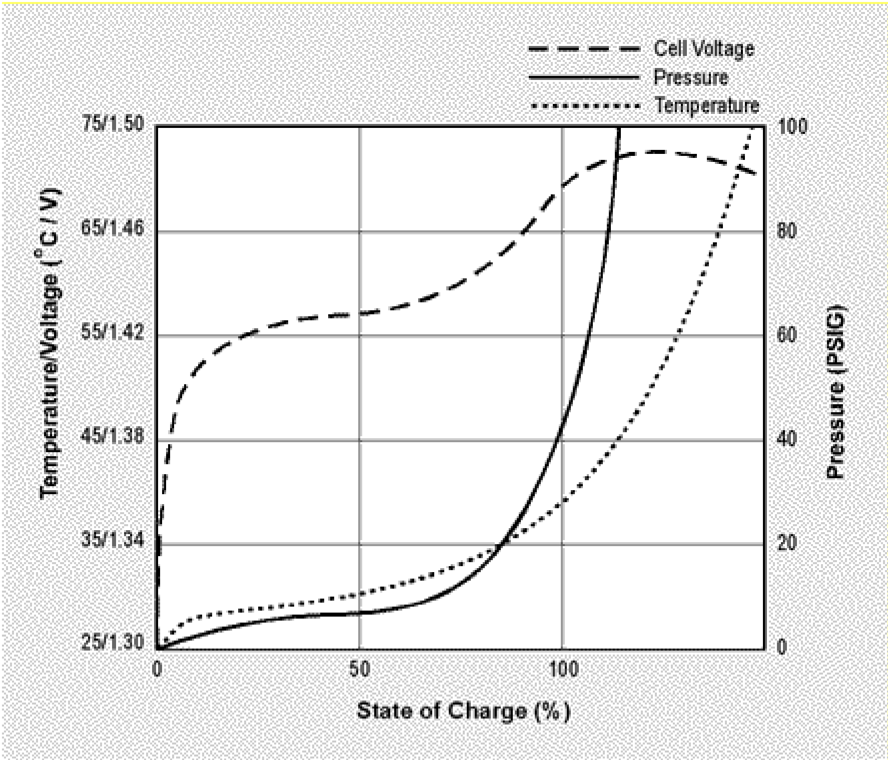
The charge efficiency is dependent on temperature amongst other factors with lower temperatures resulting in reduced efficiency. The overall charge efficiency on a slow overnight charge for the different battery types are provided in Table 2.2.2, Section 2.2.2. This ranges from 70% efficiency for a nickel metal-hydride battery to over 90% for lithium-ion and NaNiCl batteries. The charge characteristics of the three most common battery types used in BEVs are discussed below.

The charge and discharge current of a battery is measured in C-rate. A battery rated at 1C means that a 1,000mAh[50] battery would provide 1,000 Ma (milliamps) for one hour if discharged at a 1C rate. The same battery discharged at 0.5C would run for 2 hours.

Nickel based batteries
For nickel-based batteries, in the initial 70% charge, the charge acceptance is close to 100%. The battery remains cool as all the energy is absorbed. Currents of several times the C rating can be applied without heat build up. Ultra fast chargers use this phenomenon to charge a battery to 70% within minutes. Past 70% the battery loses the ability to accept charge and the pressure and temperature increases. This is shown in Figure A1.1

[49] http://www.mpoweruk.com/chargers.htm
[50] mAh – milliampere-hour. This is a 1,000th of an ampere hour and is used to describe the energy charge that a battery will hold and how long a device will run before it needs recharging.

Figure A1.1: Charge characteristics of a nickel-cadmium cell[51]



In an attempt to gain a few extra capacity points, some chargers apply a measured amount of overcharge. The capacity gain is about 6%. The negative aspect of this is the shorter cycle life

Lithium-ion batteries
Lithium-ion batteries cannot be 'super fast' (less than 1 hour) charged. Instead the manufacturers charging technique must be followed. Figure A1.2 shows the voltage and current as the lithium-ion battery passes through the charging stages. Increasing the charge current does not reduce the charge time by much. Although the voltage peak is reached quicker, the topping charge will take longer. Fast charging (3 – 6 hours) eliminates Stage 2 and is ready at about 70% charge at the end of stage 1. The topping charge typically takes twice as long as stage 1[52]. Lithium-ion batteries are unable to absorb overcharge and therefore are designed to limit the charge voltage and have pressure and temperature sensors which if activated stop the charging process.

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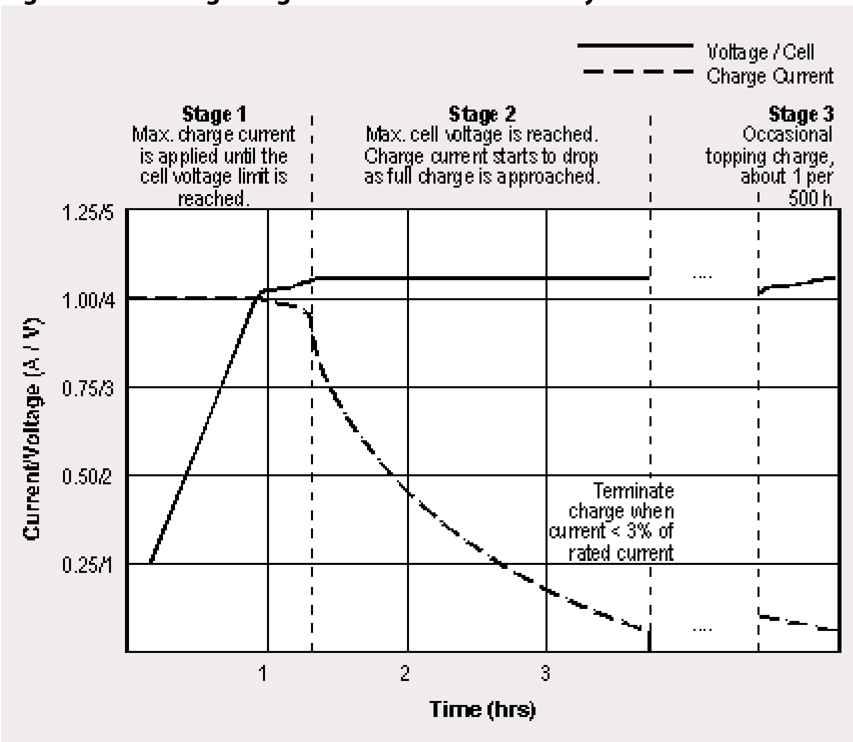
[51] http://www.batteryuniversity.com/partone-11.htm The characteristics are similar to a nickel-metal hydride battery.
[52] http://www.batteryuniversity.com/partone-12.htm

Figure A1.2: Charge stages of a lithium-ion battery



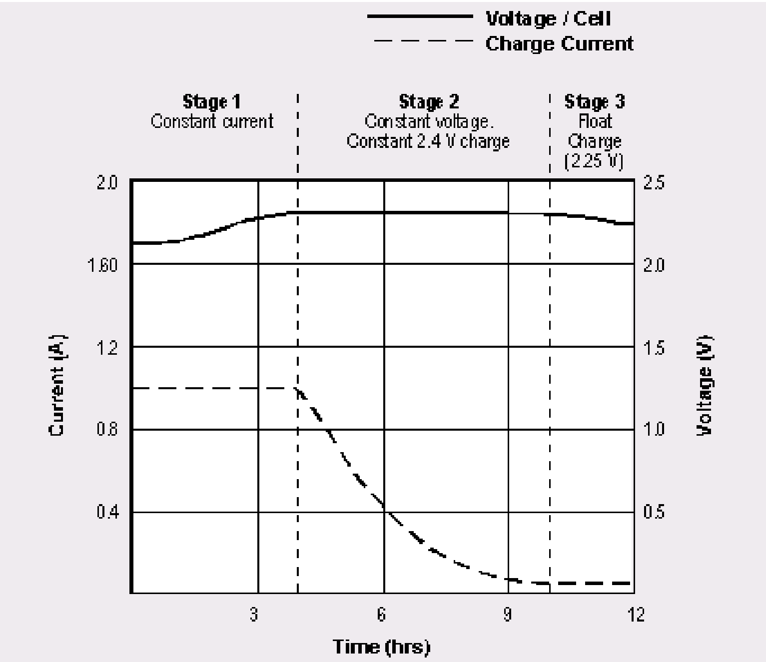
Lead-acid batteries

Lead-acid batteries cannot be fully charged as quickly as nickel and lithium based batteries.

It takes 5 times as long to charge a lead acid battery as it does to discharge it; for nickel the ratio is 1:1 and for lithium-ion the ratio is around 1:2[53]. The charging process is similar to lithium ion batteries. A constant current is applied which raises the battery voltage to a preset level. Typically stage 1 takes around 5 hours and at this point the battery will be 70% charged. During Stage 2 the current is gradually reduced as the cell is being saturated. This stage takes another 5 hours and is an essential stage as if omitted the battery would eventually lose the ability to fully charge. The final stage is the 'float charge', which compensates for the self-discharge (see Section 2.2.2). This is shown below.

[53] http://www.batteryuniversity.com/partone-13.htm

Figure A1.3: Charge stages of a lead acid battery



The correct setting of the voltage limit is critical. Setting the voltage limit is a compromise. On one hand, the battery wants to be fully charged to get maximum capacity and avoid sulphation on the negative plate. However on the other hand, a continually over-saturated condition however, would cause grid corrosion on the positive plate. It also promotes gassing, which results in venting and loss of electrolyte.

Further advancements to those discussed in previous sections have recently been made in the time required to re-charge batteries. For example, Altairnano claims that their nanosafe cell provides distinct advantages over other batteries in that they can be charged to over 80% in less than a minute[54].

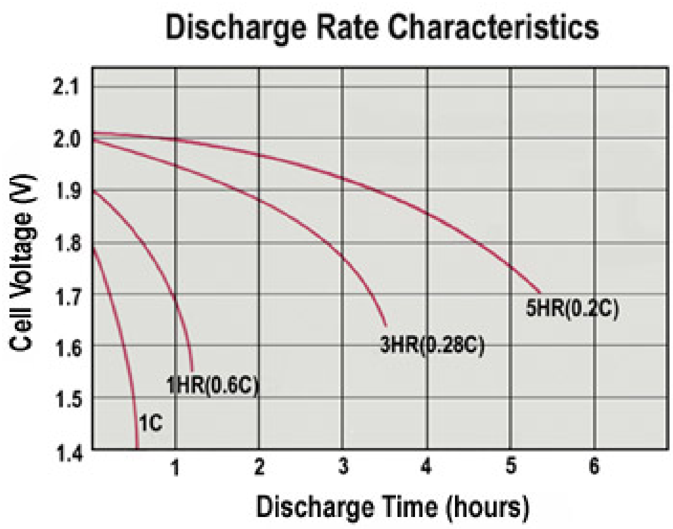
For information on the different charging options and methods available, please see Section 5.

Discharge efficiency

A battery can either be discharged at a low rate over a long time or at a higher rate over a shorter period of time. Figure 2.2 below shows the discharge characteristics of a lead acid battery at various loads as expressed by the C rate. At 1C a 10Ah battery discharges in less than an hour. At 0.2C, the same battery discharges in approximately 5 hours. The relationship is not exactly linear because some energy is lost due to internal losses and this is particularly the case with large loads.

[54] http://www.altairnano.com/documents/NanoSafeBackgrounder060920.pdf Website accessed July 2007.

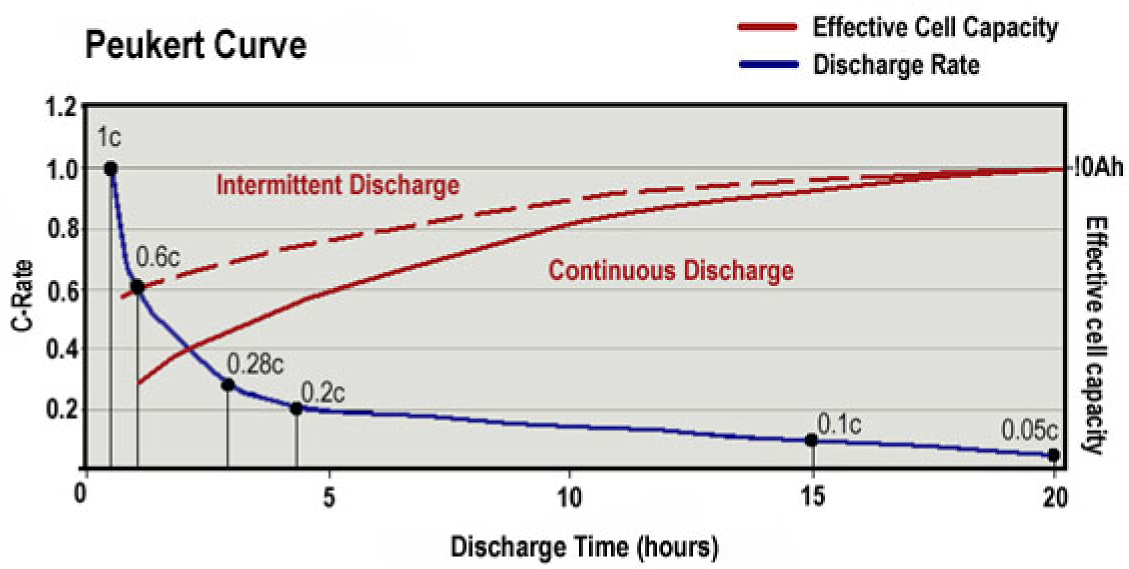
Figure A1.4: Typical discharge curves of a lead acid battery as a function of C rate[55]



The discharge voltage of lead acid batteries decreases in a rounded profile towards the period of cut-off, whereas nickel and lithium based batteries have more of a steady voltage level throughout the discharge period and then drop rapidly at the end of discharge.

Batteries are stressed the most if allowed to discharge at a steady rate. This is the opposite of an internal combustion engine, which operates most efficiently under this scenario. On a battery the intermittent load allows a level of recovery of the chemical reaction that produces electrical energy. This is particularly important for lead acid batteries. Figure 2.2b below provides the effective cell capacity of a lead acid battery under a continuous discharge and an intermittent discharge. This is known as the Peukert curve.

Figure A1.5: The Peukert Curve[55]



For further information on battery electric vehicle technologies, please see:

- The International Energy Agency Implementing Agreement on hybrid and electric vehicles http://www.ieahev.org/electric.html
- Idaho National Laboratory http://avt.inel.gov/fsev.html

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[55] http://www.batteryuniversity.com/partone-16a.htm

Appendix 2 Emissions Performance

Table 2.2.4a: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric car, petrol car and diesel car under the "average" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	27,828	26,622
In-use fuel cycle emissions: CO_2	15,000	3,896	2,738
Production & recycling/disposal: CO_2	3,708	1,491	1,548
Total CO_2 emissions	**18,708**	**33,215**	**30,907**
In-use tailpipe emissions: CO	0.0	65.0	12.0
In-use fuel cycle emissions: CO	0.0	2.1	1.7
Production & recycling/disposal: CO	24.4	14.1	14.1
Total CO emissions	**24.4**	**81.2**	**27.9**
In-use tailpipe emissions: hydrocarbons	0.0	2.8	3.6
In-use fuel cycle emissions: hydrocarbons	0.7	86.7	33.0
Production & recycling/disposal: hydrocarbons	2.9	3.3	3.3
Total hydrocarbons emissions	**3.6**	**92.8**	**39.8**
In-use tailpipe emissions: NOx	0.0	12.3	50.1
In-use fuel cycle emissions: NOx	13.3	18.2	14.3
Production & recycling/disposal: NOx	5.4	4.1	4.1
Total NOx emissions	**18.7**	**34.5**	**68.5**
In-use tailpipe emissions: SO_2	0.0	0.1	0.1
In-use fuel cycle emissions: SO_2	10.8	0.8	0.5
Production & recycling/disposal: SO_2	2.2	0.4	0.4
Total SO_2 emissions	**13.0**	**1.2**	**1.0**
In-use tailpipe emissions: PM	0.0	0.4	2.5
In-use fuel cycle emissions: PM	0.7	39.7	29.6
Production & recycling/disposal: PM	49.6	7.6	8.3
Total PM emissions	**50.3**	**47.7**	**40.4**

Table 2.2.4b: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric car, petrol car and diesel car under the "low use" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	31,803	30,425
In-use fuel cycle emissions: CO_2	17,346	4,453	3,129
Production & recycling/disposal: CO_2	5,562	2,237	2,322
Total CO_2 emissions	**22,908**	**38,492**	**35,876**
In-use tailpipe emissions: CO	0.0	74.3	13.8
In-use fuel cycle emissions: CO	0.0	2.4	2.0
Production & recycling/disposal: CO	36.6	21.1	21.2
Total CO emissions	**36.6**	**97.9**	**36.9**
In-use tailpipe emissions: hydrocarbons	0.0	3.2	4.1
In-use fuel cycle emissions: hydrocarbons	0.8	99.1	37.7
Production & recycling/disposal: hydrocarbons	4.4	5.0	4.9
Total hydrocarbons emissions	**5.2**	**107.2**	**46.7**
In-use tailpipe emissions: NOx	0.0	14.0	57.3
In-use fuel cycle emissions: NOx	14.8	20.8	16.3
Production & recycling/disposal: NOx	8.0	6.1	6.2
Total NOx emissions	**22.9**	**40.9**	**79.8**
In-use tailpipe emissions: SO_2	0.0	0.1	0.1
In-use fuel cycle emissions: SO_2	12.0	0.9	0.6
Production & recycling/disposal: SO_2	3.2	0.5	0.6
Total SO_2 emissions	**15.3**	**1.5**	**1.2**
In-use tailpipe emissions: PM	0.0	0.4	2.9
In-use fuel cycle emissions: PM	0.8	45.4	33.8
Production & recycling/disposal: PM	74.4	11.4	12.5
Total PM emissions	**75.1**	**57.2**	**49.2**

Table 2.2.4c: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric car, petrol car and diesel car under the "high use" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	19,877	19,015
In-use fuel cycle emissions: CO_2	10,259	2,783	1,955
Production & recycling/disposal: CO_2	1,854	746	774
Total CO_2 emissions	**12,113**	**23,405**	**21,745**
In-use tailpipe emissions: CO	0.0	46.4	8.6
In-use fuel cycle emissions: CO	0.0	1.5	1.2
Production & recycling/disposal: CO	12.2	7.0	7.1
Total CO emissions	**12.2**	**55.0**	**16.9**
In-use tailpipe emissions: hydrocarbons	0.0	2.0	2.6
In-use fuel cycle emissions: hydrocarbons	0.5	61.9	23.6
Production & recycling/disposal: hydrocarbons	1.5	1.7	1.6
Total hydrocarbons emissions	**1.9**	**65.6**	**27.8**
In-use tailpipe emissions: NOx	0.0	8.8	35.8
In-use fuel cycle emissions: NOx	10.0	13.0	10.2
Production & recycling/disposal: NOx	2.7	2.0	2.1
Total NOx emissions	**12.7**	**23.8**	**48.1**
In-use tailpipe emissions: SO_2	0.0	0.1	0.1
In-use fuel cycle emissions: SO_2	8.3	0.5	0.4
Production & recycling/disposal: SO_2	1.1	0.2	0.2
Total SO_2 emissions	**9.4**	**0.8**	**0.6**
In-use tailpipe emissions: PM	0.0	0.3	1.8
In-use fuel cycle emissions: PM	0.5	28.3	21.2
Production & recycling/disposal: PM	24.8	3.8	4.2
Total PM emissions	**25.3**	**32.4**	**27.1**

VANS

Table 2.2.4d: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric van, petrol car and diesel car under the "average" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	62,770	49,004
In-use fuel cycle emissions: CO_2	19,824	8,788	5,039
Production & recycling/disposal: CO_2	6,754	2,716	2,820
Total CO_2 emissions	**26,579**	**74,274**	**56,863**
In-use tailpipe emissions: CO	0.0	71.7	84.0
In-use fuel cycle emissions: CO	0.0	4.8	3.2
Production & recycling/disposal: CO	44.4	25.7	25.7
Total CO emissions	**44.4**	**102.2**	**112.8**
In-use tailpipe emissions: hydrocarbons	0.0	3.8	9.7
In-use fuel cycle emissions: hydrocarbons	0.0	195.6	60.7
Production & recycling/disposal: hydrocarbons	5.3	6.0	6.0
Total hydrocarbons emissions	**5.3**	**205.4**	**76.4**
In-use tailpipe emissions: NOx	0.0	25.3	87.6
In-use fuel cycle emissions: NOx	0.9	41.0	26.3
Production & recycling/disposal: NOx	9.8	7.4	7.5
Total NOx emissions	**10.7**	**73.7**	**121.4**
In-use tailpipe emissions: SO_2	0.0	0.2	0.2
In-use fuel cycle emissions: SO_2	17.6	1.7	1.0
Production & recycling/disposal: SO_2	3.9	0.6	0.7
Total SO_2 emissions	**21.5**	**2.6**	**1.8**
In-use tailpipe emissions: PM	0.0	0.5	11.1
In-use fuel cycle emissions: PM	14.3	89.5	54.5
Production & recycling/disposal: PM	90.3	13.8	15.1
Total PM emissions	**104.6**	**103.8**	**80.7**

Table 2.2.4e: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric van, petrol car and diesel car under the "low use" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	64,253	49,607
In-use fuel cycle emissions: CO_2	19,000	8,996	5,101
Production & recycling/disposal: CO_2	6,754	2,716	2,820
Total CO_2 emissions	**25,755**	**75,965**	**57,528**
In-use tailpipe emissions: CO	0.0	70.2	78.4
In-use fuel cycle emissions: CO	0.0	4.9	3.2
Production & recycling/disposal: CO	44.4	25.7	25.7
Total CO emissions	**44.4**	**100.8**	**107.3**
In-use tailpipe emissions: hydrocarbons	0.0	3.6	9.6
In-use fuel cycle emissions: hydrocarbons	0.0	200.2	61.5
Production & recycling/disposal: hydrocarbons	5.3	6.0	6.0
Total hydrocarbons emissions	**5.3**	**209.9**	**77.1**
In-use tailpipe emissions: NOx	0.0	23.6	84.3
In-use fuel cycle emissions: NOx	0.9	41.9	26.7
Production & recycling/disposal: NOx	9.8	7.4	7.5
Total NOx emissions	**10.7**	**73.0**	**118.4**
In-use tailpipe emissions: SO_2	0.0	0.2	0.2
In-use fuel cycle emissions: SO_2	16.2	1.8	1.0
Production & recycling/disposal: SO_2	3.9	0.6	0.7
Total SO_2 emissions	**20.2**	**2.6**	**1.8**
In-use tailpipe emissions: PM	0.0	0.4	10.3
In-use fuel cycle emissions: PM	13.2	91.6	55.2
Production & recycling/disposal: PM	90.3	13.8	15.1
Total PM emissions	**103.5**	**105.9**	**80.6**

Table 2.2.4d: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric van, petrol car and diesel car under the "high use" scenario.

Emissions	BEV	Petrol	Diesel
In-use tailpipe emissions: CO_2	0	54,319	42,664
In-use fuel cycle emissions: CO_2	17,098	7,605	4,387
Production & recycling/disposal: CO_2	3,377	1,358	1,410
Total CO_2 emissions	**20,475**	**63,282**	**48,461**
In-use tailpipe emissions: CO	0.0	63.5	76.2
In-use fuel cycle emissions: CO	0.0	4.2	2.8
Production & recycling/disposal: CO	22.2	12.8	12.8
Total CO emissions	**22.2**	**80.5**	**91.8**
In-use tailpipe emissions: hydrocarbons	0.0	3.4	8.6
In-use fuel cycle emissions: hydrocarbons	0.0	169.3	52.9
Production & recycling/disposal: hydrocarbons	2.7	3.0	3.0
Total hydrocarbons emissions	**2.7**	**175.7**	**64.4**
In-use tailpipe emissions: NOx	0.0	22.9	78.3
In-use fuel cycle emissions: NOx	0.8	35.5	22.9
Production & recycling/disposal: NOx	4.9	3.7	3.7
Total NOx emissions	**5.6**	**62.1**	**105.0**
In-use tailpipe emissions: SO_2	0.0	0.2	0.1
In-use fuel cycle emissions: SO_2	16.7	1.5	0.8
Production & recycling/disposal: SO_2	2.0	0.3	0.3
Total SO_2 emissions	**18.7**	**2.0**	**1.3**
In-use tailpipe emissions: PM	0.0	0.4	10.1
In-use fuel cycle emissions: PM	13.8	77.5	47.5
Production & recycling/disposal: PM	45.2	6.9	7.6
Total PM emissions	**59.0**	**84.8**	**65.1**

Minibus

Table 2.2.4g: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric minibus and diesel bus under the "average" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	59,133
In-use fuel cycle emissions: CO_2	23,646	6,081
Production & recycling/disposal: CO_2	5,827	2,433
Total CO_2 emissions	**29,473**	**67,647**
In-use tailpipe emissions: CO	0.0	98.7
In-use fuel cycle emissions: CO	0.0	3.8
Production & recycling/disposal: CO	38.3	22.2
Total CO emissions	**38.3**	**124.7**
In-use tailpipe emissions: hydrocarbons	0.0	12.2
In-use fuel cycle emissions: hydrocarbons	1.1	73.3
Production & recycling/disposal: hydrocarbons	4.6	5.2
Total hydrocarbons emissions	**5.7**	**90.6**
In-use tailpipe emissions: NOx	0.0	106.2
In-use fuel cycle emissions: NOx	21.0	31.8
Production & recycling/disposal: NOx	8.4	6.5
Total NOx emissions	**29.4**	**144.4**
In-use tailpipe emissions: SO_2	0.0	0.2
In-use fuel cycle emissions: SO_2	17.1	1.2
Production & recycling/disposal: SO_2	3.4	0.6
Total SO_2 emissions	**20.5**	**1.9**
In-use tailpipe emissions: PM	0.0	13.0
In-use fuel cycle emissions: PM	1.1	65.8
Production & recycling/disposal: PM	77.9	13.1
Total PM emissions	**79.0**	**91.8**

Table 2.2.4h: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric minibus and diesel bus under the "low use" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	62,612
In-use fuel cycle emissions: CO_2	25,334	6,438
Production & recycling/disposal: CO_2	8,741	3,650
Total CO_2 emissions	**34,075**	**72,700**
In-use tailpipe emissions: CO	0.0	104.5
In-use fuel cycle emissions: CO	0.0	4.1
Production & recycling/disposal: CO	57.5	33.2
Total CO emissions	**57.5**	**141.8**
In-use tailpipe emissions: hydrocarbons	0.0	12.9
In-use fuel cycle emissions: hydrocarbons	1.2	77.6
Production & recycling/disposal: hydrocarbons	6.9	7.7
Total hydrocarbons emissions	**8.1**	**98.2**
In-use tailpipe emissions: NOx	0.0	112.4
In-use fuel cycle emissions: NOx	21.6	33.6
Production & recycling/disposal: NOx	12.6	9.7
Total NOx emissions	**34.3**	**155.7**
In-use tailpipe emissions: SO_2	0.0	0.2
In-use fuel cycle emissions: SO_2	17.6	1.2
Production & recycling/disposal: SO_2	5.1	0.9
Total SO_2 emissions	**22.6**	**2.3**
In-use tailpipe emissions: PM	0.0	13.8
In-use fuel cycle emissions: PM	1.1	69.6
Production & recycling/disposal: PM	116.9	19.6
Total PM emissions	**118.0**	**103.0**

Table 2.2.4i: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric minibus and diesel bus under the "high use" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	43,480
In-use fuel cycle emissions: CO_2	16,647	4,471
Production & recycling/disposal: CO_2	2,914	1,217
Total CO_2 emissions	**19,561**	**49,168**
In-use tailpipe emissions: CO	0.0	72.6
In-use fuel cycle emissions: CO	0.0	2.8
Production & recycling/disposal: CO	19.2	11.1
Total CO emissions	**19.2**	**86.4**
In-use tailpipe emissions: hydrocarbons	0.0	8.9
In-use fuel cycle emissions: hydrocarbons	0.7	53.9
Production & recycling/disposal: hydrocarbons	2.3	2.6
Total hydrocarbons emissions	**3.0**	**65.4**
In-use tailpipe emissions: NOx	0.0	78.1
In-use fuel cycle emissions: NOx	16.3	23.4
Production & recycling/disposal: NOx	4.2	3.2
Total NOx emissions	**20.5**	**104.7**
In-use tailpipe emissions: SO_2	0.0	0.1
In-use fuel cycle emissions: SO_2	13.4	0.9
Production & recycling/disposal: SO_2	1.7	0.3
Total SO_2 emissions	**15.1**	**1.3**
In-use tailpipe emissions: PM	0.0	9.6
In-use fuel cycle emissions: PM	0.9	48.4
Production & recycling/disposal: PM	39.0	6.5
Total PM emissions	**39.8**	**64.4**

Midibus

Table 2.2.4j: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric midi bus and diesel bus under the "urban" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	443,252
In-use fuel cycle emissions: CO_2	37,965	45,580
Production & recycling/disposal: CO_2	26,487	11,059
Total CO_2 emissions	**64,452**	**499,891**
In-use tailpipe emissions: CO	0.0	536.3
In-use fuel cycle emissions: CO	0.0	28.7
Production & recycling/disposal: CO	174.1	100.7
Total CO emissions	**174.1**	**665.7**
In-use tailpipe emissions: hydrocarbons	0.0	208.3
In-use fuel cycle emissions: hydrocarbons	1.8	549.1
Production & recycling/disposal: hydrocarbons	20.9	23.5
Total hydrocarbons emissions	**22.6**	**780.9**
In-use tailpipe emissions: NOx	0.0	2,214.8
In-use fuel cycle emissions: NOx	33.7	238.1
Production & recycling/disposal: NOx	38.3	29.3
Total NOx emissions	**72.0**	**2,482.3**
In-use tailpipe emissions: SO_2	0.0	1.4
In-use fuel cycle emissions: SO_2	27.4	8.7
Production & recycling/disposal: SO_2	15.4	2.6
Total SO_2 emissions	**42.8**	**12.7**
In-use tailpipe emissions: PM	0.0	20.1
In-use fuel cycle emissions: PM	1.8	493.1
Production & recycling/disposal: PM	354.2	59.3
Total PM emissions	**356.0**	**572.4**

Table 2.2.4k: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric midi bus and diesel bus under the "inter-urban" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	578,154
In-use fuel cycle emissions: CO_2	69,547	59,452
Production & recycling/disposal: CO_2	26,487	11,059
Total CO_2 emissions	**96,034**	**648,666**
In-use tailpipe emissions: CO	0.0	599.6
In-use fuel cycle emissions: CO	0.0	37.5
Production & recycling/disposal: CO	174.1	100.7
Total CO emissions	**174.1**	**737.8**
In-use tailpipe emissions: hydrocarbons	0.0	226.6
In-use fuel cycle emissions: hydrocarbons	3.2	716.2
Production & recycling/disposal: hydrocarbons	20.9	23.5
Total hydrocarbons emissions	**24.1**	**966.3**
In-use tailpipe emissions: NOx	0.0	2,866.9
In-use fuel cycle emissions: NOx	61.8	310.6
Production & recycling/disposal: NOx	38.3	29.3
Total NOx emissions	**100.1**	**3,206.9**
In-use tailpipe emissions: SO_2	0.0	1.9
In-use fuel cycle emissions: SO_2	50.2	11.3
Production & recycling/disposal: SO_2	15.4	2.6
Total SO_2 emissions	**65.7**	**15.8**
In-use tailpipe emissions: PM	0.0	22.8
In-use fuel cycle emissions: PM	3.2	643.1
Production & recycling/disposal: PM	354.2	59.3
Total PM emissions	**357.4**	**725.2**

Table 2.2.4l: Estimated emissions (Kg) arising from the production, disposal and operating of a battery electric midi bus and diesel bus under the "express" scenario.

Emissions	BEV	Diesel
In-use tailpipe emissions: CO_2	0	674,513
In-use fuel cycle emissions: CO_2	102,634	69,361
Production & recycling/disposal: CO_2	26,487	11,059
Total CO_2 emissions	**129,121**	**754,934**
In-use tailpipe emissions: CO	0.0	592.2
In-use fuel cycle emissions: CO	0.0	43.7
Production & recycling/disposal: CO	174.1	100.7
Total CO emissions	**174.1**	**736.7**
In-use tailpipe emissions: hydrocarbons	0.0	215.9
In-use fuel cycle emissions: hydrocarbons	4.7	835.6
Production & recycling/disposal: hydrocarbons	20.9	23.5
Total hydrocarbons emissions	**25.6**	**1,074.9**
In-use tailpipe emissions: NOx	0.0	3,321.2
In-use fuel cycle emissions: NOx	91.1	362.4
Production & recycling/disposal: NOx	38.3	29.3
Total NOx emissions	**129.5**	**3,712.9**
In-use tailpipe emissions: SO_2	0.0	2.2
In-use fuel cycle emissions: SO_2	74.1	13.2
Production & recycling/disposal: SO_2	15.4	2.6
Total SO_2 emissions	**89.6**	**18.0**
In-use tailpipe emissions: PM	0.0	22.9
In-use fuel cycle emissions: PM	4.7	750.3
Production & recycling/disposal: PM	354.2	59.3
Total PM emissions	**359.0**	**832.6**

Hybrid cars

Table 2.3.3a: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid car under the "average" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	48,812	62,770	37,993	49,004
In-use fuel cycle emissions: CO_2	6,680	8,788	3,907	5,039
Production & recycling/disposal: CO_2	4,981	2,716	5,086	2,820
Total CO_2 emissions	**60,473**	**74,274**	**46,985**	**56,863**
In-use tailpipe emissions: CO	62.8	71.7	68.4	84.0
In-use fuel cycle emissions: CO	3.7	4.8	2.5	3.2
Production & recycling/disposal: CO	9.9	25.7	9.9	25.7
Total CO emissions	**76.3**	**102.2**	**80.8**	**112.8**
In-use tailpipe emissions: hydrocarbons	3.4	3.8	6.9	9.7
In-use fuel cycle emissions: hydrocarbons	148.7	195.6	47.1	60.7
Production & recycling/disposal: hydrocarbons	5.1	6.0	5.1	6.0
Total hydrocarbons emissions	**157.2**	**205.4**	**59.1**	**76.4**
In-use tailpipe emissions: NOx	23.0	25.3	66.9	87.6
In-use fuel cycle emissions: NOx	31.1	41.0	20.4	26.3
Production & recycling/disposal: NOx	7.0	7.4	7.0	7.5
Total NOx emissions	**61.1**	**73.7**	**94.3**	**121.4**
In-use tailpipe emissions: SO_2	0.2	0.2	0.1	0.2
In-use fuel cycle emissions: SO_2	1.3	1.7	0.7	1.0
Production & recycling/disposal: SO_2	2.1	0.6	2.1	0.7
Total SO_2 emissions	**3.6**	**2.6**	**3.0**	**1.8**
In-use tailpipe emissions: PM	0.5	0.5	8.8	11.1
In-use fuel cycle emissions: PM	68.0	89.5	42.3	54.5
Production & recycling/disposal: PM	59.1	13.8	60.4	15.1
Total PM emissions	**127.6**	**103.8**	**111.4**	**80.7**

Table 2.3.3b: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid car under the "low use" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	25,210	31,803	23,988	30,425
In-use fuel cycle emissions: CO_2	3,450	4,453	2,467	3,129
Production & recycling/disposal: CO_2	4,102	2,237	4,188	2,322
Total CO_2 emissions	**32,762**	**38,492**	**30,642**	**35,876**
In-use tailpipe emissions: CO	65.1	74.3	8.0	13.8
In-use fuel cycle emissions: CO	1.9	2.4	1.6	2.0
Production & recycling/disposal: CO	8.2	21.1	8.2	21.2
Total CO emissions	**75.2**	**97.9**	**17.8**	**36.9**
In-use tailpipe emissions: hydrocarbons	2.9	3.2	2.6	4.1
In-use fuel cycle emissions: hydrocarbons	76.8	99.1	29.7	37.7
Production & recycling/disposal: hydrocarbons	4.2	5.0	4.2	4.9
Total hydrocarbons emissions	**83.9**	**107.2**	**36.5**	**46.7**
In-use tailpipe emissions: NOx	12.9	14.0	46.7	57.3
In-use fuel cycle emissions: NOx	16.1	20.8	12.9	16.3
Production & recycling/disposal: NOx	5.7	6.1	5.8	6.2
Total NOx emissions	**34.7**	**40.9**	**65.3**	**79.8**
In-use tailpipe emissions: SO_2	0.1	0.1	0.1	0.1
In-use fuel cycle emissions: SO_2	0.7	0.9	0.5	0.6
Production & recycling/disposal: SO_2	1.7	0.5	1.8	0.6
Total SO_2 emissions	**2.5**	**1.5**	**2.3**	**1.2**
In-use tailpipe emissions: PM	0.4	0.4	2.1	2.9
In-use fuel cycle emissions: PM	35.1	45.4	26.7	33.8
Production & recycling/disposal: PM	48.7	11.4	49.7	12.5
Total PM emissions	**84.2**	**57.2**	**78.5**	**49.2**

Table 2.3.3c: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid car under the "high use" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	15,756	19,877	14,992	19,015
In-use fuel cycle emissions: CO_2	2,156	2,783	1,542	1,955
Production & recycling/disposal: CO_2	1,367	746	1,396	774
Total CO_2 emissions	**19,280**	**23,405**	**17,930**	**21,745**
In-use tailpipe emissions: CO	40.7	46.4	5.0	8.6
In-use fuel cycle emissions: CO	1.2	1.5	1.0	1.2
Production & recycling/disposal: CO	2.7	7.0	2.7	7.1
Total CO emissions	**44.6**	**55.0**	**8.7**	**16.9**
In-use tailpipe emissions: hydrocarbons	1.8	2.0	1.6	2.6
In-use fuel cycle emissions: hydrocarbons	48.0	61.9	18.6	23.6
Production & recycling/disposal: hydrocarbons	1.4	1.7	1.4	1.6
Total hydrocarbons emissions	**51.2**	**65.6**	**21.6**	**27.8**
In-use tailpipe emissions: NOx	8.1	8.8	29.2	35.8
In-use fuel cycle emissions: NOx	10.1	13.0	8.1	10.2
Production & recycling/disposal: NOx	1.9	2.0	1.9	2.1
Total NOx emissions	**20.0**	**23.8**	**39.2**	**48.1**
In-use tailpipe emissions: SO_2	0.1	0.1	0.0	0.1
In-use fuel cycle emissions: SO_2	0.4	0.5	0.3	0.4
Production & recycling/disposal: SO_2	0.6	0.2	0.6	0.2
Total SO_2 emissions	**1.1**	**0.8**	**0.9**	**0.6**
In-use tailpipe emissions: PM	0.3	0.3	1.3	1.8
In-use fuel cycle emissions: PM	22.0	28.3	16.7	21.2
Production & recycling/disposal: PM	16.2	3.8	16.6	4.2
Total PM emissions	**38.5**	**32.4**	**34.6**	**27.1**

VANS

Table 2.3.3d: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid van under the "average" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	48,812	62,770	37,993	49,004
In-use fuel cycle emissions: CO_2	6,680	8,788	3,907	5,039
Production & recycling/disposal: CO_2	4,981	2,716	5,086	2,820
Total CO_2 emissions	**60,473**	**74,274**	**46,985**	**56,863**
In-use tailpipe emissions: CO	62.8	71.7	68.4	84.0
In-use fuel cycle emissions: CO	3.7	4.8	2.5	3.2
Production & recycling/disposal: CO	9.9	25.7	9.9	25.7
Total CO emissions	**76.3**	**102.2**	**80.8**	**112.8**
In-use tailpipe emissions: hydrocarbons	3.4	3.8	6.9	9.7
In-use fuel cycle emissions: hydrocarbons	148.7	195.6	47.1	60.7
Production & recycling/disposal: hydrocarbons	5.1	6.0	5.1	6.0
Total hydrocarbons emissions	**157.2**	**205.4**	**59.1**	**76.4**
In-use tailpipe emissions: NOx	23.0	25.3	66.9	87.6
In-use fuel cycle emissions: NOx	31.1	41.0	20.4	26.3
Production & recycling/disposal: NOx	7.0	7.4	7.0	7.5
Total NOx emissions	**61.1**	**73.7**	**94.3**	**121.4**
In-use tailpipe emissions: SO_2	0.2	0.2	0.1	0.2
In-use fuel cycle emissions: SO_2	1.3	1.7	0.7	1.0
Production & recycling/disposal: SO_2	2.1	0.6	2.1	0.7
Total SO_2 emissions	**3.6**	**2.6**	**3.0**	**1.8**
In-use tailpipe emissions: PM	0.5	0.5	8.8	11.1
In-use fuel cycle emissions: PM	68.0	89.5	42.3	54.5
Production & recycling/disposal: PM	59.1	13.8	60.4	15.1
Total PM emissions	**127.6**	**103.8**	**111.4**	**80.7**

Table 2.3.3e: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid van under the "low" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	48,286	64,253	37,251	49,607
In-use fuel cycle emissions: CO_2	6,608	8,996	3,831	5,101
Production & recycling/disposal: CO_2	4,981	2,716	5,086	2,820
Total CO_2 emissions	**59,875**	**75,965**	**46,167**	**57,528**
In-use tailpipe emissions: CO	58.7	70.2	58.3	78.4
In-use fuel cycle emissions: CO	3.6	4.9	2.4	3.2
Production & recycling/disposal: CO	9.9	25.7	9.9	25.7
Total CO emissions	**72.3**	**100.8**	**70.7**	**107.3**
In-use tailpipe emissions: hydrocarbons	3.1	3.6	6.0	9.6
In-use fuel cycle emissions: hydrocarbons	147.1	200.2	46.1	61.5
Production & recycling/disposal: hydrocarbons	5.1	6.0	5.1	6.0
Total hydrocarbons emissions	**155.3**	**209.9**	**57.3**	**77.1**
In-use tailpipe emissions: NOx	20.8	23.6	57.7	84.3
In-use fuel cycle emissions: NOx	30.8	41.9	20.0	26.7
Production & recycling/disposal: NOx	7.0	7.4	7.0	7.5
Total NOx emissions	**58.5**	**73.0**	**84.7**	**118.4**
In-use tailpipe emissions: SO_2	0.2	0.2	0.1	0.2
In-use fuel cycle emissions: SO_2	1.3	1.8	0.7	1.0
Production & recycling/disposal: SO_2	2.1	0.6	2.1	0.7
Total SO_2 emissions	**3.6**	**2.6**	**3.0**	**1.8**
In-use tailpipe emissions: PM	0.4	0.4	7.4	10.3
In-use fuel cycle emissions: PM	67.3	91.6	41.4	55.2
Production & recycling/disposal: PM	59.1	13.8	60.4	15.1
Total PM emissions	**126.8**	**105.9**	**109.2**	**80.6**

Table 2.3.3f: Estimated emissions (kg) arising from the production, disposal and operating costs of a petrol and diesel hybrid van under the "high" scenario

Emissions	Petrol hybrid	Petrol	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	43,018	54,319	33,637	42,664
In-use fuel cycle emissions: CO_2	5,887	7,605	3,459	4,387
Production & recycling/disposal: CO_2	2,491	1,358	2,543	1,410
Total CO_2 emissions	**51,396**	**63,282**	**39,639**	**48,461**
In-use tailpipe emissions: CO	56.9	63.5	64.6	76.2
In-use fuel cycle emissions: CO	3.2	4.2	2.2	2.8
Production & recycling/disposal: CO	5.0	12.8	5.0	12.8
Total CO emissions	**65.1**	**80.5**	**71.7**	**91.8**
In-use tailpipe emissions: hydrocarbons	3.1	3.4	6.5	8.6
In-use fuel cycle emissions: hydrocarbons	131.0	169.3	41.7	52.9
Production & recycling/disposal: hydrocarbons	2.6	3.0	2.6	3.0
Total hydrocarbons emissions	**136.7**	**175.7**	**50.7**	**64.4**
In-use tailpipe emissions: NOx	21.3	22.9	62.9	78.3
In-use fuel cycle emissions: NOx	27.4	35.5	18.1	22.9
Production & recycling/disposal: NOx	3.5	3.7	3.5	3.7
Total NOx emissions	**52.2**	**62.1**	**84.5**	**105.0**
In-use tailpipe emissions: SO_2	0.1	0.2	0.1	0.1
In-use fuel cycle emissions: SO_2	1.2	1.5	0.7	0.8
Production & recycling/disposal: SO_2	1.1	0.3	1.1	0.3
Total SO_2 emissions	**2.3**	**2.0**	**1.8**	**1.3**
In-use tailpipe emissions: PM	0.4	0.4	8.4	10.1
In-use fuel cycle emissions: PM	60.0	77.5	37.4	47.5
Production & recycling/disposal: PM	29.5	6.9	30.2	7.6
Total PM emissions	**89.9**	**84.8**	**76.0**	**65.1**

Minibuses

Table 2.3.3g: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid minibus under the "average" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	44,350	59,133
In-use fuel cycle emissions: CO_2	4,561	6,081
Production & recycling/disposal: CO_2	4,388	2,433
Total CO_2 emissions	**53,298**	**67,647**
In-use tailpipe emissions: CO	73.4	98.7
In-use fuel cycle emissions: CO	2.9	3.8
Production & recycling/disposal: CO	8.6	22.2
Total CO emissions	**84.9**	**124.7**
In-use tailpipe emissions: hydrocarbons	7.6	12.2
In-use fuel cycle emissions: hydrocarbons	54.9	73.3
Production & recycling/disposal: hydrocarbons	4.4	5.2
Total hydrocarbons emissions	**67.0**	**90.6**
In-use tailpipe emissions: NOx	72.6	106.2
In-use fuel cycle emissions: NOx	23.8	31.8
Production & recycling/disposal: NOx	6.0	6.5
Total NOx emissions	**102.5**	**144.4**
In-use tailpipe emissions: SO_2	0.1	0.2
In-use fuel cycle emissions: SO_2	0.9	1.2
Production & recycling/disposal: SO_2	1.8	0.6
Total SO_2 emissions	**2.9**	**1.9**
In-use tailpipe emissions: PM	9.3	13.0
In-use fuel cycle emissions: PM	49.3	65.8
Production & recycling/disposal: PM	52.1	13.1
Total PM emissions	**110.7**	**91.8**

Table 2.3.3h: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid minibus under the "low" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	46,959	62,612
In-use fuel cycle emissions: CO_2	4,829	6,438
Production & recycling/disposal: CO_2	6,581	3,650
Total CO_2 emissions	**58,369**	**72,700**
In-use tailpipe emissions: CO	77.8	104.5
In-use fuel cycle emissions: CO	3.0	4.1
Production & recycling/disposal: CO	12.9	33.2
Total CO emissions	**93.7**	**141.8**
In-use tailpipe emissions: hydrocarbons	8.1	12.9
In-use fuel cycle emissions: hydrocarbons	58.2	77.6
Production & recycling/disposal: hydrocarbons	6.6	7.7
Total hydrocarbons emissions	**72.9**	**98.2**
In-use tailpipe emissions: NOx	76.9	112.4
In-use fuel cycle emissions: NOx	25.2	33.6
Production & recycling/disposal: NOx	9.0	9.7
Total NOx emissions	**111.2**	**155.7**
In-use tailpipe emissions: SO_2	0.2	0.2
In-use fuel cycle emissions: SO_2	0.9	1.2
Production & recycling/disposal: SO_2	2.8	0.9
Total SO_2 emissions	**3.8**	**2.3**
In-use tailpipe emissions: PM	9.8	13.8
In-use fuel cycle emissions: PM	52.2	69.6
Production & recycling/disposal: PM	78.1	19.6
Total PM emissions	**140.2**	**103.0**

Table 2.3.3i: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid minibus under the "high" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	32,610	43,480
In-use fuel cycle emissions: CO_2	3,353	4,471
Production & recycling/disposal: CO_2	2,194	1,217
Total CO_2 emissions	**38,157**	**49,168**
In-use tailpipe emissions: CO	54.0	72.6
In-use fuel cycle emissions: CO	2.1	2.8
Production & recycling/disposal: CO	4.3	11.1
Total CO emissions	**60.4**	**86.4**
In-use tailpipe emissions: hydrocarbons	5.6	8.9
In-use fuel cycle emissions: hydrocarbons	40.4	53.9
Production & recycling/disposal: hydrocarbons	2.2	2.6
Total hydrocarbons emissions	**48.2**	**65.4**
In-use tailpipe emissions: NOx	53.4	78.1
In-use fuel cycle emissions: NOx	17.5	23.4
Production & recycling/disposal: NOx	3.0	3.2
Total NOx emissions	**73.9**	**104.7**
In-use tailpipe emissions: SO_2	0.1	0.1
In-use fuel cycle emissions: SO_2	0.6	0.9
Production & recycling/disposal: SO_2	0.9	0.3
Total SO_2 emissions	**1.7**	**1.3**
In-use tailpipe emissions: PM	6.8	9.6
In-use fuel cycle emissions: PM	36.3	48.4
Production & recycling/disposal: PM	26.0	6.5
Total PM emissions	**69.1**	**64.4**

Midibuses

Table 2.3.3j: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid midibus under the "urban" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	269,323	443,252
In-use fuel cycle emissions: CO_2	27,695	45,580
Production & recycling/disposal: CO_2	19,943	11,059
Total CO_2 emissions	**316,962**	**499,891**
In-use tailpipe emissions: CO	124.7	536.3
In-use fuel cycle emissions: CO	17.4	28.7
Production & recycling/disposal: CO	39.0	100.7
Total CO emissions	**181.2**	**665.7**
In-use tailpipe emissions: hydrocarbons	47.9	208.3
In-use fuel cycle emissions: hydrocarbons	333.6	549.1
Production & recycling/disposal: hydrocarbons	20.1	23.5
Total hydrocarbons emissions	**401.6**	**780.9**
In-use tailpipe emissions: NOx	548.9	2,214.8
In-use fuel cycle emissions: NOx	144.7	238.1
Production & recycling/disposal: NOx	27.4	29.3
Total NOx emissions	**721.0**	**2,482.3**
In-use tailpipe emissions: SO_2	0.9	1.4
In-use fuel cycle emissions: SO_2	5.3	8.7
Production & recycling/disposal: SO_2	8.4	2.6
Total SO_2 emissions	**14.5**	**12.7**
In-use tailpipe emissions: PM	2.4	20.1
In-use fuel cycle emissions: PM	299.6	493.1
Production & recycling/disposal: PM	236.7	59.3
Total PM emissions	**538.7**	**572.4**

Table 2.3.3k: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid midibus under the "inter-urban" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	396,678	578,154
In-use fuel cycle emissions: CO_2	40,791	59,452
Production & recycling/disposal: CO_2	19,943	11,059
Total CO_2 emissions	**457,412**	**648,666**
In-use tailpipe emissions: CO	294.7	599.6
In-use fuel cycle emissions: CO	25.7	37.5
Production & recycling/disposal: CO	39.0	100.7
Total CO emissions	**359.4**	**737.8**
In-use tailpipe emissions: hydrocarbons	107.8	226.6
In-use fuel cycle emissions: hydrocarbons	491.4	716.2
Production & recycling/disposal: hydrocarbons	20.1	23.5
Total hydrocarbons emissions	**619.2**	**966.3**
In-use tailpipe emissions: NOx	1,632.9	2,866.9
In-use fuel cycle emissions: NOx	213.1	310.6
Production & recycling/disposal: NOx	27.4	29.3
Total NOx emissions	**1,873.5**	**3,206.9**
In-use tailpipe emissions: SO_2	1.3	1.9
In-use fuel cycle emissions: SO_2	7.8	11.3
Production & recycling/disposal: SO_2	8.4	2.6
Total SO_2 emissions	**17.4**	**15.8**
In-use tailpipe emissions: PM	9.7	22.8
In-use fuel cycle emissions: PM	441.3	643.1
Production & recycling/disposal: PM	236.7	59.3
Total PM emissions	**687.7**	**725.2**

Table 2.3.3l: Estimated emissions (kg) arising from the production, disposal and operating costs of a diesel hybrid midibus under the "express" use scenario

Emissions	Diesel hybrid	Diesel
In-use tailpipe emissions: CO_2	511,506	674,513
In-use fuel cycle emissions: CO_2	52,599	69,361
Production & recycling/disposal: CO_2	19,943	11,059
Total CO_2 emissions	**584,048**	**754,934**
In-use tailpipe emissions: CO	485.5	592.2
In-use fuel cycle emissions: CO	33.1	43.7
Production & recycling/disposal: CO	39.0	100.7
Total CO emissions	**557.7**	**736.7**
In-use tailpipe emissions: hydrocarbons	174.3	215.9
In-use fuel cycle emissions: hydrocarbons	633.7	835.6
Production & recycling/disposal: hydrocarbons	20.1	23.5
Total hydrocarbons emissions	**828.0**	**1,074.9**
In-use tailpipe emissions: NOx	2,889.3	3,321.2
In-use fuel cycle emissions: NOx	274.8	362.4
Production & recycling/disposal: NOx	27.4	29.3
Total NOx emissions	**3,191.5**	**3,712.9**
In-use tailpipe emissions: SO_2	1.7	2.2
In-use fuel cycle emissions: SO_2	10.0	13.2
Production & recycling/disposal: SO_2	8.4	2.6
Total SO_2 emissions	**20.0**	**18.0**
In-use tailpipe emissions: PM	18.4	22.9
In-use fuel cycle emissions: PM	569.0	750.3
Production & recycling/disposal: PM	236.7	59.3
Total PM emissions	**824.1**	**832.6**

Appendix 3 – Capital and operating costs

Table 2.2.5a. Estimated cost of owning and operating a battery electric car

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	10,500	8,000	15,000
% of driving in city areas	25%	25%	25%
% of time battery is charged over-night	80%	80%	80%
Financial costs:			
Capital cost (after discount and including resale)	€ 34,306	€ 35,694	€ 30,815
Running costs (non-energy ie tax + maintenance)	€ 10,349	€ 13,437	€ 6,358
Running costs (energy)	€ 3,605	€ 3,609	€ 3,113
Total cost (over ownership period)	€ 48,260	€ 52,740	€ 40,285
Increased cost compared to petrol car	€ 8,854	€ 10,219	€ 7,310
Cost per tonne of CO_2 saved	€ 610	€ 656	€ 647

Table 2.2.5b. Estimated cost of owning and operating a battery electric van

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%
% of time battery is charged over-night	60%	60%	60%
Financial costs:			
Capital cost (after discount and including resale)	€ 42,565	€ 42,842	€ 40,608
Running costs (non-energy ie tax + maintenance)	€ 18,542	€ 24,075	€ 11,391
Running costs (energy)	€ 7,804	€ 6,475	€ 8,499
Total cost (over ownership period)	€ 68,911	€ 73,392	€ 60,498
Increased cost compared to petrol van	€ 13,757	€ 17,305	€ 9,174
Cost per tonne of CO_2 saved	€ 288	€ 345	€ 214

Table 2.2.5c: Estimated cost of owning and operating a battery electric full size/midi- bus

Assumption:	**Urban**	**Inter-urban**	**Mixed**
Ownership period (years)	10	10	10
Annual vehicle mileage	30,000	50,000	40,000
% of driving in city areas	90%	40%	60%
% of time battery is charged over-night	30%	20%	25%
Financial costs:			
Capital cost (after discount and including resale)	€307,539	€388,184	€413,712
Running costs (non-energy ie tax + maintenance)	€265,619	€265,619	€265,619
Running costs (energy)	€ 45,047	€ 82,521	€121,780
Total cost (over ownership period)	€618,206	€736,324	€801,112
Increased cost compared to diesel bus	€108,351	€139,720	€160,217
Cost per tonne of CO_2 saved	€ 249	€ 253	€ 256

Table 2.2.5d: Estimated cost of owning and operating a battery electric mini bus

Assumption:	**Average**	**Low Use**	**High Use**
Ownership period (years)	10	15	5
Annual vehicle mileage	17,000	12,000	25,000
% of driving in city areas	40%	40%	40%
% of time battery is charged over-night	60%	60%	60%
Financial costs:			
Capital cost (after discount and including resale)	€ 69,845	€ 70,301	€ 64,928
Running costs (non-energy ie tax + maintenance)	€ 24,147	€ 31,353	€ 14,835
Running costs (energy)	€ 8,812	€ 8,173	€ 7,833
Total cost (over ownership period)	€102,804	€109,827	€ 87,596
Increased cost compared to diesel bus	€ 30,424	€ 33,021	€ 26,781
Cost per tonne of CO_2 saved	€ 797	€ 855	€ 905

Hybrids

Table 2.3.4a: Estimated cost of owning and operating a petrol hybrid electric car

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	10,500	8,000	15,000
% of driving in city areas	25%	25%	25%
% of time battery is charged over-night	80%	80%	80%
Financial costs:			
Capital cost (after discount and including resale)	€ 24,409	€ 25,396	€ 21,925
Running costs (non-energy ie tax + maintenance)	€ 7,762	€ 10,078	€ 4,768
Running costs (energy)	€ 8,131	€ 8,078	€ 7,132
Total cost (over ownership period)	€ 40,301	€ 43,553	€ 33,825
Increased cost compared to petrol car	€ 896	€ 1,032	€ 850
Cost per tonne of CO_2 saved	€ 166	€ 180	€ 206

Table 2.3.4b: Estimated cost of owning and operating a diesel hybrid electric car

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	10,500	8,000	15,000
% of driving in city areas	40%	40%	40%
% of time battery is charged over-night	80%	80%	80%
Financial costs:			
Capital cost (after discount and including resale)	€ 26,700	€ 27,780	€ 23,982
Running costs (non-energy ie tax + maintenance)	€ 7,762	€ 10,078	€ 4,768
Running costs (energy)	€ 6,584	€ 6,545	€ 5,777
Total cost (over ownership period)	€ 41,045	€ 44,403	€ 34,528
Increased cost compared to petrol car	€ 1,640	€ 1,883	€ 1,552
Cost per tonne of CO_2 saved	€ 225	€ 240	€ 284

Table 2.3.4c: Estimated cost of owning and operating a petrol hybrid electric van

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%
% of time battery is charged over-night	60%	60%	60%
Financial costs:			
Capital cost (after discount and including resale)	€ 24,379	€ 24,539	€ 23,259
Running costs (non-energy ie tax + maintenance)	€ 11,211	€ 14,557	€ 6,888
Running costs (energy)	€ 17,992	€ 15,473	€ 19,472
Total cost (over ownership period)	€ 53,583	€ 54,569	€ 49,619
Increased cost compared to petrol van	-€ 1,570	-€ 1,519	-€ 1,705
Cost per tonne of CO_2 saved	-€ 114	-€ 94	-€ 143

Table 2.3.4d Estimated cost of owning and operating a diesel hybrid electric van

Assumption:	**Average use**	**Low use**	**High use**
Ownership period (years)	10	15	5
Annual vehicle mileage	14,000	9,000	25,000
% of driving in city areas	30%	40%	25%
% of time battery is charged over-night	60%	60%	60%
Financial costs:			
Capital cost (after discount and including resale)	€ 26,497	€ 26,670	€ 25,279
Running costs (non-energy ie tax + maintenance)	€ 11,211	€ 14,557	€ 6,888
Running costs (energy)	€ 11,917	€ 10,165	€ 12,962
Total cost (over ownership period)	€ 49,626	€ 51,392	€ 45,129
Increased cost compared to petrol van	-€ 5,528	-€ 4,696	-€ 6,195
Cost per tonne of CO_2 saved	-€ 203	-€ 158	-€ 262

Table 2.3.4e: Estimated cost of owning and operating a hybrid diesel full size/midi- bus

Assumption:	**Urban**	**Inter-urban**	**Express**
Ownership period (years)	10	10	10
Annual vehicle mileage	30,000	50,000	40,000
% of driving in city areas	90%	40%	60%
% of time battery is charged over-night	30%	20%	25%
Financial costs:			
Capital cost (after discount and including resale)	€270,212	€341,069	€363,499
Running costs (non-energy ie tax + maintenance)	€201,370	€201,370	€201,370
Running costs (energy)	€ 84,480	€124,428	€160,447
Total cost (over ownership period)	€556,063	€666,867	€725,316
Increased cost compared to diesel bus	€ 46,208	€ 70,264	€ 84,421
Cost per tonne of CO_2 saved	€ 253	€ 367	€ 494

Table 5-1: Estimated cost of owning and operating a hybrid diesel mini bus

Assumption:	**Average**	**Low Use**	**High Use**
Ownership period (years)	10	15	5
Annual vehicle mileage	17,000	12,000	25,000
% of driving in city areas	40%	40%	40%
% of time battery is charged over-night	60%	60%	60%
Financial costs:			
Capital cost (after discount and including resale)	€ 43,521	€ 43,805	€ 40,457
Running costs (non-energy ie tax + maintenance)	€ 18,973	€ 24,634	€ 11,656
Running costs (energy)	€ 13,912	€ 12,814	€ 12,566
Total cost (over ownership period)	€ 76,405	€ 81,253	€ 64,679
Increased cost compared to diesel bus	€ 4,024	€ 4,447	€ 3,863
Cost per tonne of CO_2 saved	€ 280	€ 310	€ 351

Appendix 4 – Glossary of terms

Battery instability – this is a measure of how many charges the battery can take before a cell goes bad. This can vary quite a bit depending on the chemical make up of the battery.

Carbon dioxide (CO_2) – A gas that is present in a low concentration in the Earth's atmosphere and is essential for life. It therefore does not have a direct impact on human health. In excessive quantities however, this gas can have a major impact on climate.

Carbon monoxide (CO) – is a colourless, odourless and poisonous gas produced by the incomplete combustion of fuel. It is predominately produced by road transport and in particular petrol vehicles. The gas prevents the normal transport of oxygen by the blood. This can lead to a significant reduction in the supply of oxygen to the heart, particularly in people suffering from heart disease.

Hydrocarbons (HC) – Various compounds of hydrogen and carbon atoms. Although they can be emitted into the air by natural sources (e.g., trees), the combustion of fuel is currently the biggest contributor. HC combines with NO_X to produce ozone, a toxic gas that is a major component of smog.

Midibus - a classification of single decker buses which are in size between minibuses and full size buses, with seating capacities between 20 to 40 people. Midibuses are often designed to be light weight to save on fuel (eg. smaller wheels than on larger buses), but are then less durable than full size busses.

Nitrogen oxide (NO_X) - General term applied to a variety of compounds, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide. They can cause a wide variety of health and environmental impacts, including the creation of ground level ozone (smog), acid rain, 'particulate matter', water quality deterioration, climate change and toxic chemicals.

Particulate Matter (PM) - Consists of very small liquid and solid particles floating in the air. Of greatest concern to public health are the particles small enough to be inhaled into the deepest parts of the lung, often referred to as PM_{10} and $PM_{2.5}$. PM_{10} can increase the number and severity of asthma attacks, cause or aggravate bronchitis and other lung diseases, and reduce the body's ability to fight infections. Although particulate matter can cause health problems for everyone, certain people are especially vulnerable to PM_{10}'s adverse health effects. These "sensitive populations" include children, the elderly, exercising adults, and those suffering from asthma or bronchitis.

Powertrain – Also referred to as 'drivetrain', this is the group of components that generate power and deliver it to the road surface, including the engine, transmission, driveshafts, differentials, and the final drive.

Regenerative Braking – Technology that allows energy that would otherwise be wasted as heat during braking to be recycled back into the electrical storage system.

Self-discharge – this is a measure of the rate of how a cell will loose its energy while sitting on the shelf due to unwanted chemical reactions within the cell. The rate will depend on the cell chemistry and the temperature.

Sulphur dioxide (SO_2) – is produced when fuel containing sulphur is burned. Even moderate concentrations may result in a fall in lung function in asthmatics. Tightness in the chest and coughing may occur at higher concentrations. Sulphur dioxide is considered more harmful when particulate and other pollution concentrations are high.

Torque – force causing a rotation.

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SEI is funded by the Irish Government under the National Development Plan 2007 - 2013 with programmes part financed by the European Union.