eRCVII Business Case

Social & Environmental Business Case Report

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The eRCV II repowering project offers an opportunity to overcome many of the barriers to uptake of electric vehicles amongst HGVs. It offers a cost-effective option to repower existing and potentially otherwise redundant end-of-life diesel RCVs to be fully electric.

This report presents the financial, environmental and social business case for repower of an RCV in comparison to alternative options currently available on the market. It details the capital and operational costs, as well as measuring and monetizing the environmental and social impact of each option.

The report first outlines and compares noise and air pollution (PM2.5 and NOx) and greenhouse gas emissions from three different types of refuse collection vehicles (RCVs): diesel, electric and diesel repowered to electric using a combination of real-life and modelled data. The report then compares the total costs of ownership associated with each vehicle (i.e. capital, operational and environmental financial costs).

The business case shows that repowering an end-of-life diesel RCV to be electric is the most financially viable and sustainable option: as it has the lowest emissions and costs. This report also demonstrates that a repowered diesel to electric RCV has the lowest life cycle emissions.

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1.0 Introduction

eRCVII is an Innovate UK funded project that seeks to overcome many of the current barriers to the uptake of electric heavy goods vehicles (HGVs), by testing and as such demonstrating the opportunities and constraints of repowering end-of-life diesel RCVs to be fully electric.

eRCVII is led by MagTec with DG Cities, Veolia, MicroLise, Sheffield Council and Westminster Council as consortium partners. As part of eRCVII, four end-of-life, 26 tonne diesel refuse collection vehicles have been repowered to be fully electric (both drive train and compactors). The vehicles have been trialled in two demanding real-world environments: a densely populated urban area (by Westminster Council) and a lower density and hilly area (by Sheffield Council).

2.0 Background

The UK has recently committed to being net zero carbon by 2050. According to BEIS (2020)[1], transport is the main contributor to greenhouse gas (GHG) emissions in the UK. Road transport, predominantly consisting of petrol and diesel vehicles, is the main source of these emissions.

Cars generate the most GHG emissions, followed by heavy goods vehicles (HGVs). The Heavy Duty Vehicle (HDV) CO2 emission standard (2019)[2] requires that HDV manufacturers reduce their CO2 emissions by 15% by 2025 and 30% by 2030, from 2019 emission levels. The government is also funding research and is working with industries to help accelerate the decarbonisation of HGVs. The eRCVII project aligns with the government’s ambitions by advancing zero emission technologies for HGVs and identifying the challenges that need to be taken into consideration when trying to incorporate decarbonisation of technologies, such as electric batteries, within HGVs.

GHGs are not the only pollutants of concern. Diesel vehicles, including refuse trucks also emit:

1. Tailpipe emissions:
    a. Particulate matter (PM2.5 & PM10) - which is detrimental to health and is a major contributor to poor air quality.
    b. Nitrogen dioxide (NO2) - contributes to poor air quality.
2. Tyre and road wear emissions:
    a. Particulate matter (PM2.5 & PM10).

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[1] BEIS (2020) 2018 UK Greenhouse Gas Emissions
[2] DfT (2020) Decarbonising Transport, Setting the Challenge

The electrification of HGVs can eliminate tailpipe emissions of PM and NOx and greatly reduce GHGs. With this in mind, there is no doubt that the decarbonisation of the transport sector through electrification is needed for the UK to meet its net zero carbon target. As a result, many businesses and councils are embarking on strategies to decarbonise transport through measures such as electrification.

The electrification of HGVs can be complex and costly. However, previous research in this sector, such as that conducted by Eunomia[3], has demonstrated that electric RCVs are a more financially and environmentally friendly option than their diesel counterparts.

The purchase of new vehicles is costly, both in terms of real and external costs (i.e. environmental). However, potential savings (both financial and environmental) could be achieved if end-of-life diesel RCVs are repowered to electric. This approach is much more sustainable than purchasing a new electric RCV, as emissions associated with manufacturing new vehicles are avoided.

[3] Eunomia (2020) Ditching Diesel -A Cost-Benefit Analysis of Electric Refuse Collection Vehicles

3.0 Report Purpose

This report seeks to present a comprehensive business case that compares all costs (including external costs of GHG, noise and air pollution) associated with:

- a repowered electric RCV
- a new diesel RCV and
- a new electric RCV.

The costs presented in this project are based on real world operational data collected during a four-month period of RCV operation. The comparative analysis of the diesel versus repowered electric RCV will also take into account the life cycle environmental impacts of both vehicles.

Questions raised during this project, and subsequently answered, including:

1. Is repowering an end-of-life diesel RCV financially feasible?
2. From a business perspective, is it more feasible to purchase a new diesel RCV rather than to repower an end-of-life one?
3. Is it possible to repower an end-of-life diesel RCV to be fully electric? How is this carried out?
4. What are the challenges, and opportunities, of re-powering a diesel RCV, and how might these be overcome?

The answers for questions 1 & 2 are discussed in this report, answers for the remaining questions are discussed in the 'Fleet Electrification - Lessons Learnt' report.

4.0 Methodology & Results

The following section sets out the methodology and results for identifying the lifecycle and operational environmental impacts of the new diesel RCV, repowered RCV & new electric RCV.

4.1 Life cycle analysis (LCA) environmental impacts

4.1a Methodology

Life cycle analysis considers a holistic understanding of environmental impacts by looking at emissions and impacts caused throughout each RCV's life time (i.e. stages), and not only during its operation.

LowCVP conducted an LCA to compare and understand the environmental impacts of a newly purchased diesel RCV, a repowered RCV and a newly purchased electric RCV, for the lifetime of their usage (from point of resource extraction to disposal).

An Environmental LCA was conducted for the three RCVs using the following assumptions:

1) Lifetime: 7 years
2) Mileage: 17,381kms[4] annually & 121,000 kms for 7 years
3) Diesel fuel consumption: 61 liters/100km or 4.63 MPG
4) eRCV energy consumption: 245 kWh/100km
5) UK Grid Electricity 2020: 245.37 gCO2e/kWh (average value from 2020-2027, Web Tag A3.3)
6) Battery replacement: 140,000 kms
7) Battery size: 300kwh
8) Energy density: 125 Wh/kg, battery weight equivalent to 2,400 kg
9) Usable battery capacity: 80%

The LCA outputs considered the following stages: Vehicle production & battery replacement, electricity production, fuel production, vehicle usage and & vehicle end-of-life.

[4] The total milage provided here is based on the total distance that the RCVs could hypothetically travel in a year. This is different than the total milage used to quantify emissions and costs for the real time operation of the RCVs (section 4.2), which was based on real-time data.

4.1b Results

The main results of the LCA analysis are presented below.

LCA GHG comparative analysis: production stage

A comparative LCA analysis of the three RCVs (new diesel, repower and new electric) was conducted to understand which vehicle production cycle produces the most GHG emissions.

As shown in Figure 1, the vehicle glider (body) for the three RCVs is responsible for the majority of emissions during the vehicle production stage (49 tonnes CO2e).

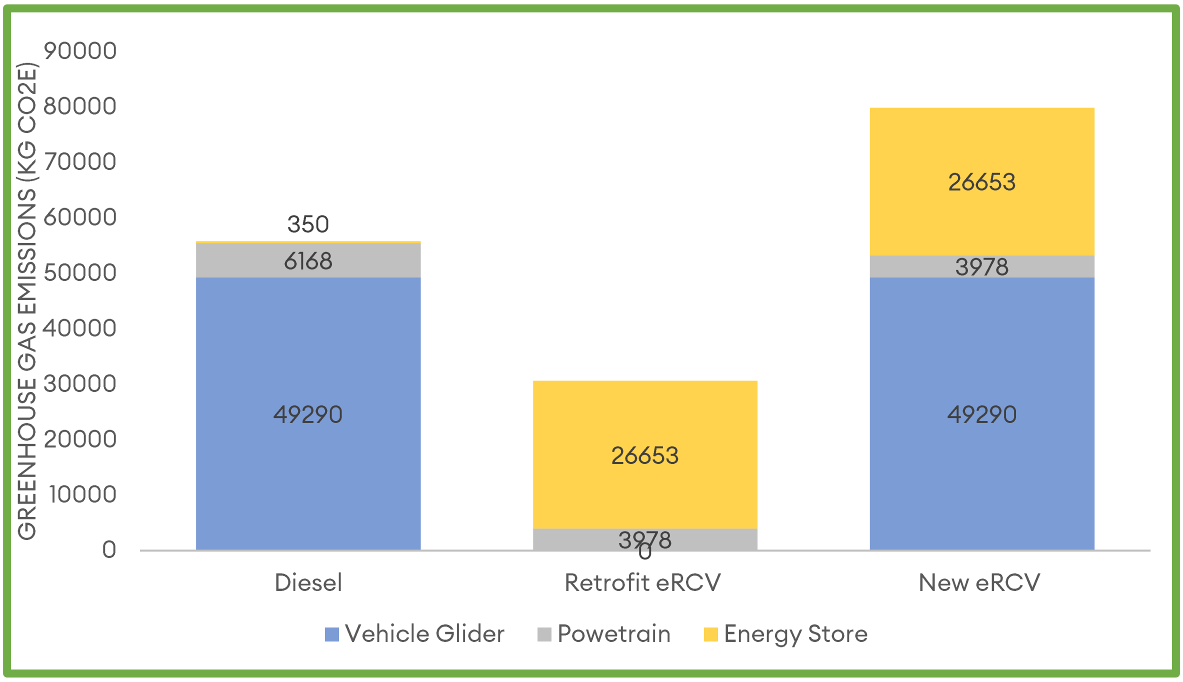

Figure 1 GHG emissions of new diesel, retrofit & new electric RCV during production stage (over 7 years)

From this analysis, it's clear that the production stage of a new eRCV emits 20% more greenhouse gas emissions compared with a new diesel due to the large amount of energy used in the creation of batteries.

Retrofitted RCVs release the least GHG emissions (25 tonnes GHG reduction) from a new diesel & a new electric, as it does not require a new body and glider to be made.

As battery production is scaled up worldwide, the embedded carbon of each battery is expected to fall, meaning that overall emissions from production of retrofit and new electric RCVs will likely decrease. Furthermore, using alternative materials to build the chassis could reduce emissions e.g. aluminium alloys and improvements in service efficiency.

LCA comparative analysis: diesel versus retrofit eRCV

A comparative LCA was conducted to compare lifecycle emissions of a diesel RCV and a retrofitted RCV for their operational period (7 years).

As shown in Figure 2, a retrofit RCV emits 72% less GHG emissions than a new diesel throughout its life (equivalent to 294 tonnes of CO2e avoided over 7 years). These savings are mostly due to the retrofit using renewable energy. Emissions are also reduced by not producing a new body and chassis (required for a diesel vehicle).

Vehicle end-of-life emissions are slightly higher for the retrofit as both diesel (from pre-retrofit) & electric parts will need to be recycled. However, these emissions are small compared to the overall GHG emissions.

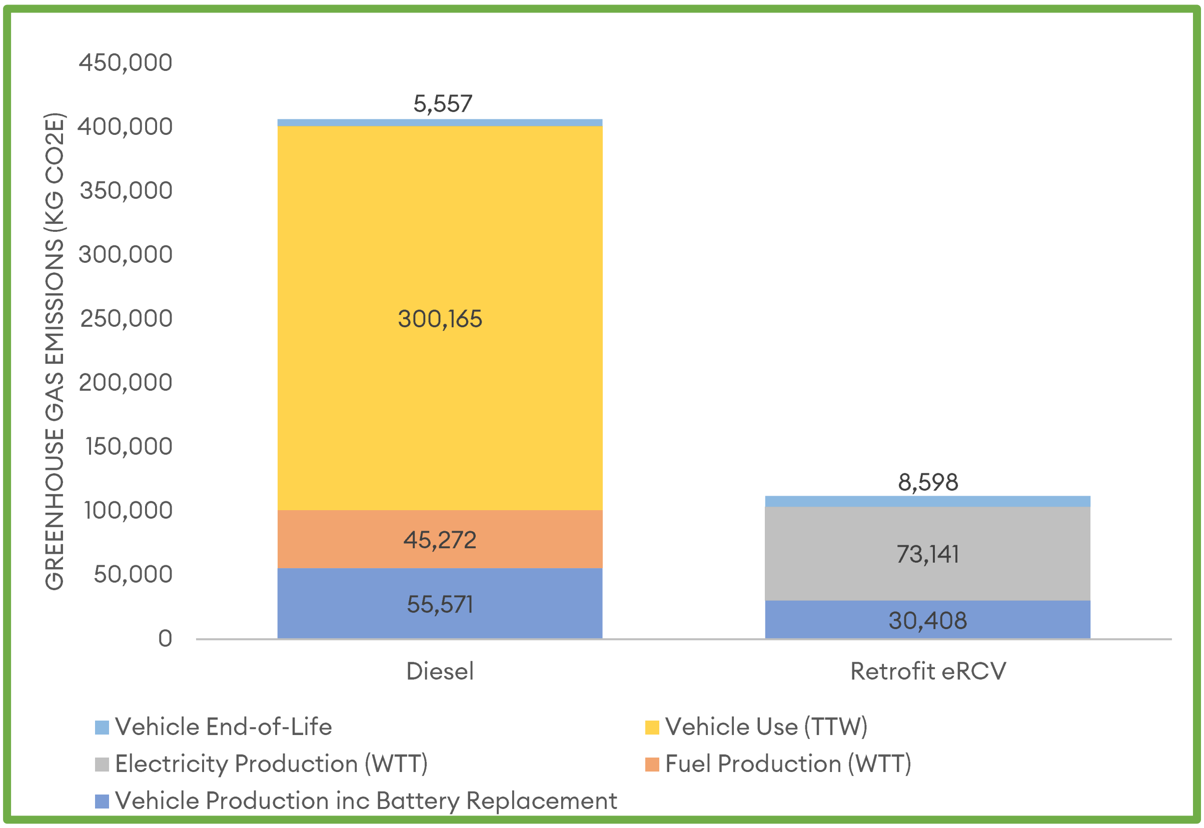

Figure 2 LCA GHG house emissions diesel versus retrofit

LCA comparative analysis: diesel versus new eRCV

As shown in Figure 3, a new electric RCV emits 57% less GHG emissions than a new diesel (equivalent to 245 tonnes of CO2e avoided over 7 years).The new eRCV saves less GHG emissions than a retrofit due to the high emissions associated with the RCV's production.

Vehicle end-of-life emissions are slightly higher for the new eRCV than a new diesel due to the recycling of the eRCV components (e.g. batteries), which have higher embodied emissions from their production. These emissions could potentially be offset through the reuse of the batteries for storage.

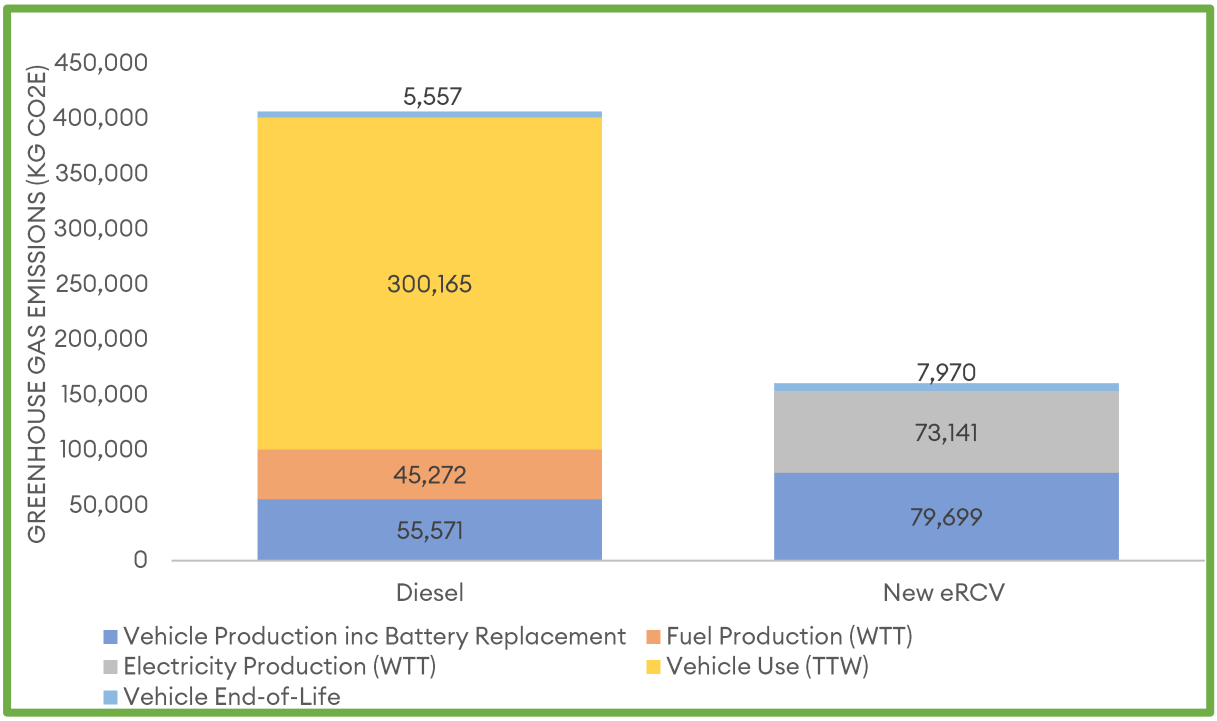

Figure 3 LCA diesel RCV versus new electric RCV over 7 years

LCA GHG Emissions: new diesel, new electric and retrofit

Of the three RCVs, a retrofit generates the least amount of GHG throughout its 7 year operation period. Whereas a newly purchased diesel RCV generates approximately 3 times more emissions per km travelled than a new electric RCV or a retrofit.

4.2 Operational environmental impacts & costs

This section outlines the social costs of noise and air pollution from the diesel RCV and its electric counterparts. Operational air emissions were calculated using real time data collected over a four month period. Operational noise pollution was calculated by noise measurement experts using drive-by measurements of diesel and electric vehicles and via a dosage meter attached to operatives.

4.2a Air pollution

Methodology & Results

Internal Combustion Engine (ICE) vehicles release toxic pollutants, such as PMx and NOx, that can lead to cardiovascular disease, lung cancer and other conditions (e.g. asthma). In London, approximately 50% of NOx and 33% of PM emissions can be attributed to road transport [5].

The damage cost approach is one of the methodologies used to conduct a transport appraisal - a process used to assess the benefits, costs and risks of a proposal. This

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[5] Greater London Authority (2020) Estimation of changes in air pollution in London during the Covid-19 outbreak

approach is applicable for transport appraisal projects that will have a small impact on air quality (below £50 million) and do not breach legal limits.

The damage costs approach applies monetary values to every tonne of emissions such as PM2.5 or NOx. These monetary values vary according to various factors such as sector, location and source of emissions.

Approach

This section outlines the steps taken to calculate the social costs of air pollutants from diesel and electric RCV vehicles. The following documents were used to define this approach:

- The Greenbook (2018)[6] is the overarching UK government guidance document for conducting appraisals. The Greenbook recommends that DEFRA's Air quality appraisal: damage cost guidance[7] is used to calculate social costs of transport projects.

- The Defra Damage Costs toolkit was used to automatically calculate the social costs of PM2.5 and NOx.

- Web Tag Data Book Sheet A3.3[8] was used to quantify greenhouse gas emissions from the electric RCV.

- DfT's TAG Unit A3 Environmental Impact Appraisal [9] document was used as a reference document for monetising emissions.

- DEFRA's air quality damage cost guidance indicates that the National Atmospheric Emissions Inventory (NAEI)[10] should be used to quantify PM2.5 and NOx emissions from the diesel and electric RCVs. Some of the emission factors provided by NAEI are the same as those presented in Web Tag Data Book (sheet A3.5).

Operational emissions were calculated based on the assumption that the diesel & retrofit RCVs would operate for 7 years throughout their lifetime, and each operational year consists of 240 days.

[6] HM Treasury (2018) The Green Book Central Government Guidance on Appraisal & Evaluation

[7] DEFRA (2020) Air quality appraisal: damage cost guidance

[8] DfT (2020) Tag Data Book July 2020 v1.13.1

[9] DfT (2019) TAG Unit A3 Environmental Impact Appraisal

[10] National Atmospheric Emissions Inventory (2020) Fleet Weighted Road Transport Emission Factor (XLSX)

Diesel RCV Emissions

1. **Identify** the amount of diesel (in litres) for a diesel RCV annually.
    a. Days per operational year: 240
    b. Litres per km: 0.61
    c. Average distance per day (km): 70.22
    d. Average distance per operational year: 16,852.80
    e. Operational period: 7 years
    f. Litres per operational year: 10,320.65

2. **Identify** the distance travelled for a diesel RCV (in km), for its operational period.
    a. Average distance per day: 70.22 km
    b. Average distance per operational year: 16,852.80 km
    c. Operational period: 7 years
    d. Average distance per operational period: 117,969.60 km

3. **Calculate GHG emissions for the operating period:** To determine the amount of GHGs that will be emitted from the use of the diesel RCV, throughout its operating period, the conversion factors provided by BEIS UK Greenhouse Gas Reporting Conversion factors were used[11]. GHG emissions were calculated by multiplying the *diesel (average biofuel blend) conversion factor* by the *litres* of diesel fuel consumed per year:
    a. BEIS diesel (average biofuel blend) conversion factor: 2.59411 kg C02e/litre
    b. GHG emissions = litres of diesel fuel per operational year × kg 2.594 C02e
    c. Litres of fuel per operational year: 10,320.65
    d. GHG emissions per year = 10,320.65 * 2.594 = 26,771.78 kg CO2e
    e. GHG emissions per operational period: 187,402.45 kg CO2e

4. **Quantify PM2.5 and NOx Emissions:** The Green Book[6] recommends that DEFRA's Damage Cost Approach is used to determine the social costs of air pollution, caused by small scale transport projects. As per DEFRA, *emission factors for rigid HGVs* (exhaust and non-exhaust) in the National Atmospheric Emissions Inventory (NAEI) were used to determine the amount of PM2.5 and NOx that will be emitted from the diesel RCV during its operating period. The emissions are calculated by

[11] BEIS (2020) Conversion factors 2019: full set (refer to 'Fuel' sheet)

multiplying the specific emission conversion factor by the kilometres (KM) travelled, as outlined below:

Table 1 Combined hot exhaust and cold start emission factors for rigid HGVs

Emission Factor (g/km)	Average distance travelled per year (km/year)	Average distance travelled per operational period (km/ 7 years)	Emissions per operational year (grams)	Emissions per operational period (grams)
NOx (1.088)	16,852.80	117,969.60	18,335.85	128,350.92
PM2.5 (0.016)			269.64	1,887.51

Table 2 Non-exhaust emission factors for rigid HGVs

Emission Factor (g/km)	Average distance travelled per year (km/year)	Average distance travelled per operational period (km/ 7 years)	Emissions per operational year (grams)	Emissions per operational period (grams)
PM2.5 tyre wear (0.012)	16,852.80	117,969.60	202.23	1,415.64
PM2.5 brake wear (0.010)			168.53	1,179.70
PM2.5 road abrasion (0.021)			353.91	2,477.36

Electric RCV Emissions (applicable to retrofit & new electric)

1. **Identify** the amount of energy (in kWh) consumed for an eRCV annually.
    a. kwh/ km= 2.4492
    b. Average distance per operational year: 16,852.80 km
    c. Average distance per operational period: 117,969.60 km
    d. kWh per operational year = 41,275.88 kWh
    e. kWh per operational period= 288,931.14 kWh

2. **Identify** the distance travelled for the operational period.

a. Average distance per day: 70.22 km

b. Average distance per operational year (240 days): 16,852.80 km

c. Average distance travelled per operational period (7 years): 117,969.60 km

3. **Calculate GHG emissions for the operating period:** To determine the amount of GHGs that will be emitted from an eRCV annually, throughout its operating period, conversion factors provided in Table A3.3 of Web Tag Data Book were used. The emission factor for 'electricity roads' was used to determine the GHG emissions that will be generated from using the RCV.

Table 3 Annual GHG Emissions for retrofit RCV

Operating Year	GHG per kWh (kg C02e/kWh)	GHG per operational year (kg C02e)
2020	0.296	(0.296 * 41,275.88) = 12,217.66
2021	0.283	11,681.07
2022	0.269	11,103.21
2023	0.255	10,525.35
2024	0.240	9,906.21
2025	0.224	9,245.80
2026	0.207	8,544.11
2027	0.189	7,801.14

GHG emissions for the eRCV for its operating period are 28,946.79 kWh, utilising an average emission factor of 0.25 kg CO2e for 2020 to 2027.

4. **Quantify PM2.5 and NOx Emissions:** '*Rigid HGVs*' emission factors provided by the National Atmospheric Emissions Inventory (NAEI) were used to quantify non exhaust PM2.5 emissions for each eRCV throughout its operating period.

<u>Exhaust Emissions (g/km)</u>

Electric RCVs do not emit tailpipe emissions of NOx and PM2.5 and as such are much more sustainable than diesel.

<u>Non exhaust emissions (g/km)</u>

Both electric RCVs and ICEs (diesel RCV) will emit non-exhaust emissions. As such the emissions presented in the following table are the same as those for the diesel RCV.

Table 4 Non-exhaust emissions

Emission Factor (g/km)	Average distance travelled per operational period (km/ 7 years)	Emissions per operational period (grams)
PM2.5 tyre wear (0.012)	117,969.60	1,415.64
PM2.5 brake wear (0.010)		1,179.70
PM2.5 road abrasion (0.021)		2,477.36

5. **Change in GHG emissions: Diesel RCV versus Electric RCV emissions:** Once the RCV GHG emissions have been quantified the difference between the total GHG emissions (7 year period) from the diesel RCV and electric RCV is calculated.

Table 5 Difference in GHG emissions: diesel RCV versus retrofit

	Diesel RCV	Electric RCV	GHG savings with eRCV
Total GHG emissions over 7 year period (kg CO2e)	187,402.45	28,946.79	85%

6. **Change in exhaust emissions from Diesel RCV and Electric RCV emissions:** Once the RCV PM2.5 & NOx emissions have been quantified, the difference between the total (7 year period) PM2.5 & NOx emissions from the diesel RCV and electric RCV is calculated.

Table 6 Diesel RCV versus retrofit RCV - exhaust emissions

	Diesel RCV	Electric RCV	Savings with eRCV
PM2.5 (g) for 7 year period	1,887.51	0	100%
NOx (g) for 7 year period	128,350.92	0	100%

7. **Change in non-exhaust emissions from Diesel RCV and Electric RCV emissions:** The same amount of non-exhaust emissions were emitted for both the diesel and electric RCVs, over their 7 year operating period.

Table 7 Diesel RCV versus retrofit RCV - non-exhaust emissions

	Diesel RCV	Electric RCV	Savings with eRCV
PM2.5 tyre wear (g)	1,415.64	1,415.64	0%
PM2.5 brake wear (g)	1,179.70	1,179.70	0%
PM2.5 road abrasion (g)	2,477.36	2,477.36	0%

Summary of Operational Emissions

This section summarises and compares total emissions that would be generated from the use of a diesel versus electric RCV for their 7 year operation period. The emissions presented below only account for the usage stage of the RCVs and as such differ from lifecycle emissions presented in section 4.1.

Real time data collected from the four-month operational period of the diesel & electric RCVs demonstrates that the electric RCV will emit a considerably lower amount of exhaust emissions compared to the diesel RCV, for the same operating period of 7 years.

Table 8 Summary of operational GHG, NOx & PM2.5 emissions (7 years) for diesel & retrofit RCV

		Diesel RCV	Electric RCV	Savings with eRCV (%)
GHG Emissions	GHG (kg C02e)	187,402.45	28,946.79	85%
Exhaust Emissions	PM2.5 (g)	1,887.51	0	100%
	NOx (g)	128,350.92	0	100%
Non Exhaust Emissions	PM 2.5 Tyre wear (g)	1,415.64	1,415.64	0%
	PM2.5 Brake Wear (g)	1,179.70	1,179.0	0%
	PM2.5 Road Abrasion (g)	2,477.36	2,477.36	0%

4.2b Monetising Emissions

Exhaust Emissions (PM2.5 & NOx)

As per DEFRA's damage cost approach[7], only tailpipe emissions (PM2.5 & NOx) & GHG emissions are monetised. The following steps were followed to monetise these emissions for the diesel RCVs. Electric RCVs do not have tailpipe emissions and as such their costs for these pollutants are zero.

Damage costs are monetary values provided to reflect the societal impact of pollutants emitted. Damage costs for a pollutant are calculated per tonne of emissions and are based on national average costs for various pollutions (including PM2.5 & NOx).

1. **Identify the appropriate damage cost:** As per DEFRA's Damage Cost Approach[7], emissions can be monetized by first identifying the appropriate damage cost for the assessed pollutant measured in £/tonne. For this project, Road Transport damage costs for NOx and PM2.5 were used.

    a. NOx national average cost for road transport: 9,066 (£/tonne)

    b. PM2.5 national average cost for road transport: 81,518 (£/tonne)

2. Adjust damage costs to relevant base year prices: GDP deflators are used to adjust the damage cost from 2017 (national average base price) to the project's base appraisal year, which is 2020. According to the Damage Cost Guidance, the ratio of the GDP deflator index values for 2020 and 2017 are divided to get the GDP deflator ratio (1.058), which is multiplied by the damage cost value to get the rebased values of £9,594.489 for NOx & and £86,269.98 for PM2.5. These must then be adjusted for inflation (i.e uplifted).

3. Uplift damage costs by 2% per year: Damage costs must be uplifted by 2% per year, from the project baseline year (2020) onwards. The uplifted factor is used to demonstrate that the willingness to pay for health will increase with GDP growth. Uplifted damage costs are calculated by multiplying the yearly adjusted damage cost (step 2) by the appropriate uplift factors provided in the Air Quality Damage Cost ToolKit (Table 9 below). This gives the yearly central damage costs that will be used to monetise emissions (see next step).

Table 9 NOx and PM2.5 damage costs adjusted for inflation

Year	NOx – Road Transport Damage Cost Adjusted for Inflation (£)	PM2.5 – Road Transport Damage Cost Adjusted for Inflation (£)
2020	10,182	91,553
2021	10,386	93,384
2022	10, 593	95,252
2023	10,805	97,157
2024	11,021	99,100
2025	11,242	101,082
2026	11,467	103,104
2027	11,696	105,166

Source: Air Quality Damage Cost Appraisal Toolkit[7]

4. **Calculate benefits for each year:** Uplifted damage costs must then be multiplied by the yearly emissions (in tonnes). This results in the annual social cost for each year of the project.
   - NOx emissions per year (tonnes): 0.01833585
   - PM2.5 emissions per year (tonnes): 0.00026964

Table 10 Annual costs of NOx and PM2.5

Year	NOx - Central Damage Cost (£)	PM2.5 - Central Damage Cost (£)	Annual NOx Cost (£)	Annual PM2.5 - Cost (£)
2020	10,182	91,553	187	25
2021	10,386	93,384	190	25
2022	10, 593	95,252	194	26
2023	10,805	97,157	198	26
2024	11,021	99,100	202	27
2025	11,242	101,082	206	27
2026	11,467	103,104	210	28
2027	11,696	105,166	214	28

5. **Discount annual pollution costs:** The annual social costs for each pollutant are discounted annually by 3.5% to determine the present value of future costs. To calculate the discounted costs, present pollution costs are multiplied by the appropriate discount factor. To calculate the discounted costs for the following year, the current year's pollution costs are multiplied by the inflation factor, and are then multiplied by the appropriate discount factor.

The following table presents the final annual cost of both PM2.5 & NOx (exhaust emissions) for the diesel RCV, which have been discounted and adjusted for inflation. These costs are not applicable for the electric RCVs as they do not generate these emissions through their tailpipes.

Table 11 Annual NOx & PM2.5 costs discounted (final costs)

Year	Diesel RCV NOx Exhaust Emission Costs (£)	Diesel RCV PM2.5 Exhaust Emission Costs (£)
2020	187	25
2021	184	24
2022	181	24
2023	179	24
2024	176	23
2025	174	23
2026	171	23
2027	169	22

GHG Emissions (diesel & electric RCV)

The following steps were taken to calculate the social cost of GHGs from the diesel & electric RCVs:

6. **Quantify GHG emission.**

Table 12 Annual GHG Emissions - retrofit & diesel

Operating Year	GHG per operational year (tonnes of C02e/year) - electric	GHG per operational year (tonnes of CO2e/year) - diesel
2020	12.22	26.77
2021	11.68	26.77
2022	11.10	26.77
2023	10.53	26.77
2024	9.91	26.77
2025	9.25	26.77
2026	8.54	26.77
2027	7.80	26.77

7. **Identify whether the GHG emissions are within the traded or the non-traded sector:** In carbon valuation, GHG emissions are categorised as traded or non-traded sector emissions. Non traded sector emissions are those from petrol, diesel, gas and oil, and as such are applicable for the diesel RCV. Whereas, traded sector emissions are used for the electric RCV.

Traded and non-traded sector emission costs (£/tonne) are provided in the following table. These are based on 2010 price year:

Table 13 GHG Emission values (£/tonne)

Operating Year	Central Traded Value (£/tonne) - electric RCV (source: TAG Databook v1.13.1 (July 2020) Table A3.4 [8]	Central Non-Traded Value (£/tonne) - diesel RCV (source: TAG Databook v1.13.1 (July 2020) 'GHG' tab[8]
2020	12.2	59.96
2021	18.2	60.83
2022	23.5	62.57
2023	29.5	63.44
2024	35.6	64.31
2025	40.8	65.18
2026	46.9	66.05
2027	53	66.92

8. **Monetise the annual value of emissions for each year:** the yearly GHG emissions are multiplied by the non-traded or traded sector carbon values (£/tonne) provided in TAG Data Book. This calculation generates an annual social cost of carbon (£) per tonne of emissions.

9. **Calculate the present value of GHG emissions** by multiplying the annual social cost of GHG (£/tonne) by the discount rate for the corresponding emissions year (discount of 3.5% is used). GHG emission costs for the diesel and retrofit RCV are presented in the following table:

Table 14 Annual GHG emission costs (retrofit & diesel)

	Diesel (£/year) (discounted)	Electric (£/year) (discounted)
2020	1,137.98	105.67
2021	1,115.45	145.62
2022	1,108.56	172.68
2023	1,085.97	198.53
2024	1,063.63	217.87
2025	1,041.56	225.16
2026	1,019.78	231.10
2027	998.27	230.38

4.2c Noise Pollution

In comparison to carbon emissions, less research has been carried out into quantifying the cost of noise pollution, particularly for larger vehicles. However, its impact on quality of life and health is becoming of increasing concern, shown to not only be a nuisance and cause of sleep disturbance, but also negatively impact long-term health. In 2017, Hansell (et al) published a paper[12] showing a significant association between increasing levels of road noise and a deterioration in cardiovascular health. The World Health Organisation has estimated that throughout western Europe, noise pollution results in 1-1.6m lost years of life each year[13].

As such, it's important to ensure that the risks of noise pollution are accounted for in appraisals. Defra provides guidance on assessing the impacts of transport related noise from different sources, including road transport. Guidance provided by Defra

[12] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5837618/
[13] WHO (2011) Burden of disease from environmental noise

follows the Impact Pathway Approach which covers the impact on annoyance, sleep disturbance and health.

This section outlines the steps taken to calculate the social costs of noise pollution from both the diesel and electric RCV vehicles.

The following documents were used to define this approach:

- DoT's TAG Unit A3 Environmental Impact Appraisal[9] document was used as a reference document for monetising noise pollution.
- The results of the steps described below were used to fill out the TAG Noise Assessment Workbook[14], which automatically monetises noise pollution from the diesel and the electric RCV. The worksheet describes the different noise exposure levels and thus the % of population (households) that will be affected by sleep disturbance, annoyance and amenity.

Monetising noise pollution:

1. The first step in monetising noise pollution is to determine how much noise is being emitted. To do this, the following steps were taken by Veolia and expert noise consultants (EuroEnvironmental Ltd):
    a. The number of houses that will be affected by the noise emitted for the diesel and electric RCV were identified. For Sheffield this number was 1,200, for Westminster it was 7,987. An average of the two was therefore taken (4,954).
    b. Document number of houses subject to varying noise levels during the day (07:00 to 23:00 hours) (from <45 decibels to 81+ decibels). These figures were derived by performing in-situ testing at Westminster and Sheffield by noise measurement experts. Noise measurements were gathered using a probe and dosimeter attached to operatives in order to compare the noise level of the diesel vs electric vehicles through-out their shift. Measurements were taken of the noise emitted when each vehicle was being driven, idling and when operating the bin lift and compactor. From the exercise, the following results were derived:

[14] DfT Tag: Environmental Worksheets, Noise Assessment Workbook

Table 15 Noise Readings via two methodologies for Sheffield and Westminster. Data gathered September 2020

		Sheffield	Westminster
Methodology 1: In-vehicle	**Electric (dB)**	69.7	64.9
	Diesel (dB)	72.3	71.2
Methodology 2: Dosemeter	**Electric (dB)**	69.5	78.5
	Diesel (dB)	72.5	83.7
	Number Households	**1200**	**7987**

From these results, the following averages were derived, which were used in subsequent calculations for the overall business case:

i. The average noise of the diesel vehicle (across both methodologies, in both Sheffield and Westminster) when being driven was 71.85dB.

ii. The average noise of the electric vehicle (across both methodologies, in both Sheffield and Westminster) when being driven was 67.20dB.

iii. A comprehensive report of the results from this exercise is included in the appendix of this report.

iv. In each instance we compared the difference in exposure between average noise levels [51-54 dB - as per UK guidance levels[15]] to the noise level of each vehicle.

v. This analysis is done for the first operating year of the project (2020). The impacts (and associated costs - see below) are assumed to remain constant for the remaining operating years.

c. The TAG Noise Assessment Workbook worksheet automatically calculates the social cost of noise from the diesel and the electric RCVs per year over a 16-hour period. However, as the vehicles are assumed to only disturb each household for a maximum of 5 minutes by each

[15] BS 8233: 2014 Guidance on Sound Insulation and Noise Reduction for Buildings

dwelling, the results were divided by 192 to reduce the exposure time from 16 hours to 5 minutes.

d. Both electric and diesel vehicles are louder than baseline noise levels, therefore there is always a social cost of the noise emissions from the RCV. However, this cost varies depending on the average noise measured from the diesel and the electric RCVs. In this case, the social cost of noise over the operational period per year was significantly lower for the electric RCV than the diesel RCV.

Table 16 Average noise (dB) for diesel & retrofit & associated costs

	Diesel RCV	Electric RCV
Number of households	4594	
Noise (dB)	71.2	67.2
Cost of change in noise from 51-54dB in 16-hour period) (2020)	£3,934,790.67	£2,169,833.02
Cost of 5-minute period (focus of detailed business case) (2020)	£20,493.70	£11,301.21

e. Social costs of noise are automatically discounted (3.5% annually) and adjusted for inflation.

5.0 Business Case Results, Summary & Conclusion

A business case was developed to compare all the costs associated with the operation of the RCV vehicles, including the noise and emission costs discussed in section 4.2. The purpose of the business case was to compare the total costs (including environmental) associated with the operation of an RCV and to determine which RCV powertrain option (new diesel, retrofit or new electric) is the most financially feasible & sustainable option.

The following assumptions were used to develop the business case:

- All costs are adjusted to the UK's current 2% inflation rate
- There are 240 days in an operational year
- There are 7.9 months in an operational year
- Each vehicle is assumed to operate for 7 years
- Appropriate discount factors have been applied where applicable

5.1 Overall results & summary

The eRCVII project sought to understand whether an end-of-life diesel RCV repowered to electric is more financially feasible and sustainable than purchasing a new diesel or electric RCV.

In order to answer this question, a financial and environmental business case was conducted, comparing the operational, capital and environmental costs and benefits of the three options for RCV – new diesel, new electric and retrofit electric RCV.

In order to gather real-life data to form part of this busines case, two RCV types (diesel and retrofit electric) were operated in a real-world environment for four months as part of the eRCV II project. Using data collected from this period, alongside real-life costs from partners in the eRCV II project, the following information was calculated annually and for a 7 year period for each option. Consumption and performance data was also estimated for a new electric RCV to fully understand if an electric retrofit is feasible.

The measures included within the business case, and the time period they were measured across, are detailed below:

5.1a Operational (Opex) & capital (Capex) financial costs:

Opex and capex costs were calculated for a new diesel, a new electric and a retrofit electric using real-time monitoring data and information provided by partners within the eRCV II project. Where applicable, revenue streams were also applied.

5.1b Environmental measures and financial costs:

The following environmental measures were estimated based on real-time monitoring data and specific measurement exercises conducted in situ (e.g. noise levels). The following environmental measures have been included within the business case, over the following time periods:

Noise and air pollution emissions:

- GHG: annual & for 7 year total
- Exhaust PM2.5 & NOx: annual & 7 year total
- Non-exhaust PM2.5 & NOx: annual & 7 year total
- Noise: annual & 7 year total

Although environmental costs are not accounted for, eRCVII sought to include them in an effort to present and compare the real financial burden of the diesel and the electric retrofit RCVs. As such, a monetary value was provided for the annual and total noise and air pollution emissions as per UK government guidance & current standards.

5.1c Results

From completing the business case, it is evident that of the three RCV options, the electric retrofit is the most financially feasible and sustainable. Although upfront costs of this option are high (due to retrofit technicalities), its overall financial costs are still lower than a new diesel or a new electric RCV.

Furthermore, although a new electric and a retrofit electric RCV have the same environmental operational emissions and costs, the retrofit has lower financial costs (£385,909 vs £484,409) for its 7 year period, and a higher revenue stream.

Table 17 provides a comprehensive comparison of the total costs associated with a diesel RCV, a retrofit & a new electric RCV. The costs provide the total costs accumulated over a period of 7 years.

Table 17 Cost comparison: diesel, retrofit & new electric RCV

	New Diesel RCV	Retrofit electric RCV	New Electric
Capital Costs	£175,000	£352,000	£450,000
Operational Costs	£361,044	£94,409	£94,409
Revenue	-£5,000	-£65,000	-£60,000
Environmental Costs	£186,226	£98,553	£98,553
TOTAL (excluding environmental)	£531,044	£385,909	£484,409
GRAND TOTAL	£717,270	£484,462	£582,962

In addition to quantifying and comparing the operational emissions and costs, this project also considered the lifecycle emissions (i.e from resource extraction to disposal) of a diesel, retrofit electric and a new electric RCV. The outcomes of this research also demonstrate that the retrofit electric RCV produces the least GHG emissions through its lifecycle.

As such, of the three RCV options, a retrofit RCV has the largest financial cost savings & overall emission savings, compared to a new diesel and a new electric RCV.

Detailed business case of the three different options is provided below.

Option 1 Diesel	2020	2021	2022	2023	2024	2025	2026	2027	Discount Rate
Capex Costs									Discount Rate
New vehicle	£175,000	£0	£0	£0	£0	£0	£0	£0	N/A
Opex Costs - Adjusted for inflation									Discount Rate
AD Blue	£8,183	£8,347	£8,514	£8,684	£8,858	£9,035	£9,215	£9,400	0%
Operational vehicle monitoring	£118	£121	£123	£126	£128	£131	£133	£136	0%
Diesel Fuel	£16,366	£16,693	£17,027	£17,368	£17,715	£18,069	£18,431	£18,799	0%
Vehicle License	£720	£734	£749	£764	£779	£795	£811	£827	0%
Annual Insurance	£2,000	£2,040	£2,081	£2,122	£2,165	£2,208	£2,252	£2,297	0%
London Congestion Charge	£2,520	£2,570	£2,622	£2,674	£2,728	£2,782	£2,838	£2,895	0%
Average Cost Maintenance	£6,850	£7,900	£10,500	£12,700	£14,050	£16,200	£17,900	£18,250	0%
Noise & Air Pollution Costs - Discounted & Adjusted for inflation (based on government guidance)									Discount Rate
PM2.5	£25	£24	£24	£24	£23	£23	£23	£22	3.50%
NOx	£187	£184	£181	£179	£176	£174	£171	£169	3.50%
GHG	£1,138	£1,138	£1,131	£1,108	£1,085	£1,062	£1,040	£1,018	3.50%
Noise	£20,494	£20,904	£21,322	£21,748	£22,183	£22,627	£23,079	£23,541	3.50%
Revenue Stream									Discount Rate
RCV resale value	-£5,000								N/A
TOTAL									
FINANCIAL ONLY	£206,757	£38,406	£41,616	£44,438	£46,423	£49,220	£51,581	£52,604	
SUB-TOTAL								£531,044	
ENVIRONMENTAL	£21,844	£22,249	£22,657	£23,059	£23,467	£23,886	£24,313	£24,750	
SUB-TOTAL								£186,226	
FINANCIAL & ENVIRONMENTAL	£228,601	£60,655	£64,273	£67,497	£69,890	£73,106	£75,894	£77,354	
GRAND TOTAL								£717,270	

Option 2 Retrofit RCV	2020	2021	2022	2023	2024	2025	2026	2027	Discount Rate
Capex Costs									Discount Rate
EV drive train (inc. 300kWh batteries) - components only	£197,000	£0	£0	£0	£0	£0	£0	£0	N/A
Battery charge point installation cost	£25,000	£0	£0	£0	£0	£0	£0	£0	N/A
Refurbishment cost	£35,000	£0	£0	£0	£0	£0	£0	£0	N/A
New vehicle body	£70,000								
Drive train installation & removal of diesel system	£25,000	£0	£0	£0	£0	£0	£0	£0	N/A
Opex Costs - Adjusted for inflation									Discount Rate
Charging cost	£6,448	£6,577	£6,708	£6,843	£6,980	£7,119	£7,261	£7,407	0.00%
Average Maintenance cost	£1,370	£1,580	£2,100	£2,540	£2,810	£3,240	£3,580	£3,650	20.00%
Operational vehicle monitoring	£120	£122	£125	£127	£130	£132	£135	£138	0.00%
Annual Insurance	£2,000	£2,040	£2,081	£2,122	£2,165	£2,208	£2,252	£2,297	0.00%
Noise & Air Pollution Costs - Discounted & Adjusted for inflation									Discount Rate
PM2.5	£0	£0	£0	£0	£0	£0	£0	£0	3.50%
NOx	£0	£0	£0	£0	£0	£0	£0	£0	3.50%
GHG	£106	£149	£176	£203	£222	£230	£236	£235	3.50%
Noise	£11,301	£11,527	£11,758	£11,993	£12,233	£12,477	£12,727	£12,982	3.50%
Revenue Stream									Discount Rate
RCV resale value	-£60,000								N/A
Sale of diesel engine	-£500								N/A
TOTAL									
FINANCIAL ONLY	£301,438	£10,319	£11,014	£11,632	£12,084	£12,700	£13,229	£13,492	
SUB-TOTAL								£385,909	
ENVIRONMENTAL ONLY	£11,407	£11,676	£11,934	£12,195	£12,455	£12,707	£12,963	£13,217	
SUB-TOTAL								£98,553	
FINANCIAL & ENVIRONMENTAL	£312,845	£21,995	£22,948	£23,828	£24,539	£25,407	£26,192	£26,708	
GRAND TOTAL								£484,462	

Option 3 New electric RCV	2020	2021	2022	2023	2024	2025	2026	2027	Discount Rate
Capex Costs									Discount Rate
Newly purchased electric RCV	£425,000	£0	£0	£0	£0	£0	£0	£0	N/A
Battery charge point installation cost	£25,000	£0	£0	£0	£0	£0	£0	£0	N/A
Opex Costs -Adjusted for inflation									Discount Rate
Charging cost	£6,448	£6,577	£6,708	£6,843	£6,980	£7,119	£7,261	£7,407	0.00%
Average maintenance cost	£1,370	£1,580	£2,100	£2,540	£2,810	£3,240	£3,580	£3,650	20.00%
Operational vehicle monitoring	£120	£122	£125	£127	£130	£132	£135	£138	0.00%
Annual insurance	£2,000	£2,040	£2,081	£2,122	£2,165	£2,208	£2,252	£2,297	0.00%
Noise & Air Pollution Costs - Discounted & Adjusted for inflation									Discount Rate
PM2.5	£0	£0	£0	£0	£0	£0	£0	£0	N/A
NOx	£0	£0	£0	£0	£0	£0	£0	£0	N/A
GHG	£106	£149	£176	£203	£222	£230	£236	£235	3.50%
Noise	£11,301	£11,527	£11,758	£11,993	£12,233	£12,477	£12,727	£12,982	3.50%
Revenue Stream									Discount Rate
Resale value of new electric RCV	-£60,000								N/A
TOTALS									
FINANCIAL ONLY	£399,938	£10,319	£11,014	£11,632	£12,084	£12,700	£13,229	£13,492	
SUB-TOTAL								£484,409	
ENVIRONMENTAL ONLY	£11,407	£11,676	£11,934	£12,195	£12,455	£12,707	£12,963	£13,217	
SUB-TOTAL								£98,553	
FINANCIAL & ENVIRONMENTAL	£411,345	£21,995	£22,948	£23,828	£24,539	£25,407	£26,192	£26,708	
GRAND TOTAL								£582,962	


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