Efficient and affordable Zero Emission logistics through
NEXT generation **E**lectric **TRUCK**s

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D3.5
Report on first TCO assessment with mission profiles

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Legal disclaimer

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
TCO	Total Cost of Ownership
KPI	Key Performance Indicator
BEV	Battery Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
FMU	Functional Mockup Unit
ZEV	Zero Emission Vehicle
UC	Use Case
HGV	Heavy Goods Vehicle
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
BMS	Battery Management System

EXECUTIVE SUMMARY

NextETRUCK aims to address different optimization challenges regarding tomorrow's urban and suburban logistics for medium-duty vehicles into a systems approach that is reliable, strongly integrated, affordable, and flexible enough to be re-applied to different applications via dedicated tools/methods.

In the design stages of the project, an initial assessment of Total Cost of Ownership (TCO) is needed to allow right-sizing of components related to the NextETRUCK innovations. This first assessment should aid in minimising vehicle TCO while delivering the relevant improvements to the truck's systems.

This report summarises the data available on cost and operational differences between the NextETRUCK and baseline vehicles to calculate likely TCO savings.

The initial TCO assessment takes the form of a generic 16t model integrating all of the project innovations possible to estimate at this stage. This estimate was selected while specific details from each Original Equipment Manufacturer's (OEM's) own developed models are still pending. The TCO saving relative to Internal Combustion Engine Vehicle (ICEV) and Battery Electric Vehicle (BEV) baselines are estimated for each of the three use cases planned for the NextETRUCK trial.

The results of the first assessment show a strong variation in the vehicle-level TCO saving achieved by the NextETRUCK across the planned use cases, due to differences in the planned operations of vehicles at each site and local factors such as energy pricing. The achievable TCO saving at the vehicle level is also shown to be strongly dependent on the specification of the battery and motor power, highlighting the importance of considering TCO within the sizing optimization process for these design areas.

This initial TCO assessment forms the basis for future implementation into the optimization process and the evaluation of the fleet-level TCO saving evidenced by the project demonstrator vehicles in future work packages. The target fleet-level TCO saving defined in the project KPIs will rely on success of the holistic design strategies of the project, in delivering savings with both the physical vehicle considered within WP3, and the operational savings achieved through the project's software-based innovations.

1 INTRODUCTION

1.1 About NextETRUCK

NextETRUCK is a 3-year Horizon Europe project that develops ZEV concepts tailored for regional medium freight haulage, running from 1 July 2022 until 31 December 2025.

The project aims at playing a pioneering role in the decarbonisation of vehicle fleets, demonstrating next-generation e-mobility concepts. It also contributes to the development of zero-emission vehicles and ecosystems that are holistic, innovative, affordable, competitive, and synergetic.

NextETRUCK is expected to build concepts tailored for regional medium freight haulage with at least a 10% increase in energy efficiency compared to existing highest-end benchmark electric vehicles. In addition, it shall prepare concept and infrastructure demonstrators for fast charging and offer new business models to increase end-user acceptance and foster the market uptake of the project solutions.

The project's consortium consists of 19 partners from 8 countries: The Netherlands, Belgium, Germany, Spain, Greece, Austria, Turkey, United Kingdom[1]. The project's coordinator is TNO (Netherlands Organization for Applied Scientific Research).

NextETRUCK shall conduct demonstrations in Istanbul, Barcelona, and Utrecht.

1.2 Purpose of the deliverable

This deliverable describes the process of the initial assessment of the total cost of ownership in the planned vehicle demonstration use cases. This first assessment is performed as part of Work Package 3 and focussed on understanding the impact of design changes towards the target reduction of the Total Cost of Ownership (TCO) for the NextETRUCK vs baseline vehicles as specified in the project KPIs.

[1] The UK participants in this project are co-funded by the UK.

1.3 Structure of the deliverable and its relation with other work packages/deliverables

This deliverable report is structured with the following sections:

- Section 1: introduces the NextETRUCK project and the role of this deliverable within the wider context of the project.
- Section 2: description of the total cost of ownership calculation framework to be used in this work package.
- Section 3: presentation of the information available from project partners and assumptions made to define the differences in costs and performance between NextETRUCK and baseline designs.
- Section 4: summary of the first TCO results. Includes comparison of the NextETRUCK and baseline vehicles in different circumstances and sensitivity analysis to assumed external factors.
- Section 5: summary conclusions of the first TCO assessment.

This deliverable is linked to the following WPs and Tasks:

- WP2: Use case and preliminary KPI definitions in D2.1 is used as the basis for assumptions on the lifetime operation of the NextETRUCK vehicles for TCO calculation.
- WP3: The TCO considers all design changes between the baseline electric vehicle and NextETRUCK, meaning design details from each WP3 subtask are considered. The work of this report will also have a direct link with T3.1 through future linking of the TCO calculation to the component right-sizing optimization process developed in T3.1.
- WP8: Project KPIs as defined in WP8 are used as the target for TCO saving. The TCO calculation process established in WP3 will also form the basis for the demonstrator TCO evaluation in WP8.

2 INITIAL TCO ASSESSMENT FRAMEWORK

2.1 Problem Definition

The tasks in Work Package 3 centre around the first stages of design optimisation for the NextETRUCK project, including right-sizing of vehicle systems and setting the first low-fidelity models in place to form the basis for the vehicle Digital Twin. During the early design stages of the project, these tasks aim to facilitate the specification of systems within the proposed NextETRUCK design. It is therefore important to understand the implications of design choices in relation to overall project KPIs, including the reduction of the Total Cost of Ownership (TCO) of the vehicle.

To estimate the potential cost impact of design choices in a way that is compatible with the other tasks of this work package, Task 3.6 is focussed on designing a framework to assess the impact on TCO to achieve two goals:

- Initial TCO assessment of the NextETRUCK against equivalent baseline vehicles within the design stages of the project, where exact specifications and operational data are not yet available.
- Provide means to estimate the TCO impact of any design change possible for the Task 3.1 optimisation loop intended to right-size components of the vehicle powertrain, as shown in Figure 1.

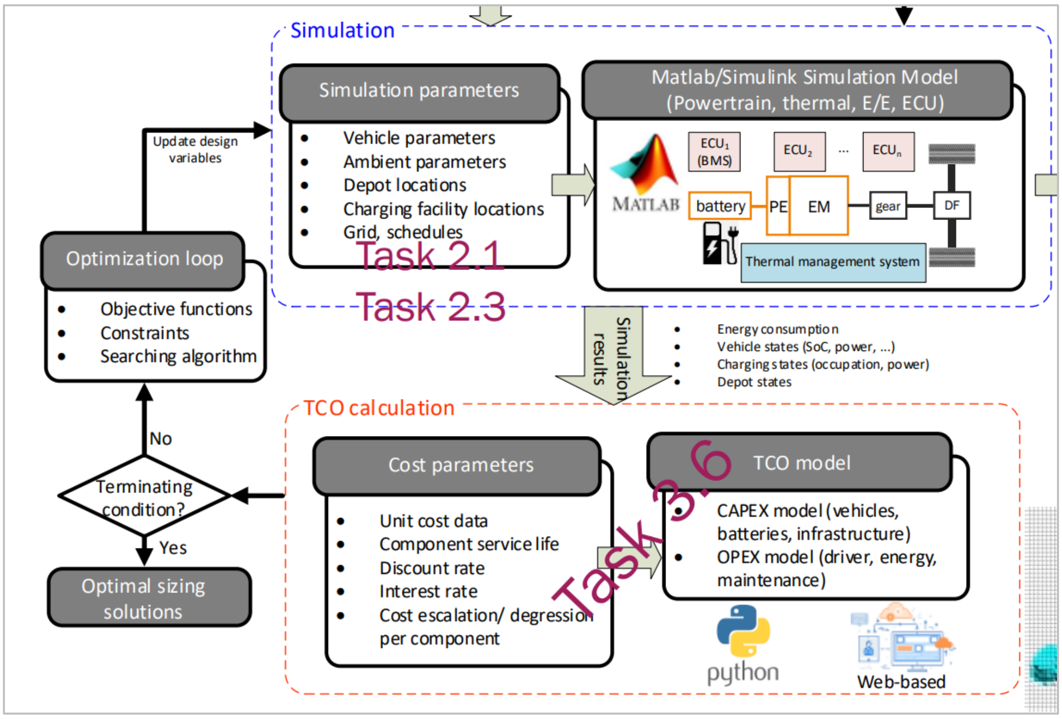


Figure 1: Planned Interaction between Task 3.6 TCO Calculation and Task 3.1 Optimization

The TCO assessment framework presented in this report has some limitations due to its focus on the first specifications for the physical vehicle. The calculation primarily considers the cost changes to the NextETRUCK at the vehicle level rather than fleet level, as the WP3 design areas primarily concern the impacts to the vehicle itself and not its infrastructure. The first assessment also does not include the impacts of the project's software/management innovations to be developed in future work packages. Operational costs due to personnel or operations changes between the baseline and NextETRUCK (payload variation, route changes, double shifting facilitated by charger innovations, etc.) are also not considered at this stage. Consequently, it is expected that the TCO savings estimated within this task will not fully meet the project's overall target values as described in Table 1.

Table 1: Project KPIs related to TCO

KPI-6	KPI-6a	20% TCO reduction of ZEV is achieved when compared with a modern e-truck
	KPI-6b	TCO parity with ICE 2020 trucks.
KPI-10		15% TCO reduction for the fleet charging infrastructure

2.2 TCO Assessment Framework

2.2.1 First TCO Assessment

The timing of Task 3.6 within the early stages of design specification means that the first TCO assessment needs to be completed before exact materials or specifications have been assigned to the design changes between the baseline vehicle and NextETRUCK. The lack of specification in each area of innovation makes it difficult to assess the exact expected TCO impact for each design area. To allow a first assessment of TCO, a more general approach is made to first evaluate the baseline vehicle(s), and then estimate changes made to the NextETRUCK.

The project KPIs related to the vehicle TCO have two targets: a 20% reduction relative to baseline Battery Electric Vehicle (BEV), and parity to Internal Combustion Engine Vehicle (ICEV). A baseline is therefore needed for both ICEV and BEV costs. It is assumed that the capital and operational costs for the NextETRUCK can be considered as a modification to the BEV baseline vehicle costs. Two potential routes were planned to estimate the cost impact of NextETRUCK modifications:

- 'Bottom up' approach, considering each vehicle component and calculating the individual costs of the design changes applied.
- 'Top down' approach, considering the costs and performance of the baseline vehicle as a whole and to what level it must change in order to satisfy project KPIs.

The first approach is preferable in terms of understanding the impact of each design area separately, but with the data burden placed largely on OEMs and design partners at a time when exact specifications have not been made. Additionally, it is expected that each design change has impacts that span outside of the direct area of influence of the specified system (e.g. increasing battery size might directly increase vehicle range, but also increase the weight, internal layout, and payload capacity of the vehicle leading indirectly to an altered energy consumption rate while driving). The second approach is expected to be easier to complete with publicly available data, but allowing a less detailed analysis of the impact of individual design choices.

The framework agreed for the first TCO assessment is a hybrid of the two approaches, where an attempt is made to gather data within each project design area (detailed in Section 3), with the broader public data analysis used as backup where data was not available. The net capital expenditure (CAPEX) equal to vehicle depreciation, and operational expenditure (OPEX) of each baseline are calculated using the following equations:

$$CAPEX = \sum Retail\ Costs\ Vehicle - \sum Local\ Purchase\ Subsidies - \sum Residual\ Values\ Vehicle$$

$$OPEX = \sum Lifetime\ Refuelling\ Costs + \sum Lifetime\ Maintenance\ Costs + \sum Lifetime\ Tax + \sum Lifetime\ Additional\ Costs$$

Additional conditions are set for the first assessment, including:

- Calculations are based on current prices and at production scales comparable to public data sources unless otherwise stated. Where historic cost data is used, an equivalent 2023 price is estimated by applying the cumulative inflation rate since the year of data collection. A more detailed view on future manufacturing/fuel prices and more explicit consideration of the intended NextETRUCK production scales will be assessed in the TCO calculation of the demonstrators later in the project.
- Annual operations in each use case are estimated using the use case (UC) missions as defined in WP2. We assume consistent use through the year, 5 days a week by default. No seasonal variations in operations were considered.
- Any operational differences between baseline and NextETRUCK (e.g. due to eco-routing system dynamically changing routes) are not considered to ensure a like-for-like comparison of vehicles.
- We assume no cost implication to the slight reduction in payload capacity vs the ICEV baseline.
- It is assumed that all use cases have sufficient time for an overnight charge at depot, hence no costs due to operational time loss for charging.
- All vehicles are assumed to be able to complete their daily cycles without use of public charging, so all BEV refuelling costs are priced at local electricity cost.
- Local vehicle road taxes and subsidies at each UC are considered where available. Local VAT is not considered.
- Changes to local manufacturing and maintenance costs due to differing costs of labour at each UC are not considered.
- Economies of scale that apply at fleet level are not considered (e.g. CAPEX discounts for larger fleet sizes, charger sharing etc.)

2.2.2 TCO Integration in Powertrain Optimization

For an overall minimal system cost design, multiple interactions between powertrain component sizes must be taken into account. Vehicle energy consumption has a strong impact on battery cost, which has the largest share in system cost. Vehicle consumption itself is strongly influenced by all components of the electric powertrain. Hence additional cost for a more efficient machine or inverter can often be more than compensated by savings in the significantly more expensive battery.

Due to high system complexity, it is not possible for an expert to consider all relevant correlations for a minimal system cost design with given requirements and assumptions at the vehicle level. Therefore, a simulation-based system development approach using a multi objective optimization (MOO) methodology developed in D3.1 can be used to minimize the TCO as shown in Figure 2.

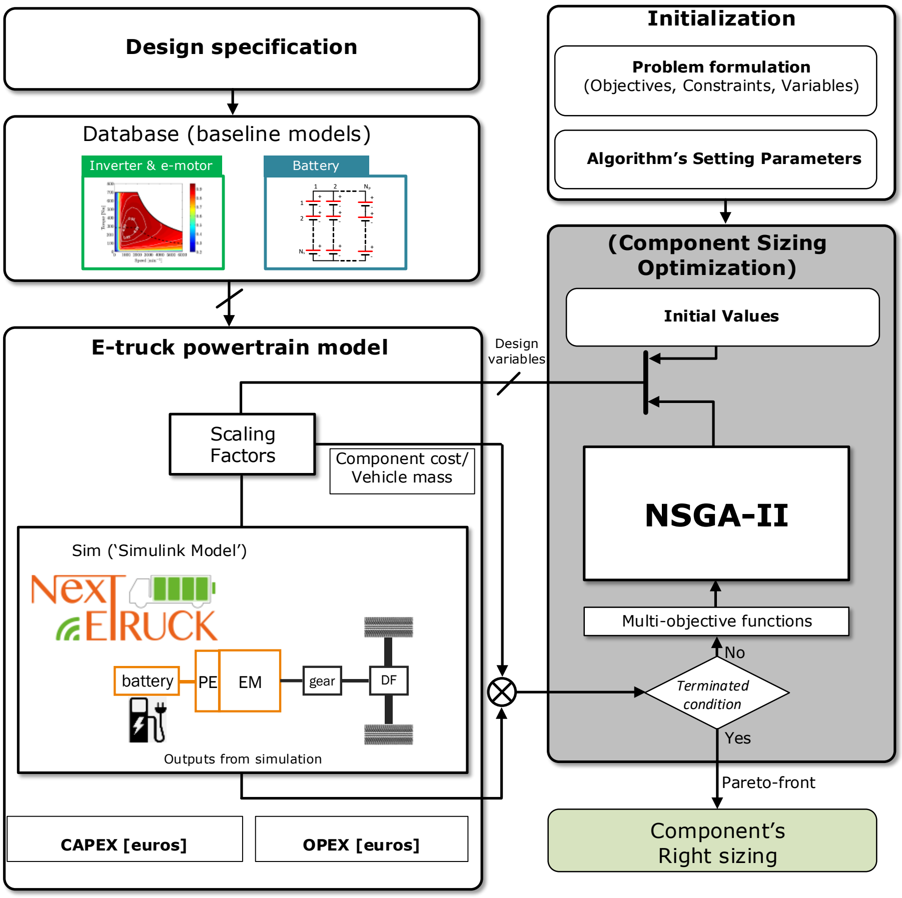


Figure 2: TCO (CAPEX and OPEX) integration in powertrain optimization framework

To allow TCO to be used as one of the objectives within the optimization loop, the TCO calculation must be able to interface with the loop detailed in Deliverable 3.1. The calculation must be able to receive inputs of the current value of the optimization variables, and results of the energy simulation stage that reflect a realistic energy consumption of the whole vehicle. TCO estimation must then be supplied an output to the optimization loop to allow for the next iteration of the loop to be completed. The following details are planned for future implementation within the project but not implemented within WP3:

- The impact of variables that can be changed within the optimization loop (battery size, motor power, transmission ratio) needs to be possible to assess for any value the components to be sized might be able to take. A model is required for CAPEX change per unit for these variables (see Section 3.6). OPEX changes will be calculated in the simulation stage.
- Design changes that are fixed outside of the optimization loop (thermal design, thermal control etc.) will have CAPEX impacts calculated once based on their fixed changes to the vehicle. Non-energy related OPEX impacts will also be assessed once (e.g. maintenance impacts). Energy-related OPEX costs are captured by the energy simulation as part of the optimisation loop.
- Component independent parts of TCO (software design changes, local taxes/subsidies etc) will be assumed to provide a fixed percentage TCO saving based on best available information for the completion stage of the project when the optimization loop is implemented. This is considered an appropriate estimate for design-stages decision making, as final values for the actual benefit of most of these systems will not available until the vehicle demonstrations at the end of the project.

3 VEHICLE DESIGN AND COSTS ASSUMPTIONS

This section presents the assumptions made about the baseline and NextETRUCK vehicle designs and costs, summarising by each design area the information available from project partners or public data sources used where such information was not available.

Project partners were asked, where possible, to estimate the cost changes associated with design updates between the baseline BEV and NextETRUCK models. Where an estimate was not possible to make due to lack of specified components etc., a 10% CAPEX increase was applied to areas with a physical change to the vehicle to estimate the increased costs due to the potential use of lower-maturity components, additional development or supply costs incurred by the manufacturers etc. As this 10% increase is a best estimate in an area with considerable uncertainty, variations on this factor are included in a sensitivity analysis and presented in Section 4.2.2.

3.1 Baseline Vehicles

As a first assessment, a 'generic' model of the truck baseline and NextETRUCK is used based on an average between known specifications of the three OEM baseline models as described in Deliverable 3.1. The generic vehicle details are summarised in Table 2. This approach was chosen for the following reasons:

- Data giving precise specifications for both ICEV and BEV baseline vehicles was not available from all project OEMs at this stage of the project.
- Not all project vehicles are being produced to the same specifications or receiving the same combination of the project's innovations, making it difficult to isolate the impact of the NextETRUCK innovations.
- Direct costs for specific OEM developments within the project cannot be published due to commercial sensitivity.

Table 2: Summary of Assumed Generic NextETRUCK Vehicle Attributes

Parameter	Baseline ICE Comparator	Baseline BEV Comparator	NextETRUCK
Truck type	Rigid		
Powertrain type	Center mounted motor driving rear axle		
Gross trailer weight	16t		
Wheel configuration	4x2		
Battery installed capacity	n/a	200 kWh	200 kWh
Motor Continuous Power	230 kW		230 kW

Operations of the vehicles were assumed to match the Use Case (UC) missions as defined in Work Package 2, except for the UC3 vehicle to be developed by Tevva, which was updated to demonstrate in the UK in place of the original planned Utrecht use case. As specific information on the UK duty cycle was not available, it was assumed that the UK cycle would match the Utrecht cycle in terms of planned mileage and route intensity. The UC2 average daily mileage was also reduced to address concerns within the project team about the possibility of demonstrating 200km daily use for the full demonstration period. A summary of the assumed annual operation patterns and the local operational costs are shown in Table 3.

Table 3: Summary of Assumed Use Case Operational Attributes

	Ford (Turkey) **UC1**	**Irizar (Spain)** **UC2**	**Tevva (UK)** **UC3**	**EU27 Average Current Costs**
Daily km	200	100	200	
Days per week	5	5	5	
Annual km	52000	26000	52000	
First Ownership Period	7 years	7 years	7 years	
Baseline Charger Efficiency	0.87	0.87	0.87	
NextETRUCK Charger Efficiency	0.90	0.90	0.90	
Diesel EUR/litre	€1.25 [1]	€1.57 [2]	€1.66 [3]	€ 0.95 [4]
Electricity EUR/kWh	€0.07 [5]	€0.10 [6]	€0.29 [3]	€ 0.19 [7]
ICE Annual Tax	€0*	€213.00	€345.00 [8]	
BEV Annual Tax	€0*	€0	€0	
ICE Additional Lifetime Costs (incl. ZEV subsidies)	€0	€0	€0	
BEV Additional Lifetime Costs (incl. ZEV subsidies)	€0 [9]	-€20000.00 [10]	-€ 28750.00 [11]	

*Assumed zero for commercial vehicles [12]

Annual energy consumption of the baseline vehicles was estimated using the use case duty cycles as defined in Work Package 2, and the existing generic vehicle simulation tool developed by AVL-AT. It was assumed for this first TCO assessment that AVL-AT's generic 16t BEV modelled energy consumption rate on each of the defined duty cycles is representative of each use case's average annual energy consumption. For future iterations of the TCO calculation, a more specific energy consumption for the exact specifications of the NextETRUCK design is planned. Firstly, calculated using the full integration of all FMUs within VUB's optimization loop, and finally the measured demonstrator energy consumption for the end-of-project TCO evaluation.

The fuel consumption of the diesel equivalent baseline vehicles was estimated by applying a conversion factor based on typical MJ/km energy consumption of ICEV and BEV 12t-16t vehicles found by the International Transport Forum [13]. The ratio of consumption between typical ICEV and typical BEV models was applied to the UC-specific simulated BEV consumption rates to estimate the rate of diesel consumption of an equivalent ICEV on the same UC duty cycle.

The NextETRUCK energy consumption was estimated by assuming each vehicle would achieve the target 10% energy saving per km as specified in the project KPIs. Assumed consumption rates for each use case are summarised in Table 4.

Table 4: Summary of Assumed Average Energy Consumption per Use Case

	Baseline ICE Comparator	Baseline BEV Comparator	NextETRUCK
UC1	0.326 litres/km	1.11 kWh/km	0.999 kWh/km
UC2	0.272 litres/km	0.93 kWh/km	0.835 kWh/km
UC3	0.316 litres/km	1.08 kWh/km	0.970 kWh/km

3.2 Vehicle Thermal Design

Updates to the thermal systems of the vehicle are being developed within the project by two different project partners: firstly related to cabin HVAC, and secondly thermal management within the rest of the vehicle. These two systems are expected to interact, but each design partner was approached for any available estimated data on cost or energy impacts.

All innovations implemented in the NextETRUCK are in the early stages of development, which means that cost information is not always available. For the cabin thermal design there are only estimations available for a basic thermal system and the new thermal system. Included in these estimations are only the components in the thermal system; so no development, manufacturing, storage or other costs. The costs are further based on assumptions and can vary drastically for different production quantities and technical details.

Estimated relative cost difference (CAPEX)

- Basic Thermal System: € 1,079
- New Thermal System: € 1,123

An estimation of the power saving of the new cabin thermal system was also provided. The power saving is an average where extreme and common temperature points are weighted together.

Estimated relative energy saving (OPEX)

- 500W during vehicle operating hours. For calculation purposes, this power saving was assumed to contribute to the overall saving of 10% energy consumption per km during operation.

The development of the rest of the vehicle’s thermal systems is currently in the simulation phase, which means that there is no cost information available at this time in the project. Costs will be become available when the thermal controls will enter the implementation phase.

3.3 Battery Management System

Updates to the vehicle Battery Management System (BMS) consist of a software and hardware part, however as both are still in the development stage, no solid cost data is available. It is expected that the hardware will not be much different in cost. Additional costs or cost savings for the software will become available when the BMS will enter the implementation phase.

Estimated relative cost difference (CAPEX)

- Hardware: No difference between BEV baseline and NextETRUCK
- Software: Additional development cost assumed to be reflected within the 10% cost increase applied to all e-drivetrain components between baseline and NextETRUCK.

BMS capital costs were assumed to be included in the e-drivetrain component breakdown as presented in [14]. These costs were adapted for the TCO calculation for this report while in-project data was not available.

Estimated relative cost difference (OPEX)

- It is expected that the BMS may allow for a longer battery lifetime, potentially increasing the residual value of the vehicle or reducing the need for battery replacement within the vehicle's lifetime. However, as this cannot be reasonably estimated at this stage it is omitted from this calculation.

3.4 In-Vehicle Infotainment System

The In-Vehicle Infotainment (IVI) device serves a dual purpose: firstly, it caters to the driver's needs by delivering essential information, guidance, and interface options. Secondly, it collects crucial vehicle and mission data during operations, transmitting it to the cloud for further analysis. Within this device, multiple software tools will be implemented, serving as the driver's interface across various modules developed under the NextETRUCK project. Notably, the primary software, as depicted in Figure 3, acts as a client for the Logistics Planner & Mission Assignment module. Its functions include:

- Presenting current route and mission information, encompassing details about cargo, quantities, time windows, origin, destination, and displaying the optimal route along with charging station information.
- Providing vehicle-specific information such as remaining battery power, speed, maintenance alerts, and other pertinent details.
- Delivering additional messages or notifications crucial for the driver's attention.

Figure 3: Logistics Planner & Mission Assignment vehicle client

The proposed IVI incorporates all the above functionalities into one unit and this is the main differentiation from the existing IVI systems on the baseline trucks. Advanced IVI systems already exists in the market as originally equipped units or aftermarket ones. However, the flexibility of enhancing the NextETRUCK system with future functionalities is an advantage that could potentially reduce costs of unit upgrade.

Estimated relative cost difference (CAPEX)

Regarding the expected costs in hardware and software, the consortium does not foresee major differentiations from the baseline trucks. The information display (a tablet in NextETRUCK case) will cost less than 1000 EUR which represents the price of a unit from a shop. For mass vehicle production, the price per unit will be less than 200 EUR per unit. Moreover, current e-vehicles are offered with large infotainment units that can display large amounts of information and can satisfactory serve the NextETRUCK IVI functionalities. In this case, no additional costs are foreseen for hardware.

In terms of software, the only expected cost is the merging of the functionalities into a common platform which cannot be higher than 50 EUR per truck in mass vehicle production. Software updates or upgrades are considered as an aftersales service and are not applicable as basic vehicle costs.

As far as the vehicle connectivity with a server and the data transfer is concerned, this already exists -as a service to the customer/fleet owner- and will not increase the TCO. An average value of connectivity costs and the services to the customer is about 10-20 EUR per truck per month which is not expected to change in the NextETRUCK case.

Expected changes to OPEX

The main change in OPEX is expected to be related to the energy savings because of the NextETRUCK eco-routing guidance and charging instruction through a comprehensive strategy. Another influencing parameter to OPEX is the more accurate time window scheduling which results in costs savings. Regarding the energy saving by applying a multi-objective eco-routing strategy (eco- and travel time-optimum routing), the energy consumption can be reduced 10-14% depending on the congestion level [15]. However, without simulation or demonstration derived data at the time of this deliverable, any potential reduction of the operational costs for each use case's specific duty cycle cannot be quantified and is therefore omitted from the first TCO assessment.

3.5 IoT System

It was assumed that the IoT system, alongside the IVI as described above, will facilitate some of the software-related improvements to the NextTRUCK by gathering telemetry data that is to be used in the project's eco-routing, eco-charging and other management strategies developed in later WPs. It is assumed that most commercial trucks will have an existing telemetry system installed, hence the IoT system will not incur a significantly higher hardware cost than the baseline unless more extensive sensors are required (not currently planned in Task 3.4).

Estimated relative cost difference (CAPEX)

- No difference between BEV baseline and NextETRUCK

Estimated relative cost difference (OPEX)

- Considered identically to the IVI system as above. Energy saving leading to operating cost reduction is expected, but cannot be quantified at this stage.

3.5.1 Predictive Maintenance

To seize the advantage of reduced energy expenses and guarantee a favourable return on investment, transportation services must extend vehicle operation durations and increase their usage intensity beyond conventional fleet practices. The implementation of predictive maintenance plays a significant role in this strategy by minimizing vehicle downtime, thus allowing them to remain on the road. Fleet managers often pre-empt costly breakdowns by replacing components earlier than necessary. However, this practice proves inefficient as it leads to premature replacement of parts before reaching their full operational lifespan. Predictive maintenance serves as an effective solution to address this inefficiency and allows fleet operators to strategically schedule vehicle servicing.

Besides the maintenance complexities associated with EVs, the constrained range they offer poses logistical hurdles for fleet operators. Data analytics and machine learning techniques are employed nowadays to build mathematical model. These models integrate the onboard battery data from the vehicle with various other influencing factors that impact the vehicle's range. Consequently, it enables predictions of both the current remaining range of the vehicle and anticipates the future decline in battery capacity over the next years.

In the plans for NextETRUCK, the focus lies on implementing thermal management for batteries and electronics, along with assessing the battery's state of health (SoH). Predictive maintenance will centre on these aspects and will not extend to other components such as air compressors, suspension, brakes, and tires, which is commonly practiced presently. When examining the available predictive maintenance solutions for EVs in the market today, NextETRUCK will not deviate from the norm, thus not foreseeing a TCO reduction compared to the current standard. The expected extension in the lifespan of batteries and electronic components due to optimized thermal management and charging strategies mirrors what is currently offered by existing predictive maintenance applications.

3.6 Optimization Loop Variables

The above sections deal with the fixed design changes for the NextETRUCK models. Design changes that will form part of the optimization loop detailed in D3.1 were considered separately, as the future integration of the TCO calculation will need to provide a cost change result for any possible value of the loop variables, it was necessary to understand how these components' costs scale.

3.6.1 Electric Drivetrain Innovation

Differences between the baseline electric drivetrain and the proposed NextETRUCK specifications will largely be reflected within the optimization loop variables as described in Deliverable 3.1. The first results presented in this report assume equivalent hardware between the baseline BEV and NextETRUCK drivetrains. However, as the specifications of the drivetrain form a part of the planned optimization loop, it was necessary to understand how the cost scales with the optimization variables used.

The electric drivetrain costs assumed in this report are based primarily on the work of Ricardo and ICCT (2021) [14] and ITF (2022) [13]. In these studies, costs of the electric drivetrain are scaled primarily with the motor continuous power rating and are assumed to have a linear relationship. Following the cited studies, we consider the following components to be a part of the electric drivetrain for costing purposes:

- High Voltage components (DC/DC converter, onboard charger, HV distribution system)
- E-Drive (e-machine, inverter and gearbox)
- Electric Steering pump
- Electric air compressor
- Battery & electronics thermal management – note that these components are included within the motor-scaled calculation in the studies above and so are included in this section until specific information on the NextETRUCK systems is available.

Estimated relative cost difference (CAPEX)

- 10% cost increase applied to all like-for-like e-drivetrain components to reflect increased costs, manufacturing etc. of project developments.

Estimated relative energy saving (OPEX)

- None specified, assumed NextETRUCK design changes will contribute to overall 10% energy consumption reduction between BEV baseline and NextETRUCK.

3.6.2 Battery Sizing

Similar to the electric drivetrain described above, the battery size specified for the NextETRUCK will depend on the outcomes of the optimization loop planned in Deliverable 3.1. Results are presented in this report based on the assumption of no physical change in battery size, with a cost sensitivity to battery size presented separately.

Studies into component costs note that commercial vehicle battery costs per kWh vary between standard automotive and heavy-duty vehicle applications due to factors including volume savings of other battery components and differences in production volume [14]. It was assumed for this report that the medium-duty vehicles considered in this project would be affected by the same issues and thus use the estimated battery pricing from the above study. It is also noted that commercial battery pricing is expected to change significantly over time [13], [14]. Costs used for the first TCO analysis assume 2023 pricing or as close as available for all components, however for future assessments of TCO, future reductions to battery prices will be more directly considered.

Estimated relative cost difference (CAPEX)

- 10% cost increase per kWh battery size applied reflect increased costs, manufacturing etc. of changing battery components from BEV baseline.

Estimated relative energy saving (OPEX)

- None specified, assumed NextETRUCK design changes will contribute to overall 10% energy consumption reduction between BEV baseline and NextETRUCK.

4 TCO RESULTS

This section presents a breakdown of the initial TCO results for the baseline vehicles in each of the three UC operating scenarios as summarised in Table 3, and an analysis of sensitivity of the results to some assumed inputs.

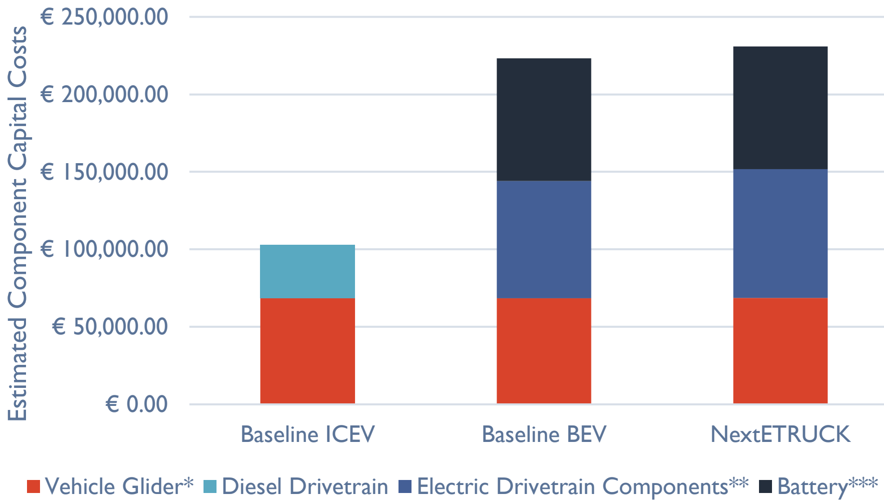
4.1 Costs Breakdown

The categories of costs within the capital, residual and operational costs of the baseline and NextETRUCK vehicles are presented below. The results in this section are presented independently of the use case, with a view on the impact of use case location presented in following sections.

4.1.1 Vehicle Capital Costs

Estimates were made for the main cost components of the generic versions of the BEV and ICEV baseline comparators using public data sources. Cost increases associated with the NextETRUCK hardware changes were applied as described in Section 3 of this report (it was broadly assumed that changed components will increase in cost by 10%) – with the results of all three generic vehicle models shown in Figure 4. Vehicle capital costs were considered at estimated retail price unless otherwise stated. Most component-level costs sources were assumed to reflect direct manufacturing cost. A retail price estimate (RPE) markup factor of 1.5 [16] was applied to direct cost totals to cover the cost of manufacture, OEM overheads, etc.

It was assumed that the vehicle glider would remain largely the same for all three vehicles. Retail cost of the ICEV comparator was estimated using a recent UK-based summary of Heavy Goods Vehicle (HGV) pricing [17]. The diesel drivetrain cost was then estimated based on the work of Hunter et al [16] and subtracted from the total retail price, leaving the remainder as the average price of the vehicle glider. As shown in the figure, it is expected that the electric drivetrain components [14] and battery pack [13] combine to make the largest part of the cost of both baseline and NextETRUCK BEV models. Local differences in manufacturing/development costs affecting parts/markup are not considered for the generic 16t comparison in this report.



*Including all non-powertrain related components of the vehicle.
**Assumed to include High Voltage (HV) components, electronics thermal management, e-drive unit, air brake compressor, steering pump.
***Priced for one battery unit of the stated capacity, assuming no battery replacement or refurbishment during lifetime.

Figure 4: Estimated Main Component Capital Costs for Generic 16t Baselines and NextETRUCK

4.1.2 Vehicle Residual Value

Residual value for the vehicles was based on the method applied in the work of ITF [13], in which the BEV battery is separated from the rest of the vehicle. The calculations in [13] assume a residual value ranging between 5-20% of original price for the battery, and a residual value ranging between 20-35% for the rest of the vehicle. The above figures are based on a 7-year first ownership period, which is also assumed for the NextETRUCK first ownership TCO. The average of the range was taken for residual value for this report. The results of residual value calculations are shown in Figure 5.

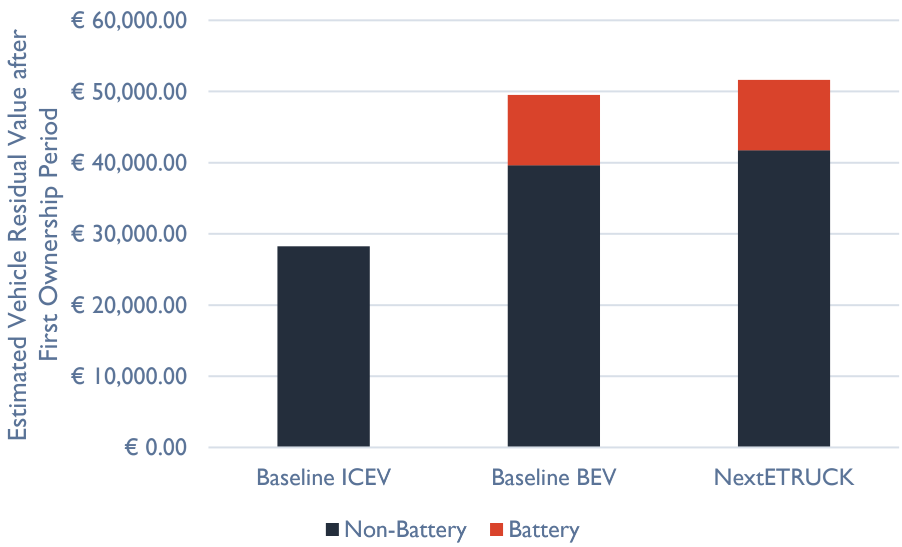


Figure 5: Estimated Residual Values for Generic 16t Baselines and NextETRUCK

4.1.3 Vehicle Operational Costs

Figure 6 shows a summary of assumed annual operational costs for the baseline and NextETRUCK vehicles if completing a cycle of 200km per day, 5 days per week. Fuel costs used in this figure are based on an average of current EU-27 energy prices as noted in Table 3, to avoid skew by disproportionate local energy costs to the generic manufacture price. Local operational costs for each UC were also calculated and are shown in the full TCO values in the following sections of this report. As shown in the figure below, the largest operational cost is the cost of refuelling each vehicle, with the diesel-based ICEV typically more expensive to fuel for the same operations as the BEV vehicles. The NextETRUCK operational cost reductions relative to the baseline vehicles are the main mechanism for offsetting any increased capital costs and delivering an overall TCO saving relative to baseline.

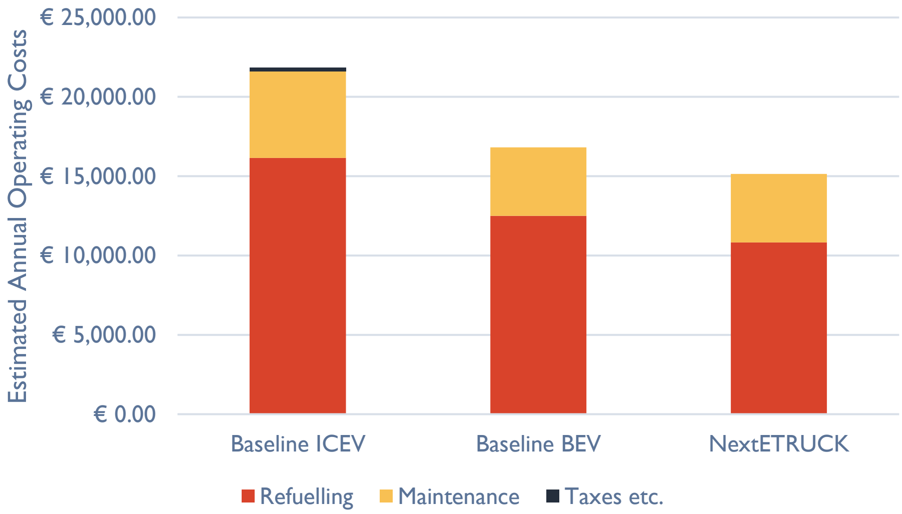


Figure 6: Estimated Annual Operational Costs for Generic 16t Baselines and NextETRUCK (EU27 Average Fuel Prices)

4.2 NextETRUCK Estimated TCO Saving

The following sections present the combined first results of TCO for all three project use cases. As mentioned in Section 2, the TCO calculated at this stage of the project is considered at vehicle-level and omits some of the software-based operational savings expected to be developed in future work packages.

4.2.1 Assumed NextETRUCK Scenario

Figure 7 shows the estimated impact of the combined assumptions as described in above sections, on the TCO per km travelled for each project use case. There is a significant variation of relative savings per use case, as shown in the figure. The varying importance of CAPEX vs OPEX in the overall TCO of the vehicle can be explained by a combination of factors, including variation in operations and relative costs of electricity vs diesel at each location. In locations where fuels are relatively expensive and a larger annual mileage is planned, such as the UK use case, operational costs of the vehicle may outweigh the increased capital required for innovation and deliver greater savings relative to the baseline vehicle. In cases where fuel is cheaper (Turkey UC) or the vehicle may have reduced annual mileage (Spain UC), it may be more important that CAPEX increases are minimised to achieve the required TCO saving.

The percentage saving estimated at the vehicle-level between BEV baseline and NextETRUCK is also summarised in Table 5. It should be noted that this estimate is not directly equivalent to the 20% target measure described in project KPI-6, as the final KPI will include additional savings from upcoming software developments, savings at the level of infrastructure, and any efficiencies introduced by the project at fleet level. However, the relatively low savings made by like-for-like energy consumption alone demonstrate the importance of considering all systems around electric fleet innovations holistically.

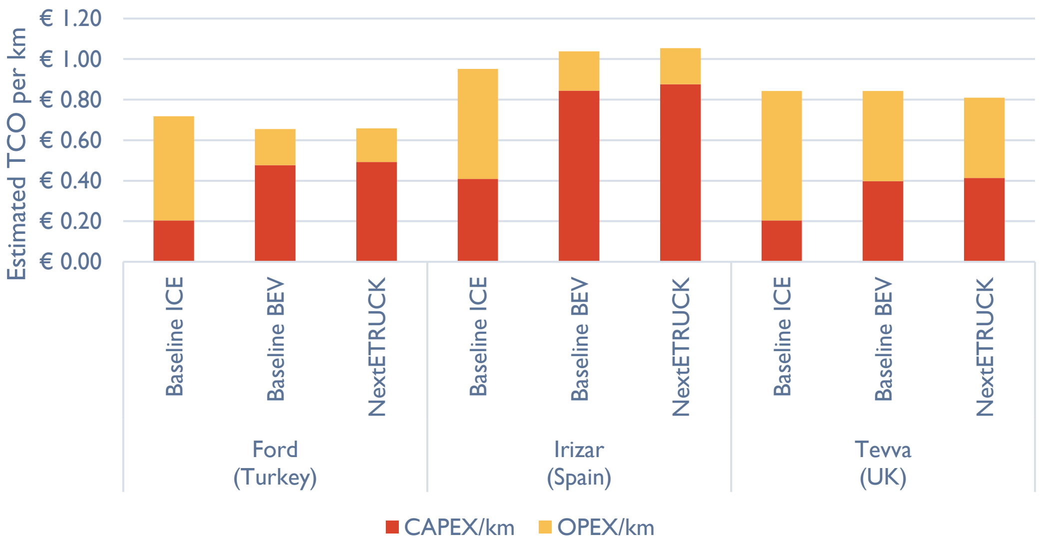


Figure 7: Estimated TCO per km for the Generic 16t Truck Model in each Use Case

Table 5: Relative TCO Saving vs BEV Baseline at Individual Vehicle Level

	Ford (Turkey)	**Irizar (Spain)**	**Tevva (UK)**
BEV % TCO Saving	-0.4%	-1.5%	3.9%

4.2.2 Sensitivity Analysis

As illustrated in Figure 7 in the previous section, the same generic vehicle applied to three different cycles and three different financial situations is estimated to have significantly different levels of cost saving. The relative cost of refuelling the vehicle between local diesel and electricity prices affects the operational savings made by the BEV baseline and NextETRUCK models.

Details of the vehicle mission/operation may affect the energy consumption rate, and so the rate of operational savings, due to distance travelled and/or intensity of duty cycle. The TCO calculation was repeated for each use case duty cycle, varying the number of kilometres travelled within the vehicle's lifetime. A summary of the results is shown in Figure 8, demonstrating that increased mileage of the vehicle can significantly increase the percentage saving relative to the BEV baseline. It should be noted that this calculation does not consider the ability of the vehicle to physically perform increased operations (either due to higher daily distance or increased vehicle lifetime), i.e. the NextETRUCK and the baseline vehicles drive the same distance. However, the relationship between operations and savings is clear, and further explains the relative saving differences the same vehicle would see between each use case.

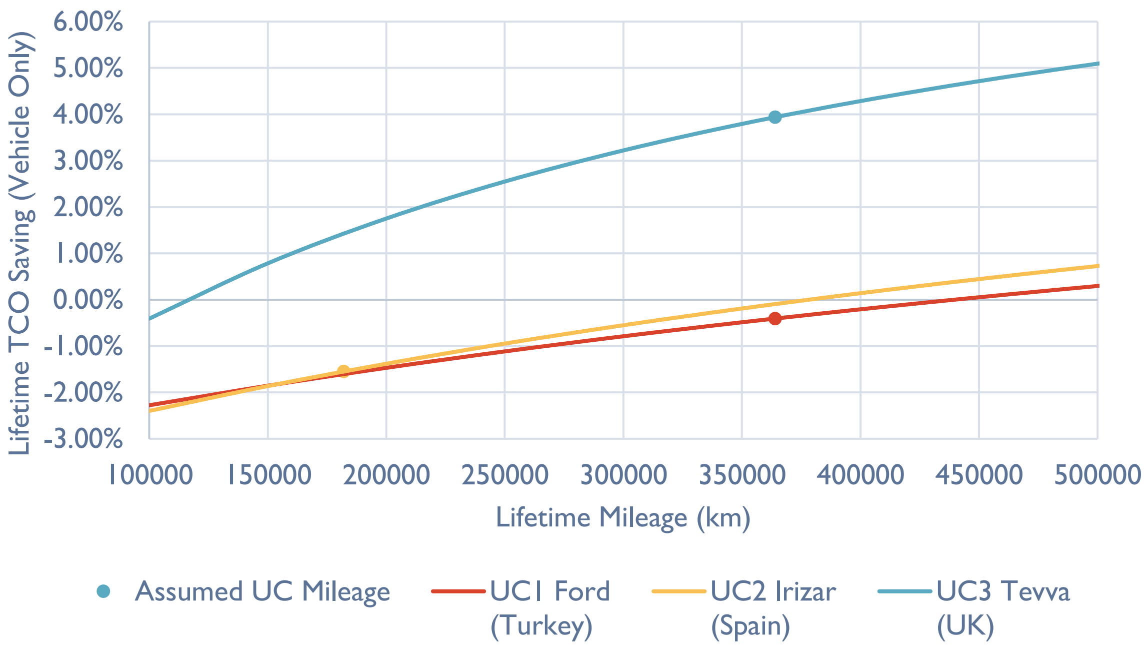


Figure 8: Estimated TCO saving vs BEV Baseline, Variation in each Use Case with varying Vehicle Lifetime Mileage

While the first TCO calculations in this report compare like-for-like generic models for the NextETRUCK and BEV baselines, the sizing of powertrain components within Task 3.1 will be revisited later in the project and will require an estimate of TCO for varying values of the optimization parameters around battery capacity and motor power. Figure 9 and Figure 10 show how TCO saving for each use case varies based on the CAPEX changes associated with varying battery capacity and motor power for the NextETRUCK models, relative to the fixed battery and motor for the BEV baseline. Energy consumption changes to the vehicle due to increasing/decreasing the vehicle weight etc. are not considered in the presented results, as these cannot be calculated until the fully connected FMU simulation is ready.

As both the vehicle battery and drivetrain components make up a large proportion of the BEV capital costs (see Figure 4), varying these factors in the NextETRUCK design gives the potential to significantly increase the TCO saving relative to the BEV baseline vehicle. It is therefore essential to understand to what extent both battery capacity and motor power can be reduced for the NextETRUCK while retaining the required performance characteristics to complete the missions defined for each use case. The full realisation of this task is planned to be implemented with the revisit of the Task 3.1 optimization process by VUB in Work Package 4.

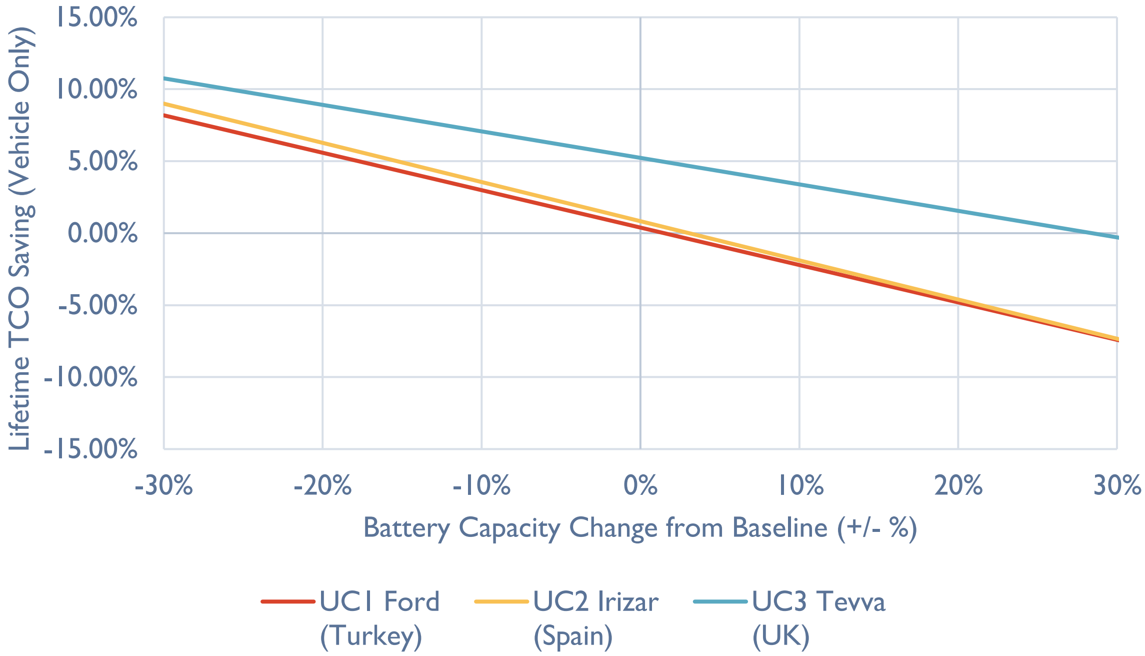


Figure 9: Estimated TCO saving vs BEV Baseline, Variation in Battery Capacity

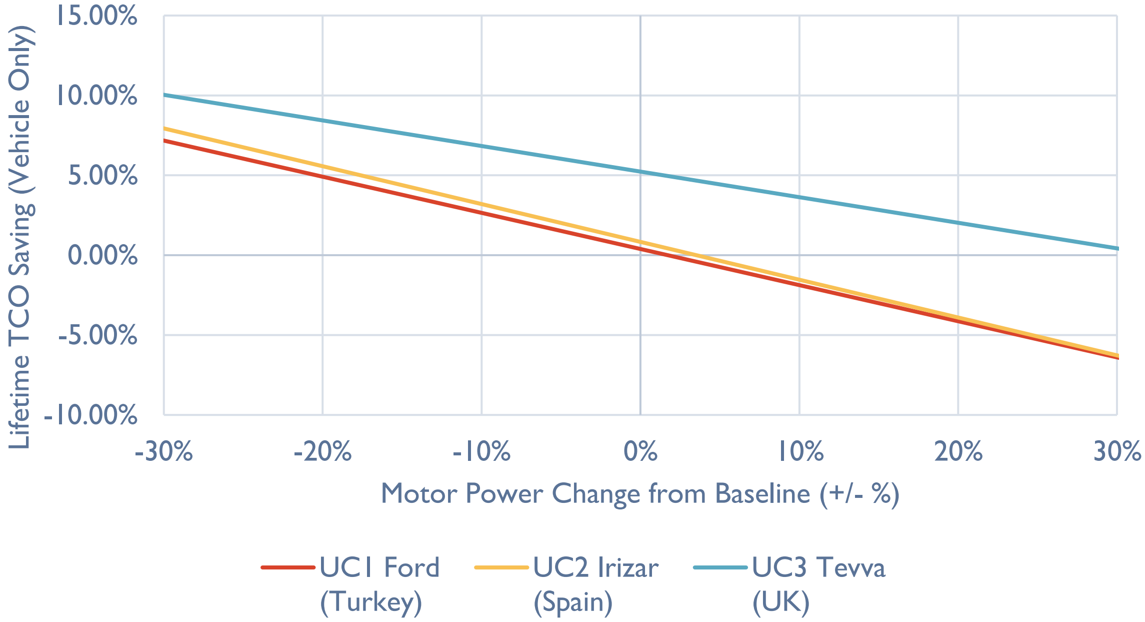


Figure 10: Estimated TCO saving vs BEV Baseline, Variation in Motor Power

In addition to the relationships described above, the TCO calculation at this stage includes assumptions related to the external conditions of the vehicles. A sensitivity analysis was conducted for a reasonable possible range of values that assumed factors could take. Sensitivity factors were varied from the default assumption one at a time, keeping all other factors constant. The results of this analysis are shown in Figure 11. Each bar in the figure represents the deviation in TCO saving made by adjusting only that factor to the low and high assumptions listed in the figure.

The factors with the greatest impact on TCO saving according to this analysis were:

- Energy savings achieved by the NextETRUCK compared to the baseline BEV, highlighting the importance of the project achieving the KPIs related to operational energy savings.
- Electricity price used for vehicle recharge.
- Annual kilometres travelled and ownership, as evidenced above in Figure 8.
- Cost increase associated with NextETRUCK innovation, which will largely depend upon the additional development and supply costs incurred by each of the project's OEMs and the production scale achievable for the NextETRUCK models.

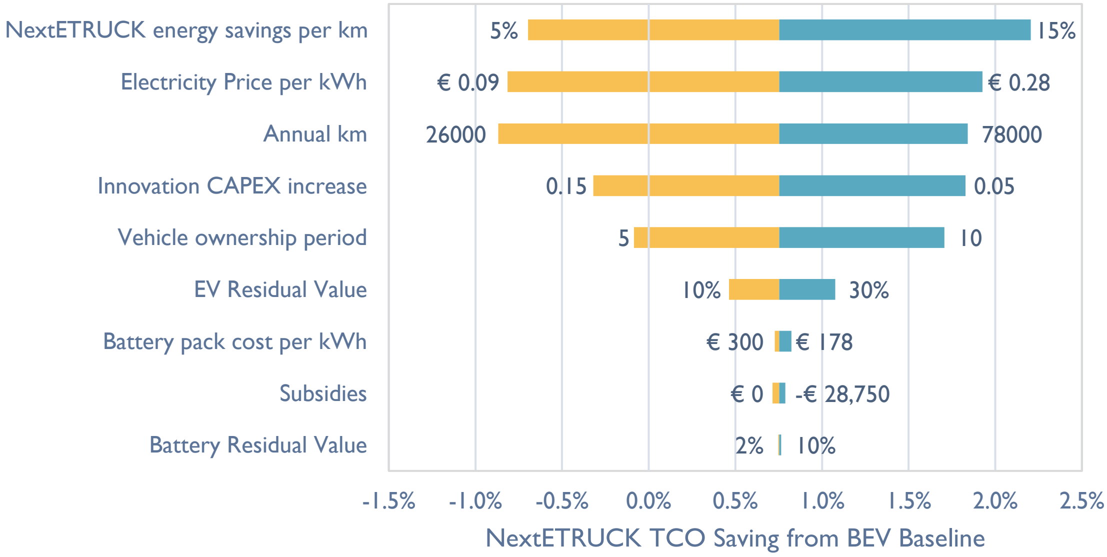


Figure 11: TCO Saving Sensitivity to External Factors

5 CONCLUSION

The first TCO assessment completed within this report demonstrates that the achievable TCO saving varies with several factors between the three planned use cases within the NextETRUCK project, even if considering the same generic vehicle model. Variations in external and operational factors may mean that the TCO saving targets for the project are more achievable in some use cases over others for the project final demonstrator. With the current assumptions, the 20% TCO fleet-level savings target as specified in the project KPIs will rely on additional savings later in the project coming from features to be developed in future Work Packages, such as: eco-routing, charger innovations, fleet-level efficiency improvements etc. Cost parity with ICEV at the fleet level will also depend on the infrastructure costs, which are not accounted for in this work package.

This report forms the first stage of analysis for TCO, focussed on a generic 16t model for the baseline and NextETRUCK vehicles. TCO should form a part of the powertrain and battery sizing optimization process as both components have a strong impact on BEV TCO.

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