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Clean and competitive solutions for all transport modes

GA No. 101084046

Zero Emission flexible vehicle platform with modular powertrains serving the long-haul Freight Eco System

ZEFES - Deliverable report

D2.2. Design optimization tool and right powertrain components' sizing

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Publishable summary

This deliverable reports the outcomes of two tasks in work package 2, specifically, task 2.3 titled '*Co-design optimization framework/tool for modular vehicle powertrain concepts (at vehicle-integration level) for TCO reduction*' and task 2.4 titled *'Right sizing of powertrain components and final design of HD electric trucks for at least 90% payload.'* As shown in Figure 1, the tasks have been performed to fulfil objective 1 - to improve modular heavy duty battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) – by employing the design optimization tool/framework (sub-objective 1.3) in ZEFES project.

In this deliverable, the integration of co-design optimization framework into the web-server simulation platform has been developed to find the right sizing of powertrain components for modular vehicle powertrain concepts. The simulation platform for the entire vehicle model, which is an integration of all powertrain components developed in task T2.2, has been utilized to evaluate vehicle performances, e.g., energy consumption, battery SoC, required for the calculation of cost functions.

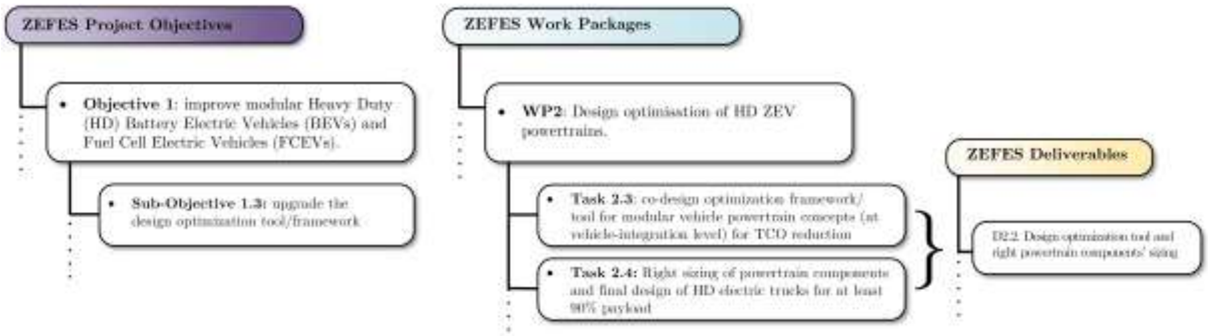

Figure 1. Workflow summary for the realisation of project objective 1 by the implementation of tasks in WP2.

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Abbreviations & Definitions

Abbreviation	Explanation
HDV	Heavy-Duty Vehicle
ZEV	Zero tailpipe Emission Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
ICE	Internal Combustion Engine
OEM	Original Equipment Manufacturer
VECTO	Vehicle Energy Consumption Calculation Tool
GCW	Gross Combination Weight
ZE-HDV	Zero tailpipe Emission Heavy Duty Vehicles
WPL	Work Package Leader within ZEFES project
BE-HDV	Battery Electric Heavy-Duty Vehicle
FCE-HDV	Fuel Cell Electric Heavy-Duty Vehicle
ISO	Interchangeable container as defined in the ISO-Norm 668
SWAP	Interchangeable container accommodating Euro-pallets for road and rail transport
Reefer	Loading unit to transport temperature-controlled cargo
USP	Unique Selling Proposition (uniqueness of ZEFES use cases)
EMS	European Modular System, HDV carrying standardised loading units for intermodal freight transport
T	Tractor unit
R	Rigid unit
ST	Semi-trailer
TR	Trailer
D	Dolly
e-ST	Electric semi-trailer
e-D	Electric dolly
CCS	Combined Charging System
MCS	Megawatt Charging System
HRS	Hydrogen Refuelling Station
vkm	Vehicle kilometers
tkm	Tonne kilometers
DTP	Digital Twin Platform
DT	Digital Twin
	Abbreviations of project partners, see **Acknowledgement** section

1 Introduction

1.1 Project Objectives

Within ZEFES, the zero-emission powertrain is either a Battery Electric Vehicle (BEV) or a Fuel Cell Electric Vehicle (FCEV) located in the prime mover. The zero-emission modular multi-powertrain has a powertrain in each vehicle unit, being BEV or FCEV for the pulling unit and a BEV powertrain in the other vehicle units, e.g., trailer and/or dolly. The advantage is an integrated powertrain for the complete vehicle, having better driving capabilities (safety) and a lower energy consumption.

In the ZEFES project, one of the expected outcomes is the demonstration of high efficiency, long-haul Heavy-Duty Vehicle (HDV) powertrains for truck-trailer combinations, Vehicle Groups 4, 5, 9, 10, 11 or 12 of VECTO, capable of 750 km range (without recharging nor refuelling) whilst operating at a minimum of 40 tons GVW under operational conditions comparable to the VECTO long haul mission profile.

ZEFES uses already highly efficient vehicles from major OEMs (hybrid HDV and ZEV). In ZEFES, these are made even more economical through improvements to many kinds of technical systems. This will make the vehicles 4% to 8% more efficient than today's HD ZEVs. The vehicles will demonstrate that a range of 750 km is feasible, both for BEVs and FCEVs, mainly due to the low energy consumption of the vehicles. The energy consumption of a loaded vehicle is expected to be around 1.17 kWh/km. Table 1 shows the comparison between a baseline ICE vehicle and future theoretical BEVs (combination of prime mover and trailer).

Table 1. Baseline ICE vehicle and future theoretical BEVs (combination of prime mover and trailer).

	Unit	2020 baseline ICE vehicle	2022 BEV 340 km	2022 BEV 750 km range	2026 BEV 750 km range	2026 BEV 550 km range
GCW [a]	kg	40,000	40,000	42,000	42,000	42,000
Battery capacity	kWh	-	540	1191	1096	804
80% usable battery	kWh	-	432	953	877	643
Energy density incl. casing weight	Wh/kg		150	150	190	190
Weight battery pack incl. casing	kg		3,600	7,941	5,787	4,244
Curb weight prime and second movers [b]	kg	17,000	15,600	15,600	15,600	15,600
Delivery load compared to current vehicles	%	100%	90%	80%	90%	96%
Energy consumption [c]	kWh/km		1.27	1.27	1.17	1.17

[a] 40 tonnes as standard vehicle weight, 42 tonnes according to EU2019/1242.

[b] Estimations of weights, assuming the weight reduction of 1400 kg for an electric powertrain.

[c] Estimation based on the current BEVs on the market and a target reduction in ZEFES of 8% for 2026.

Flexible and modular vehicle platform for both BEV and FCEV are made for all long haul, heavy-duty vehicles that use batteries and/or fuel cells. This has obvious benefits in terms of scale and time-to-market for new models. Part of the project is the physical implementation of specific powertrain components, sub-systems, their improved control systems and energy and thermal management systems. The modular driveline used for BEVs will have to be integrated in the FCEV powertrain and adapted for use in heavy duty vehicle combinations. During the project, the optimal configurations of the modular powertrains are determined. This includes the right choice of components and the best strategies for, for example, energy management, helped by the improved co-design tool which will reduce the development time and effort for new vehicles by an estimated 20%, following the expectations of 2Zero. Figure 2 shows the concept of the codesign optimization framework in the explorative design phase to quickly scan the possibilities of new technologies to find the optimal sizing.

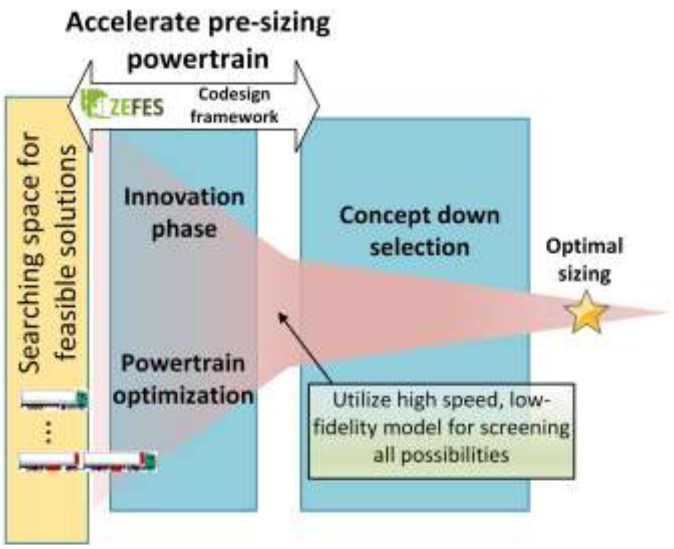


Figure 2. Concept of optimization design tool in pre-design process to scan quickly possibilities of new technologies in powertrain design.

There are six objectives stated in ZEFES as shown in Figure 3. This deliverable is linked to objective 1 that is to improve modular heavy duty BEVs and FCEVs, particularly sub-objective 1.3. The goal within ZEFES is to upgrade the design optimization tool/framework (following the outcomes of previous EU projects, i.e., ORCA, ASSURED, LONGRUN) to make it suitable for HD ZEVs to optimize the vehicle powertrain with right component sizes, considering the interaction with the charging/refuelling and energy infrastructure for long-haul trucks. This framework will consider the modularity and standardization of components to be used in different vehicles or applications, covering the need for price reductions. The tool will help to make the configuration of a vehicle for each mission profile given the VECTO cycle. This is applicable for the composition of components, the sizing of components and the vehicle management systems. The tool will be linked to vehicle models, which means that the characteristics of the real components and vehicles are used. This gives a better representation of reality.

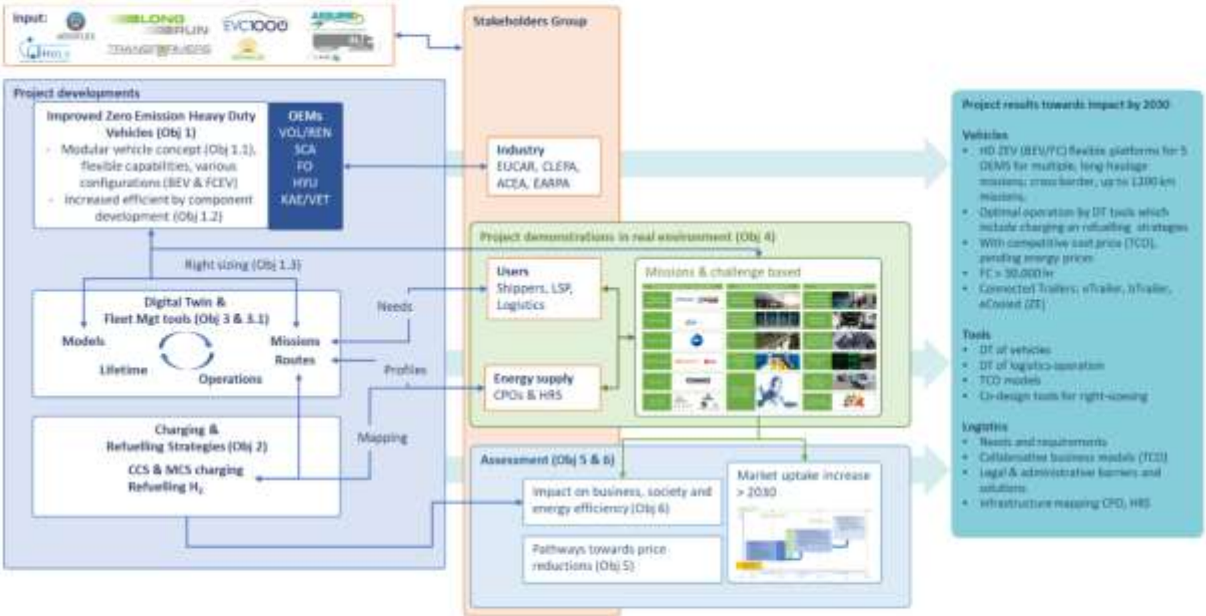


Figure 3. ZEFES overall concept.

1.2 Work Package 2 Methodology

To realize the project objective above, the technical approach of WP2 is utilised specifically (see Figure 4). Task 2.3 is about co-design optimization framework/tool for modular vehicle powertrain concepts (at vehicle integration level) for TCO reduction. The simulation platform for the entire vehicle model, which is an integration of all powertrain components developed in T2.2, will be employed to evaluate vehicle performances, e.g., energy consumption, battery SoC, required for the calculation of cost functions. This task will also properly formulate multiple cost functions, such as TCO, powertrain efficiency, vehicle acceleration and CAPEX, which play an important role in formulating the optimization problem. Design constraints will be selected from vehicle requirements defined in T2.1 to limit the searching space, whereas the optimization algorithm implemented in T2.4 will look for the optimum component sizing.

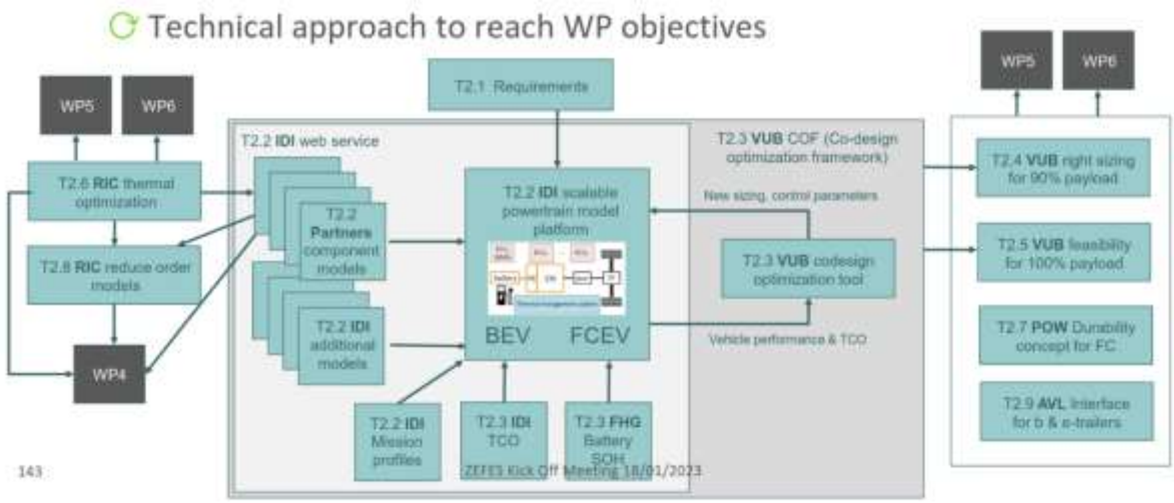


Figure 4. WP2 technical approach.

Task 2.4 aims at the right sizing of powertrain components and final design of HD electric trucks for at least 90% payload. With the COF tool, with linked vehicle models (T2.3), in this task, for each vehicle, the first right sizing of the powertrain components (of the innovations) will be provided, integrating: a. Modular LH BEV systems, b. Modular LH FCHEV systems: sizing optimization and right combinations, c. Powertrain sizing and optimization should also consider constraints from vehicle requirements (acceleration, performance targets, powertrain limits), as the matrix of defined regulatory drive cycles and specific real-world drive conditions (to also cover worst case conditions that will be demonstrated in WP8). In addition to the powertrain optimization, this task will upgrade the optimization framework to design the HW, SW and communication for interoperable MCSs based on SiC technology. It should be noted that the MCS sizing results will be included in deliverable D3.1 in WP3.

1.3 Deliverable Structure

This deliverable reports the outcome of task 2.3 and task 2.4, which is structured as follows.

- Section 1 is the introductory part giving the overall project concept, WP methodology to achieve specifically the stated objectives.
- Section 2 presents the pre-defined driving cycles that are used as the user inputs of the simulation and optimization framework.
- Section 3 explains the codesign optimization framework based on server-client interaction and shows the powertrain sizing results.
- Section 4 presents other in-house software tools developed by RIC, FHG, and VUB.
- Section 5 is the conclusion.

2 Pre-defined Driving Cycles

There are different driving cycles (or vehicle speed profiles) which have been pre-defined to feed into the simulation model.

2.1 VECTO Standardized Driving Cycles

VECTO (Vehicle Energy Consumption Calculation Tool) is a simulation tool developed by the European Commission to estimate the CO2 emissions and fuel consumption of heavy-duty vehicles (HDVs) under various driving conditions. It incorporates different driving cycles, such as regional and long-haul (see Figure 5) to simulate typical operational profiles of these vehicles. The speed [km/h] and slope [%] profile versus time [s] are stored in three different *.txt* files named, for example, *'VECTO_spdLong', 'VECTO_slpLong', and 'VECTO_timeLong'*, which are used for the simulation platform server (see Section 3.2)

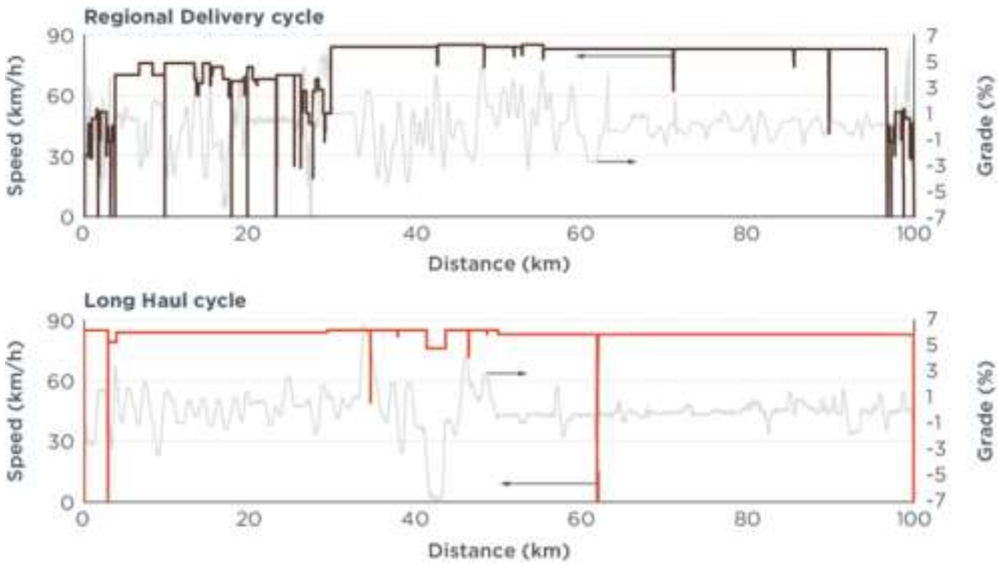


Figure 5. Vehicle driving cycles. (a) VECTO regional delivery, (b) VECTO long haul.

2.2 ZEFES Use-case Defined Driving Cycles

In WP1, 14 use-cases with multimodal rail/road transport and starting/ending points have been defined in D1.2. This deliverable D1.2 shows the shippers and the cross-border logistics missions involved in the ZEFES demonstrations, covering temperature-controlled goods, general cargo, consumer goods, parcel distribution, heavy steel products and finally automotive goods. The Appendix shows all use cases including 9 vehicles operating at maximum GCVW up to 64 tons under real time operational conditions comparable to the VECTO long haul and regional-national mission profiles and meeting the requirement of 750km unrefuelled / 400km un-recharged driving over a period of 15 months, covering 1,000,000 kilometres, representing 30,000 hours operational life. The total length of all use cases represents road use approximately 9,000km.

The speed profiles [km/h] versus time [s] are required to store in the *.txt* file to run simulations (described in Section 3.2). The flowchart in Figure 6 is employed to generate vehicle mission profiles.

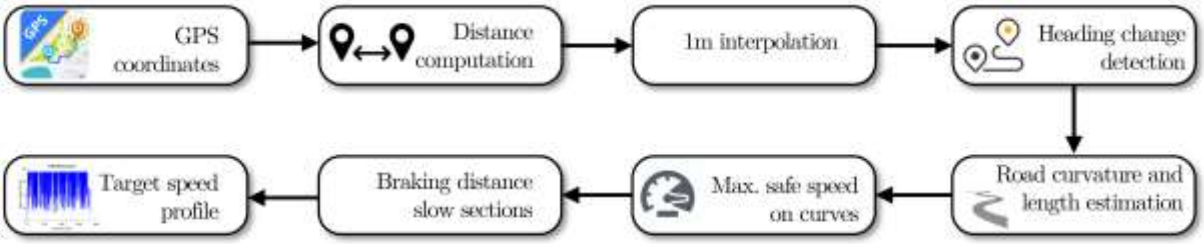


Figure 6. Flowchart for producing the vehicle mission profile of ZEFES use-cases.

Within ZEFES new technologies will be developed to achieve ranges up to 450km for BE-HDVs and up to 750km for FCE-HDVs. Among 14 UCs, some routes with 750 km daily range such as UC7.2.4, UC 7.4.1, UC 7.6.3 have been selected to generate the speed profile.

In the UC 7.2.4 VOLVO – DPD (BEV), VOL will lead the demonstration, make the vehicle combinations (R+eD+eT @ 48 tonnes GCW) available for the logistics provider, collect and hand over all necessary data for the evaluation. DPD will operate the vehicle for 6 months on their daily Rhine-Alpine corridor to transport parcels from Munich area-DE to Eindhoven-NL v.v., trip length of 675km demonstrating the vehicles capability of 750km (see Figure 7).

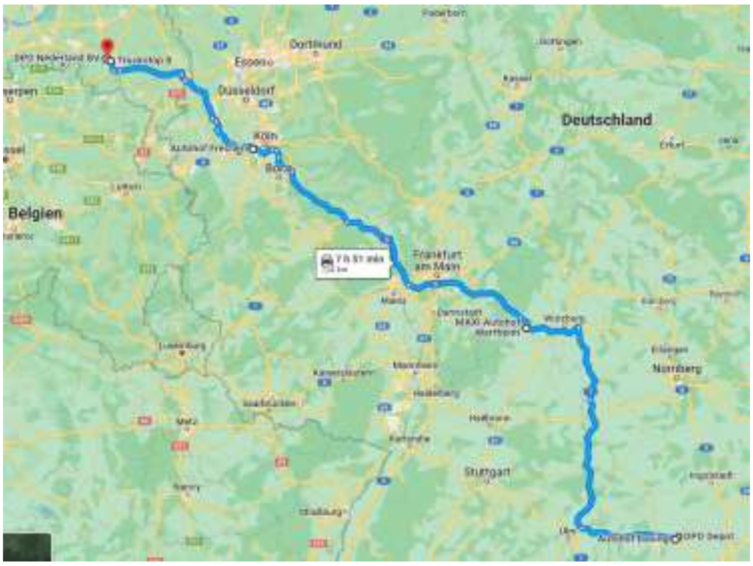
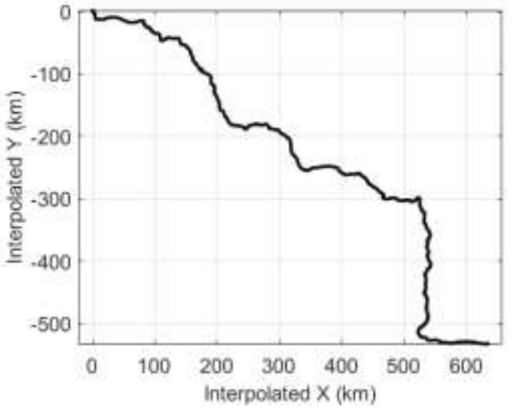
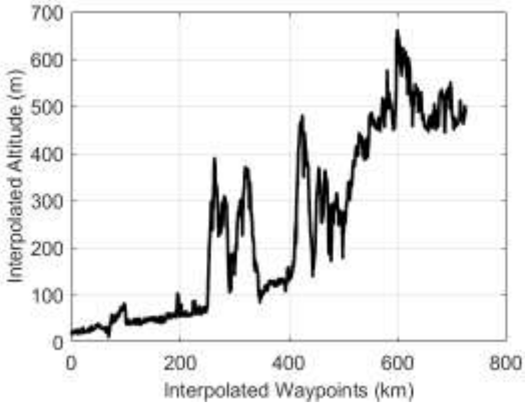


Figure 7. Demonstration route for T7.2.4 VOLVO – DPD (BEV 44-ton 750km daily long-haul cross border).

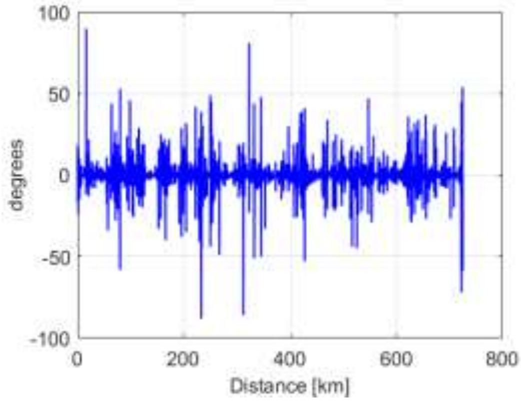
Figure 8 shows the outcomes of mission profile generators including road information such as interpolated map, altitude profile, vehicle behaviour such as steering requirement, and speed profile that will be imported into the online server simulation platform. The Appendix shows the description and generated speed results for UC 7.4.1 and UC 7.6.3.



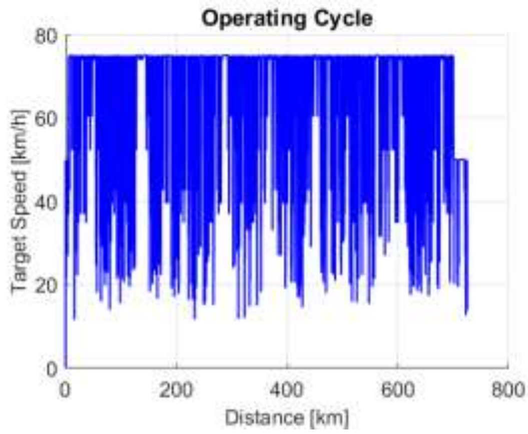
(a)



(b)



(c)



(d)

Figure 8. Road information and speed profile for T7.2.4 VOLVO – DPD (a) route and interpolated map, (b) altitude profile, (c) heading change/steering requirement, (d) speed profile (50km/h max speed constraints in urban area: 6km after starting and 20km before ending).

3 ZEFES Codesign Optimization for Powertrain

3.1 ZEFES Optimisation Framework

3.1.1 Overall Framework based on Server-Client Platform and Optimization Algorithm

As described in Figure 4 and Figure 9, IDI & WP2-partners have been developing the simulation platform which can simulate longitudinal performances and give energy consumption estimations based on simulation for the ZEVs demonstrators considered for this project. Both tools are accessible through an interface hosted in a web server with access granted to project partners and stakeholders making a difference in this project with regards to the accessibility to simulation platforms. This will permit other services to use this platform's results for their calculations in a more accessible way.

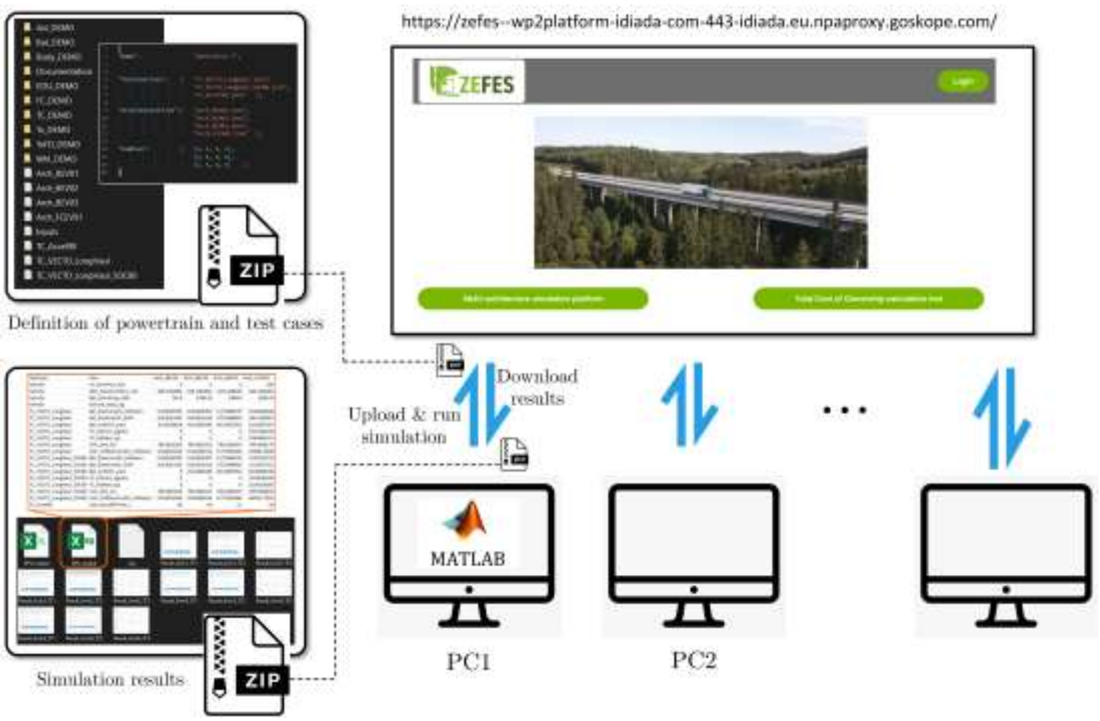


Figure 9. Server-client platform developed for ZEFES.

The simulation platform represents an energy and longitudinal dynamics vehicle model that is governed by physical equations and parametrization of the components in the model. The simulation platform aims to represent the same physical phenomena that can be simulated, and all the possible vehicle and component architectures are already pre-implemented, so that the user or machine that communicates with the platform only needs to choose the parametrization to execute, as this parametrization is the complete definition of all the parametric values that define the dynamics of each component. This difference is a breakthrough in comparison to market software that requires manual actuation for most of the architecture modifications. This breakthrough aims to make a difference in terms of automatic architecture optimization.

The tool is implemented in MATLAB/Simulink and has the possibility to add inclusions of 3rd party detailed models that are integrated as S-Functions. The whole tool is compiled to be executable in the cloud, giving open access of the simulation results to the partners and stakeholders. As this is a platform targeted to very technical profiles and automatic simulations, with hundreds of parameters required for each simulation, the interface with the platform is mainly through text files that specify the parameters of each of the components, thus allowing for easy programmatic access and modification of the parameters that define the vehicle and making it simpler for optimization purposes.

Regarding the platform access, the user will have cloud access via the web app. The access interface requests uploading of a zip file that includes all the parameters that define the desired vehicle together with the environmental conditions, speed profile and all the required parameters and signals that define the test case that the user wants to simulate. Figure 10 shows the codesign implementation incorporated between IDI web-based simulation platform and VUB's sizing optimization loop including different objective functions.

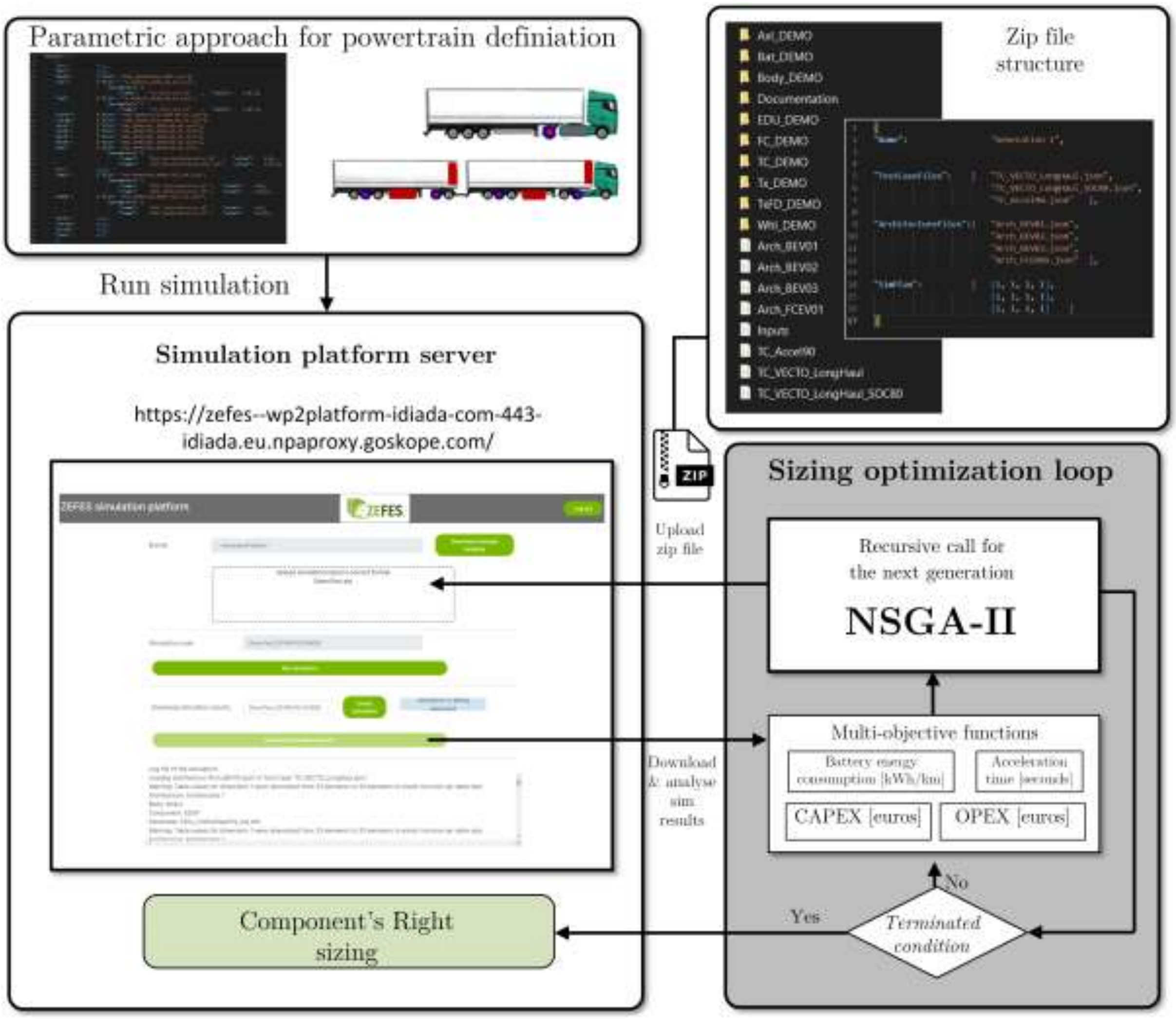


Figure 10. Powertrain optimization flowchart.

The sizing optimization loop employs NSGA-II (Non-dominated Sorting Genetic Algorithm II), which is an effective evolutionary algorithm used for solving multi-objective optimization problems. In the context of NSGA-II, the individuals in a generation are named as '*Arch_BEV01*', 'Arch_BEV02', 'Arch_BEV_n' (n is maximum number of individuals). Each zip file is considered as a generation in the NSGA-II. Due to the nature of uploading a zip file for execution in IDI's platform and downloading the

KPIs output for being post-processed in the next generation, the NSGA-II has to be implemented in the recursive manner. The pseudo code for recursive call using NSGA-II for the sizing optimization loop is shown below.

```
function [finalPopulation, finalObjValues] = nsga2Recursive(initialPopulation, LB, UB, populationSize,
generation)
  if generation == 0
    return initialPopulation and objective values
  else
    1. Generate offspring population
    2. Combine parent and offspring populations
    3. Perform non-dominated sorting
    4. Assign crowding distance to individuals in each front
    5. Perform selection to choose individuals for the next generation
    6. Recursive call for the next generation
    7. Return finalPopulation and finalObjValues
  end
end
```

The function *nsga2Recursive* is defined with parameters for the initial population, lower bounds (*LB*), upper bounds (*UB*), population size, and the number of generations. Parameters include the following.

- *initialPopulation*: The starting set of powertrain configurations.
- *LB* and *UB*: These define the feasible range for each component's sizing within the powertrain, ensuring that the configurations stay within practical limits.
- *populationSize*: The number of solutions (powertrain configurations) maintained across generations. *generation*: The current generation count, which determines when the recursion stops.

3.1.2 TCO Optimization Objective Functions

In the optimization loop, the TCO (total cost of ownership) is considered as the objective function to be minimized. Therefore, the optimization problem formulation is expressed in (eq. 1).

$$\min_{C_{BAT}[kWh], P_{EM}[kW]} \{TCO\} \tag{1}$$

Subject to constraints consisting of vehicle performance requirements.

Vehicle performance requirements	**Value**
Acceleration time 0-50 km/h	≤10 s
Acceleration time 50-80 km/h	≤15 s
Maximum gradeability	≥ 20%
Maximum speed	≥80 km/h
Driving range	≥750km

The TCO model can be formulated in different ways as follows. In this work, the TCO based on Cost per ton cargo model described in sub-section 3.1.2.2 has been selected as the objective function eq. 1 for the optimization loop because this TCO model has taken into account the payload which is a user defined input. As the payload is the function of the gross vehicle weight (see Figure 33 in the appendix A3), the 90% payload requirement will be either used directly as an user input for the TCO calculation or used indirectly to calculate the maximum weight of the powertrain components as the constraints of the optimization loop.

3.1.2.1 TCO based on Resale and Loan Length Financial Model

In ZEFES, a comprehensive formula of the TCO has been developed already in WP1 by IDI and PTV, particularly sub-task ST1.4.2 titled as '*TCO model for HD ZEV integrating operational and external cost*' and reported in the deliverable D2.1 (*Appendix A – TCO formulation*). In this deliverable D2.2, the TCO web-based tool will be also briefly described in sub-section 3.2.3.

The TCO model developed in subtask ST1.4.2 is expressed below.

$$TCO = I + \sum_{i=1}^{N} OPEX_i - P$$	P is the resale value. $$P = (V_p - V_i) * r_r/100$$
	I is the initial investment. $$I = V_p - V_i + T_p$$
	The yearly operation expenses $OPEX_i$ in each year $i = 1, 2, \ldots N$ of the N years of life. $$OPEX_i = X_i + T_o + R + M + I_c + W + L_i$$

Some elements used in OPEX calculation are explained below.

$OPEX_i$	X_i are the expenditures corresponding to recharging in the case of BEVs and to hydrogen in the case of FCEVs: $$X_i = \begin{cases} P_{e,i} * C_e * D, & for\ a\ BEV \\ P_{H2,i} * C_{H2} * D, & for\ a\ FCEV \end{cases}$$
	The ownership taxes depend on time and distance: $$T_o = T_t + T_d * D$$
	Driver wages are based on distance: $$W = W_d * D$$

All symbols and units used in TCO calculations are summarized as follows.

Symbol	Unit	Description
V_p	[€]	Vehicle purchase
V_i	[€]	Vehicle purchase incentives
T_p	[€]	Purchase and registration taxes
r_r	[%]	Resale value in percent
T_o	[€]	Ownership taxes
R	[€]	Road tolls
M	[€]	Maintenance, repairs, and inspections
I_c	[€]	Insurance costs

W	[€/km]	Driver wages
L_i	[€]	Loan interests paid at year i
D	[km]	Yearly mileage
$P_{e,i}$	[€/kWh]	Electricity price in the year i
C_e	[kWh/km]	Electricity consumption
$P_{H2,i}$	[€/kg]	Hydrogen at-the-pump price in the year i
C_{H2}	[kg/km]	Hydrogen consumption
T_t	[€/year]	Time-based taxes
T_d	[€/km]	Distance-based taxes
W_d	[€/km]	Distance-based driver wages

Loan interests are calculated according to the French loan method with constant interest rate. The needed parameters to define the loan are loan size S_l [€], loan length N_l [years] and yearly interest rate r_l. The repayment term is expressed in (eq.2).

$$C_l = S_l * \frac{r_l * (1 + r_l)^{N_l}}{(1 + r_l)^{N_l} - 1} \tag{2}$$

The loan interests $i_{l,i}$ are calculated as a constant interest rate applied to the pending loan amount $P_{l,i}$ (eq.3), the amortized amount $A_{l,i}$ is the difference between the repayment term and the loan interests (eq.4), and the pending amount decreases by the amortized amount with respect to the previous year (eq.5).

$$i_{l,i} = r_l * P_{l,i} \tag{3}$$

$$A_{l,i} = C_l - i_{l,i} \tag{4}$$

$$P_{l,i} = P_{l,i-1} - A_{l,i} \tag{5}$$

In the time of opening the loan ($i = 0$), the pending interests are the loan size $P_{l,0} = S_l$.
In the next year of the loan length and afterwards interests are zero if the loan length is shorter or equal than the life length. Otherwise, in the model used here it is considered that the interests pending after the vehicle life are returned in the last year. Mathematically:

$$L_i = \begin{cases} 0, & N_l \leq N,\ \ i = N_l + 1, \dots, N \\ \sum_{i=N}^{N_l} L_i\,, & N_l > N,\ \ i = N \end{cases} \tag{6}$$

The net present value of the TCO is also calculated:

$$NPV = I + \sum_{i=1}^{N} \left(\frac{OPEX_i}{(1 + r)^i} \right) - \frac{P}{(1 + r)^N} \tag{7}$$

Where r is the yearly inflation rate.

3.1.2.2 TCO based on Cost per Tonne Cargo Model

Another methodology calculating the TCO is based on cost per tonne cargo (per km, indicated as t.km) which is of key importance for the logistics sector. It is a full-cost accounting methodology where all costs (CAPEX and OPEX) incurred by the customers in running their business are accounted. If for a new vehicle this parameter is not competitive with current vehicles, potential customers will not make the decision to buy, to change to a BEV or FCEV.

In this TCO model, the CAPEX includes different costs such as the investment (implicitly refer to powertrain cost), depreciation, duty, tax, interest, and insurance that the owner incurs. These costs may be single events or recurring costs that remain fixed over a period. These costs have been identified per annum. The OPEX costs include the energy costs, maintenance costs, toll fees and all the costs dependent on the utilization of the vehicle and can be distance or period specific.

The TCO based on Cost per Ton Cargo Model is explained in detail in Appendix A3 in this deliverable. The fixed and variable cost elements i.e., investment, maintenance as well as tyres – are vehicle-combination-specific and based on the data from [1]. Taxes and insurance are dependent on the combination, but only on the number of trailers and dollies. By contrast, administration, driver training, driver wages and telematics as well as the electricity/hydrogen prices are constant cost elements for all vehicle combinations. Vehicle insurance is excluded from the analysis as there are still lots of uncertainties regarding insurance premiums for BETs in the EU according to [1]. The final cost calculations are provided on the assumptions of a 5-year ownership term with an annual utilization of 130,000 kms and 90% load utilization in every trip.

3.2 ZEFES Simulation Platform Server

Based on the functional requirements of each component, and the connection among the components connected into the multi-architecture platform, a detailed interface specification has been defined and agreed between WP2 partners. The purpose of the document is to track inputs, outputs, and parameters of each component, to ensure model exchangeability between partners and facilitate the integration of new models into the simulation platform. The parameters required for a complete definition of each of the components are set according to the specifications, and the modular more detailed compiled models developed by FHG, RIC and MICH will need to precisely follow the same specifications regarding outputs, inputs and parameters naming.

3.2.1 Multi-architecture Implementation

The architecture of the truck for the simulation platform consists of a generic model which contains all the available architectures of all requestable components of the modular truck vehicle. This modular truck can have up to 4 different bodies: tractor, first semitruck, dolly and second semitruck. In each of the modular distributions available for the user, different configurations of these can be used and the user can choose which components and bodies will be used for each architecture to simulate.

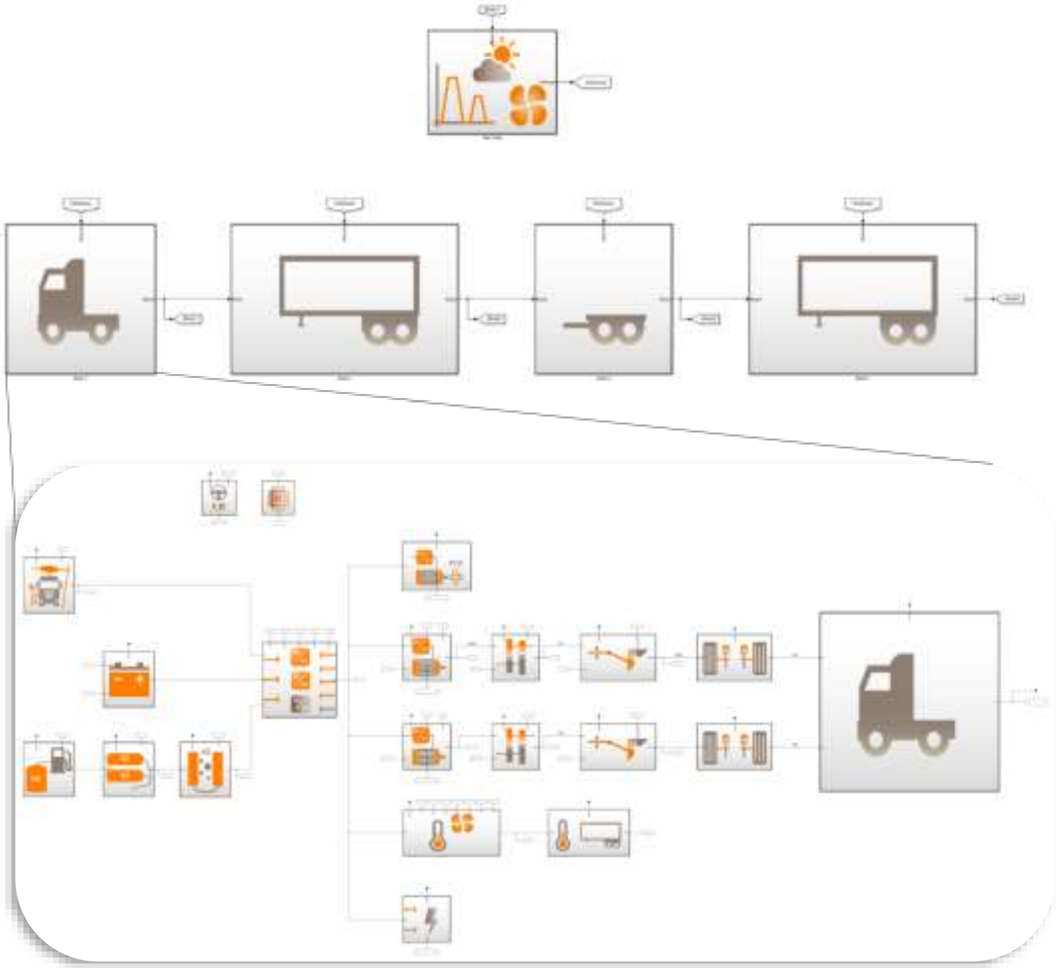


Figure 11. Simulink model of the truck with its subcomponents for each body.

The multi-architecture definition requires two main files that must always be provided: an architecture file and a test case file. On one hand, the architecture file has a structure definition for all the components, and each of the components will be defined with an additional json file, fully defining all the vehicle dynamics. Figure 12 (left) has an example of the architecture definition of a truck with a tractor and semitrailer bodies. On the other hand, the test case file defines all the inputs regarding the cycle to simulate, i.e. environmental characteristics (temperature, humidity, pressure, wind, etc.), speed profile, slope and situational characteristics that changes the architecture for the cycle (for example, simulate a cycle in which the vehicle starts at a specific SoC). Figure 12 (right) has an example of the test case definition.

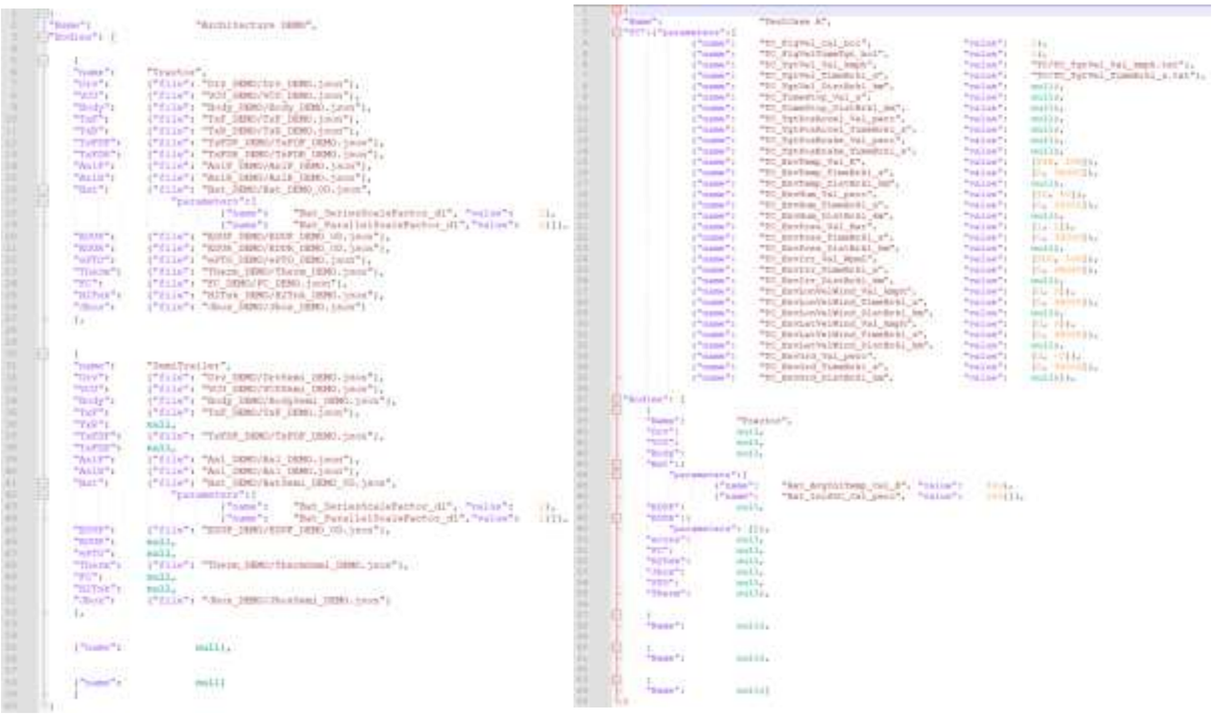


Figure 12. Demo json file for the truck architecture.

3.2.2 Component Variants

Regarding the components' selection, an example can be seen in Figure 13. For each of the components, there is a selector that allows the user to choose either a *null* component (non-existent, will be bypassed or removed), or a component variant available on the body. In the case of the battery, the user has the option to choose the IDI generic model of the battery, or the more precise model given by FHG, and this block distribution will adapt the component to the distribution chosen by the platform user.

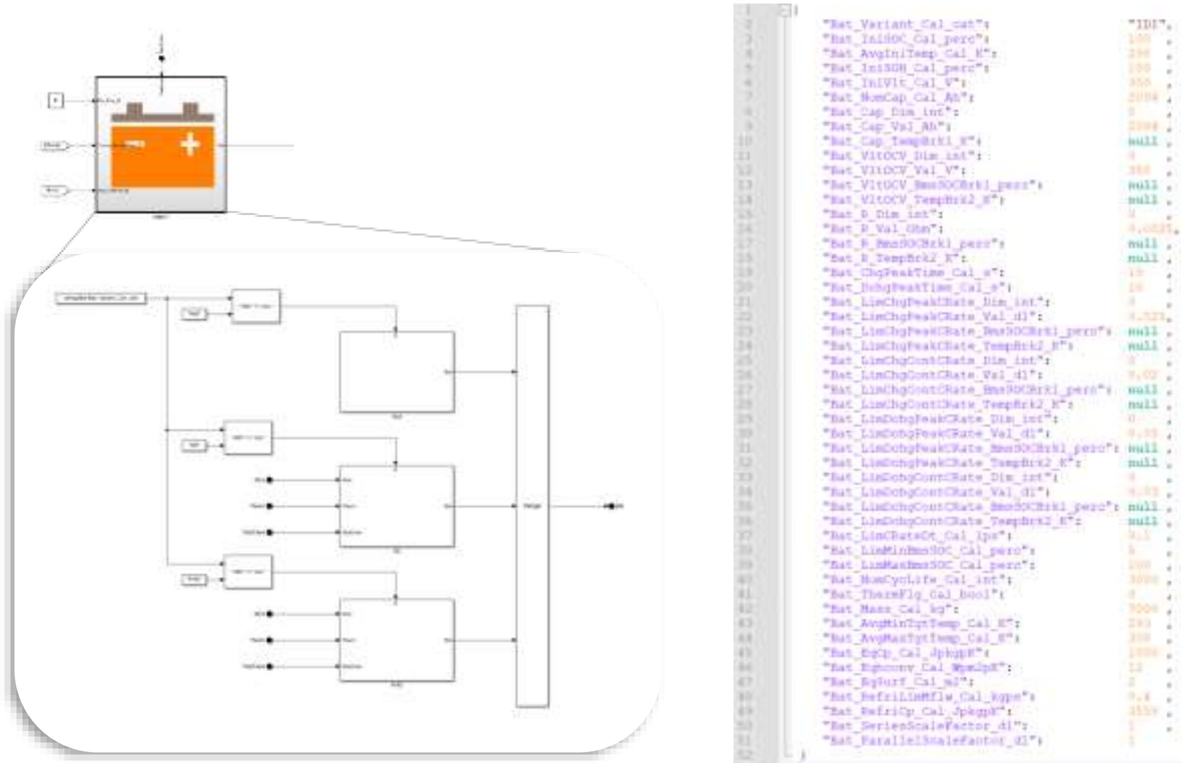


Figure 13. Simulink model of the battery and a json example for an IDI 0D battery definition.

Each of the components in the vehicle architecture is defined in a structured format. Figure 13 shows an example of the component definition of a battery, with a parametric definition of all the characteristics of the desired battery to simulate, in this case using 0D definition on the IDI variant.

3.2.3 TCO Web-based Tool

The TCO calculation website is depicted in Figure 14. This tool was designed to cover the main scenarios that need to be calculated in the project, yet with an understandable and self-explaining interface. This tool is targeted both for expert developers and logistic operators, therefore it was important to make the interface accessible. All the default values defined in the tool represent a reasonable starting point extracted from literature and validated in TCO workshops with OEMs and logistic operators.

The TCO calculation tool is implemented in Python with a user-friendly interface and the formulation is based on a deep literature review to define cost contributions as per state-of-the-art. The cost-contributions were adapted to the ZEFES logistic use-case and validated trough workshops with logistic and OEM stakeholders.

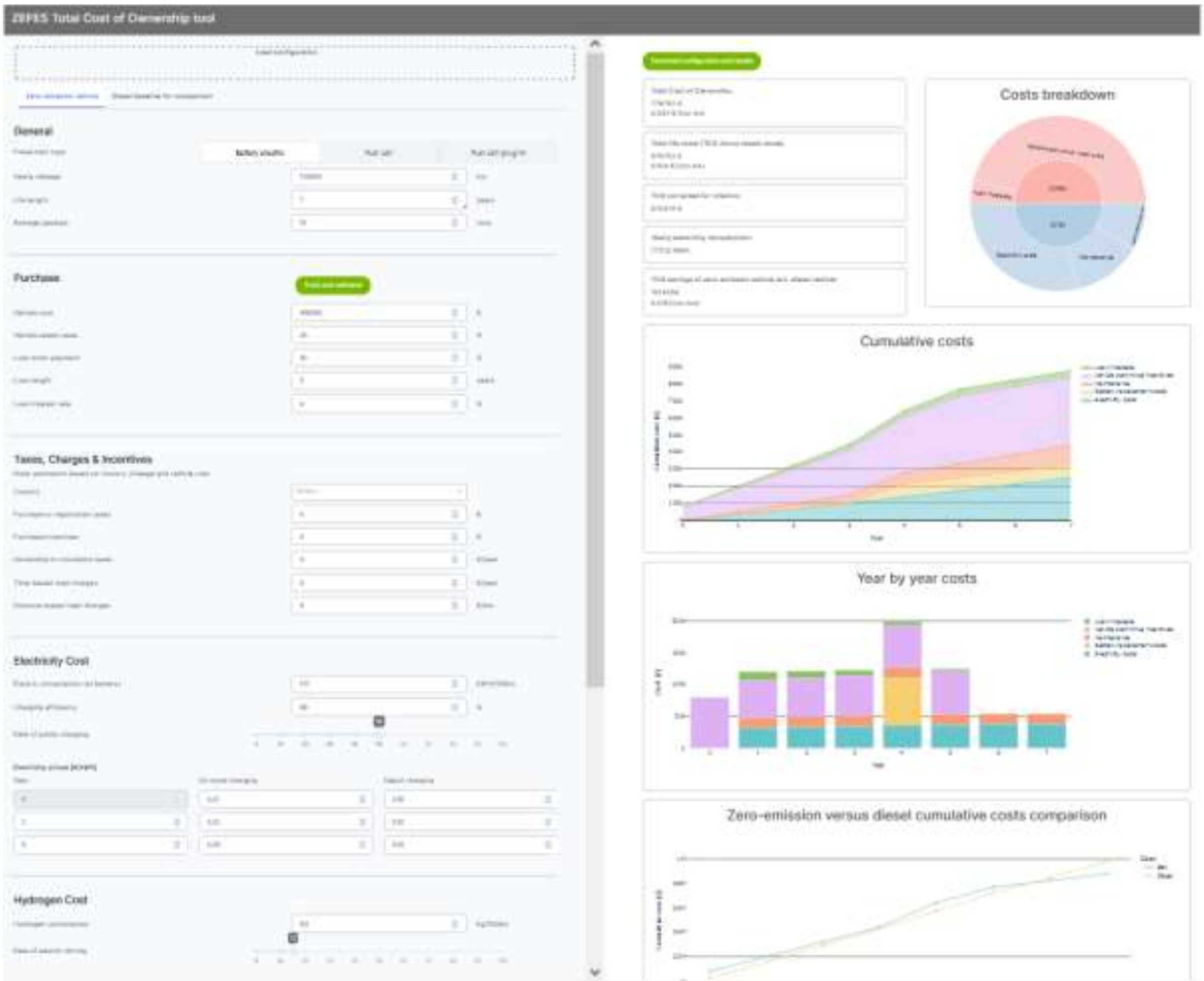


Figure 14. Web page of the TCO tool.

Using this tool, users can specify parameters such as energy prices for electricity and hydrogen, battery replacement costs, purchasing and taxes/incentives considerations among others. The tool can give the results in a visual format via graphic plots, and it will also give tabulated data and values so that the user can have more precise results to use for their purposes.

3.3 Simulation Results

For the validation of the simulation platform, some simulations have been defined following the input interfaces, and simulated. The results are shown in this section along with a description of the output given by the platform and the analysis of the results. For the validation of the platform, three different component combinations have been considered, and three different test cases have been defined for the vehicles to carry out, all of them consisting of repeated VECTO long haul profiles to simulate a standardised real truck logistic operation.

For the vehicles, two BEVs are defined, one with DEMO parametrization of components (BEV1), and another with triple parallel scale factor on batteries (BEV2, which gives triple capacity and triples the current limits). Moreover, a FCEV is defined, which has a doubled parallel scale factor on the battery and the addition of FC and H2Tnk components.

Three test cases are defined, two test cases that request a VECTO long haul speed cycle run on repeated profiles until the cycle reaches around 750km, and an acceleration from 0 to 90km/h for performance simulation. Regarding the long-haul test cases, the first one specifies the batteries to start at 80% SoC. The second long haul cycle is used only for the FCEV and has an initial 13% SoC and a double scale factor for the FC (which doubles its nominal power) and will be used to validate that the split power controller (SPC) works properly on low SoC and ran out H2 situations, in which the vehicle must limit the power requests (traction, thermal and ancillaries) and eventually stop the vehicle.

3.3.1 VECTO Long Haul Cycle for BEV1 and BEV2

The VECTO long haul cycle is set as target for the BEVs architecture, with an initial 80% SoC. The first simulation has as a battery configuration the default DEMO parameter definition, and is done to check the battery limitations and the requirement of a scaling of the components to follow this cycle. The second configuration has a power scaling that allows the vehicle to fulfil the required profile.

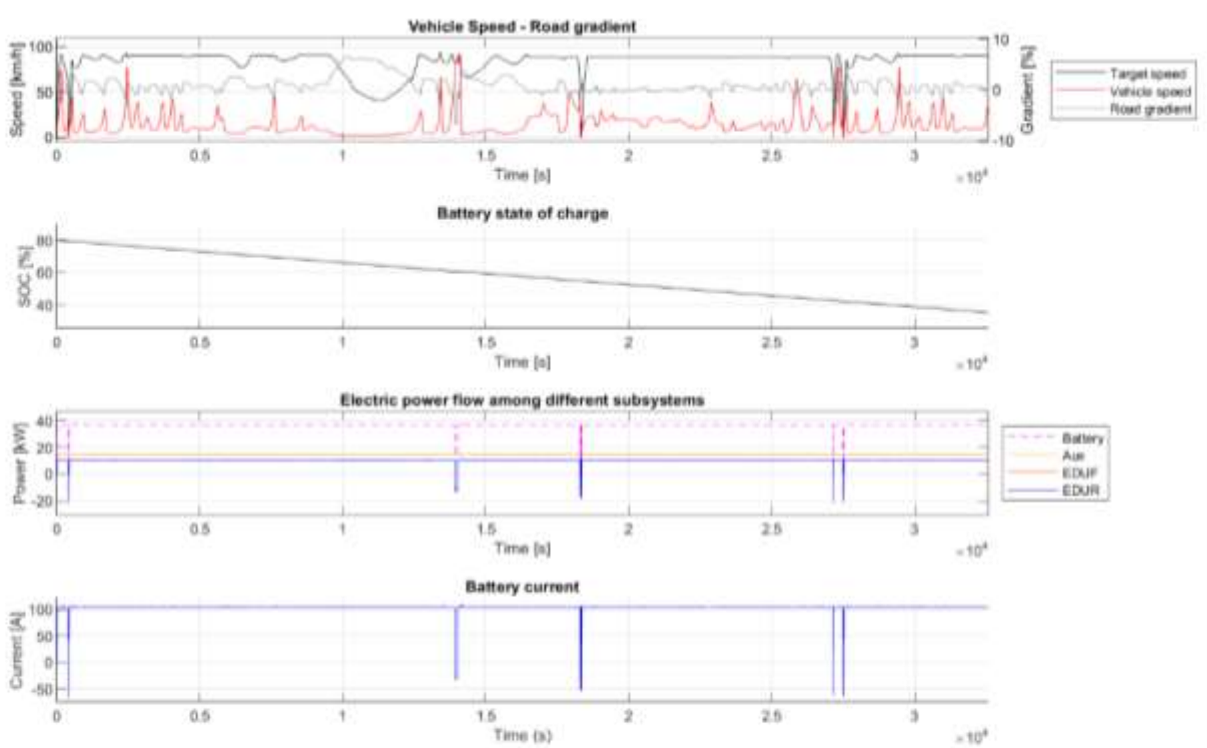


Figure 15. Simulation results for BEV1 architecture (BEV1 initial 80% SOC, VECTO long haul cycle 750km).

As can be seen in Figure 15, the original battery DEMO, used for the BEV1 configuration, has current limitations that do not allow the EDUs to give the required power to follow the specified speed cycle. Thus, the vehicle can not follow the target. Since the target is updated every timestep to keep the simulated trajectory coherent with the cycle, it can be easily seen that the defined profile targets for this simulation cannot be followed on the defined simulation time, and this can be seen as just a slightly bigger distance than an only VECTO long haul can be followed in that time.

The same cycle has been requested to simulate with the BEV2. In this case, having a triple parallel scale factor has also tripled the current limits of the batteries, and thus the available power that can be used to feed the EDUs. As can be seen in Figure 16, with this configuration the cycle can be followed along the 750km of trajectory.

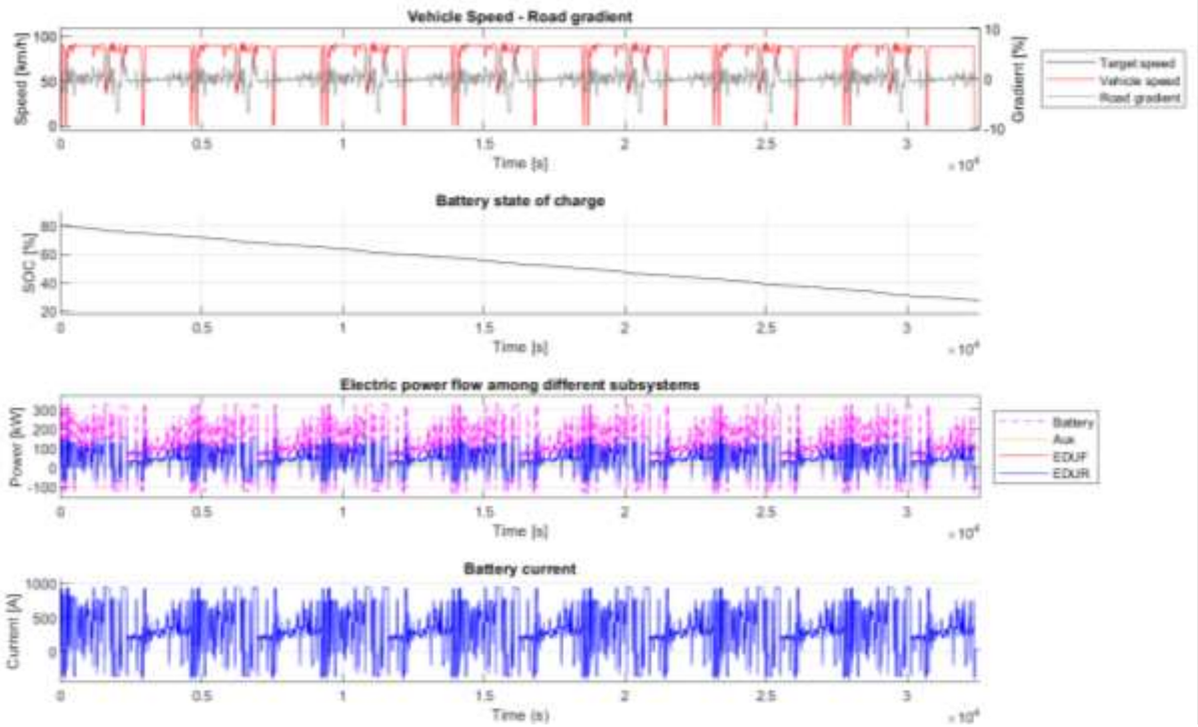


Figure 16. Simulation results for BEV2 architecture (BEV2 initial 80% SOC, VECTO long haul cycle 750km).

3.3.2 VECTO Long Haul Cycle for FCEV

The VECTO long haul cycle is set as target for the FCEV architecture, giving two cases of study: initial 80% battery SoC, and initial 13% battery SoC with a doubled power scale factor for the FC. The low initial SOC simulation is used to validate the SPC performance on limited power and energy availability, and to check that the battery limits are considered for SOH of the battery purposes. Both cases have the default DEMO H_2 tank capacity of 40kg availability (after depressurization considerations).

Regarding the first simulation, with FCEV defined by the default DEMO parameters of all components, it can be observed that the target cannot be followed without scaling the battery to fulfil the power requirements. Despite that, it can also be noted that the vehicle speed is closer to the target with a FCEV thanks to the extra power availability. It can be noted though that after 7.5 hours the H_2 tank drains and there is no more availability of power from the FC, being the battery the only component that gives power and making it more difficult for the vehicle to follow the speed target and not reaching the 750km target.

Also, since the SoC is reduced during the simulation, the equivalent H_2 consumption is over the actual H2 consumption due to the energy given by the battery, which is corrected to equivalent H_2 with the corresponding efficiency considerations.

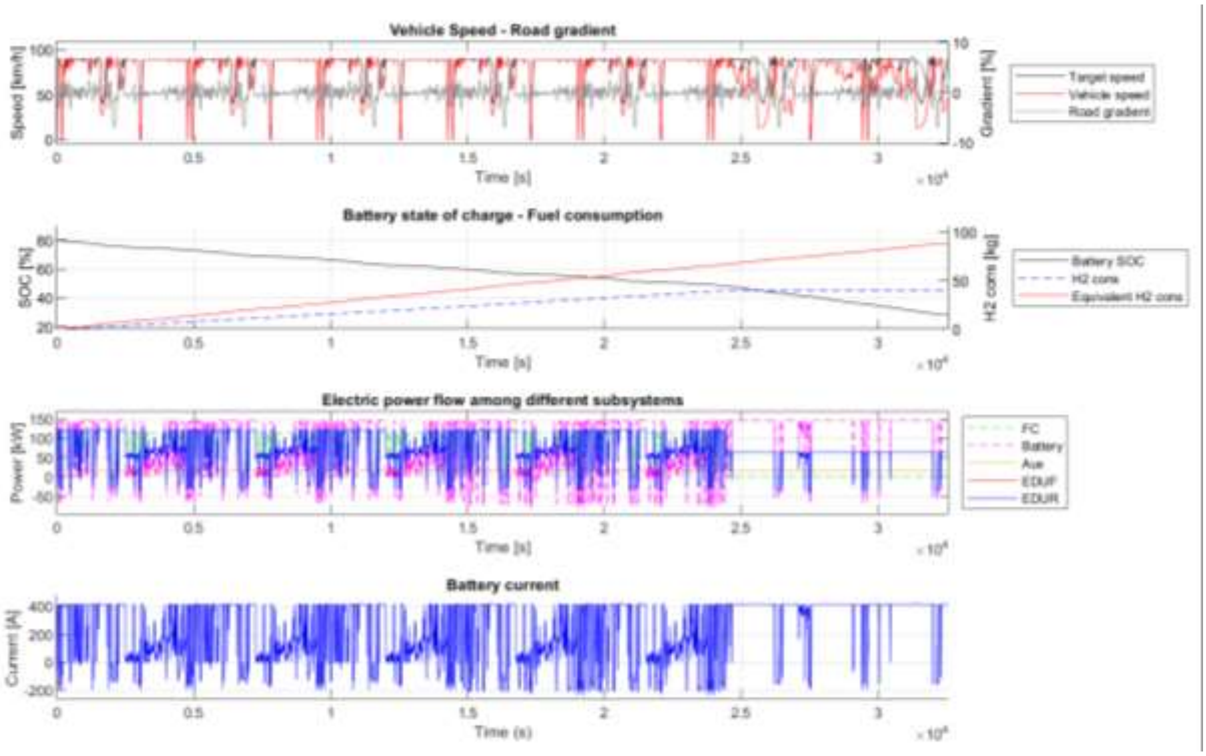
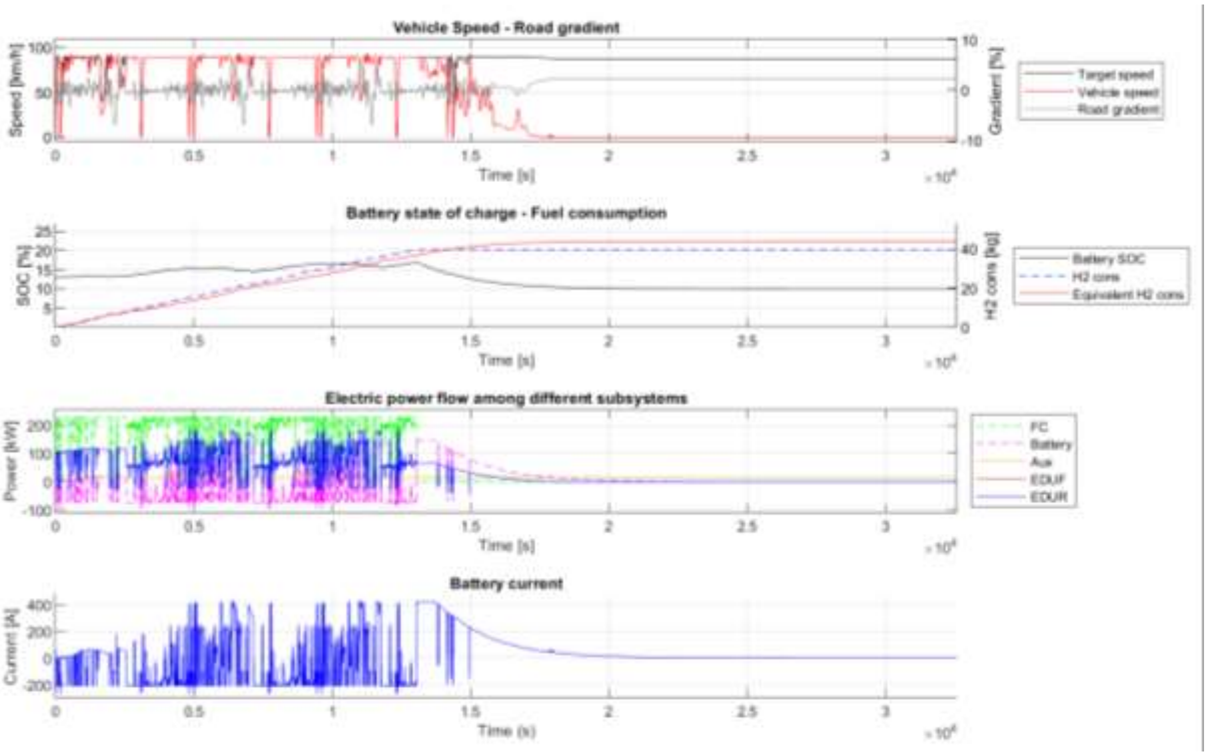


Figure 17. Simulation results for FCEV architecture (initial 80% battery SOC, VECTO long haul cycle 750km).

In the following simulation, several characteristics can be observed regarding the SPC performance and its interaction with FC and battery. The simulation shown in can be divided into 4 different sections.



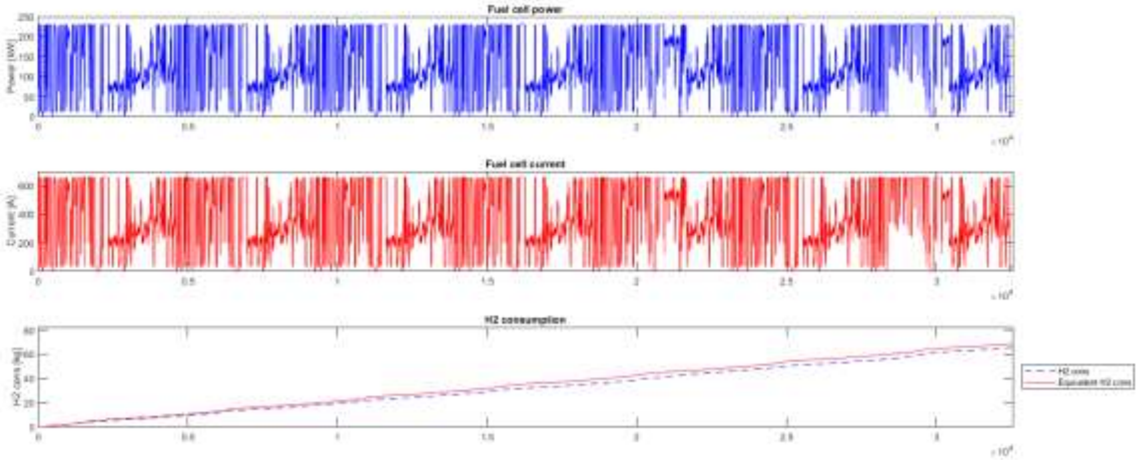


Figure 18. Simulation results for FCEV architecture (initial 13% battery SOC and doubled FC power scale factor, VECTO long haul cycle 750km).

First, the traction limited section can be observed, in which the SoC is under 15% and the SPC logic applied a limitation to the battery to avoid discharging it. During the simulation time goes until around 1 hour 15 minutes, the speed profile cannot be perfectly followed, and the battery current is mostly negative (charging mode), with some punctual positive peaks that are limited inversely proportional to the SoC.

Next, the normal operation mode, which goes until the H2 runs out, at around 4 hours 15 minutes. In this section the SPC also considers the low SoC of the battery and is in charging mode, but it does not apply any traction limitations, discharging the battery if it is needed to supply the power consumers. In this section the SoC keeps rising due to the average power demand being lower than the FC nominal power.

Following, the third mode in which the H2 runs out and there is no availability of power from the FC. In this mode, all the power is given by the battery, and its current limitations make the FCEV not able to follow the target. This section can be distinguished on the power plot in which the maximum power availability from the battery is approximately constant since there is no traction limitation.

Finally, the traction limitation section, in which the SoC goes below 15%, which is the parametric limit defined for the SPC to start limiting the battery power. After traction is limited, other consumers begin to also be limited such as ancillary electric consumers, ePTO, or the thermal system. As defined on the SPC logic, the limitation is applied proportionally to the SoC, giving zero power when 10% SoC is reached.

3.4 Powertrain Sizing At Least 90% Payload

Table 2 shows the comparison in the powertrain sizing between the baseline vehicle and optimized simulation results. The user can set the payload to 90%.

Battery sizes and battery costs also are reduced for the same range. In the baseline vehicle, a battery size would be 1,153 kWh to achieve 750 km range. After running optimization and simulation, this size can be reduced to 956 kWh. This means a battery cost savings of around € 11,000 per truck. For the total number of vehicles with ZEFES technology which will be produced until 2040, this means around € 9 bn savings.

Thanks to the lower energy use, the smaller batteries needed, the higher payload, the right-sizing of batteries, the modularity and up-scaling towards mass production, the TCO will decrease up to 20%, which has a large effect on the transport costs for society.

Table 2. Powertrain sizing comparison between baseline and optimized simulation results.

				UC7.2.2, 7.2.3, 7.3.1, 7.3.3, 7.3.4		UC7.2.3	UC7.3.4	UC7.2.3
EV	Parameter	Unit	Baseline	Without fast char.	With fast charging	e-dolly e-trailer	b-trailer	Cooled e-trailer
	User Defined Input							
	Payload of 44t GCW	kg	20,334	21,370				
BEV								
	Primary bat capacity	kWh	1153	956	540	750	700	700
	Added bat capacity	kWh	-	-	-	200	250	400
	Primary EDU power	kW	600	628.73	610	500	650	700
	Added EDU power	kW	-	-	-	100	-	-
	Gear ratio (5:1)	-	-	-	-	-	-	-
	Final drive ratio (2:1)	-	-	-	-	-	-	-
	KPIs							
	Battery energy use	kWh/km	1.27	1.17	1.16	1.17	1.17	1.17
	Powertrain efficiency	%	-	82	82	82	82	82
	TCO	€/tonne.km	0.0266	0.0213	0.0214	0.021	0.0213	0.0215
	ΔTCO effect	**%**	**-**	**-20**	**-20**	**-20**	**-20**	**-20**
				UC7.3.2, 7.3.3, 7.6.1, 7.6.2, 7.6.3				UC7.3.2, 7.3.3
FCEV		Unit	Baseline	Without fast char.	With fast charging	e-dolly e-trailer	b-trailer	Cooled e-trailer
	Primary bat capacity	kWh	300	300	200	-	-	250
	Added bat capacity	kWh	-	-	-	-	-	72
	Primary EDU power	kW	600	628.73	-	-	-	450
	Added EDU power	kW	-	-	-	-	-	100
	FC power	kW	250	220	220	-	-	220
	H2 tank mass	kg	32	57	32	-	-	45
	Gear ratio (5:1)	-	-	-	-	-	-	-
	Final drive ratio (2:1)	-	-	-	-	-	-	-
	KPIs							
	Battery energy use	kWh/km	0.88	0.56	-	-	-	-
	FC H2 use	kg/100km	10	9	-	-	-	-
	Powertrain efficiency	%	-	44	-	-	-	-
	TCO	€/ton.km	0.5	0.4	-	-	-	-
	ΔTCO effect	**%**	**-**	**-20**	-	-	-	-

4 Other Software for Pre-sizing Powertrain Optimisation

Along with the optimization framework incorporated with the web-based tool developed by IDI as described in Section 3, there are also different standalone softwares, namely AIM, IVI, and EPOWERS which were developed in-house by RIC, FHG, and VUB, respectively. The targeted features of the design tools are described below.

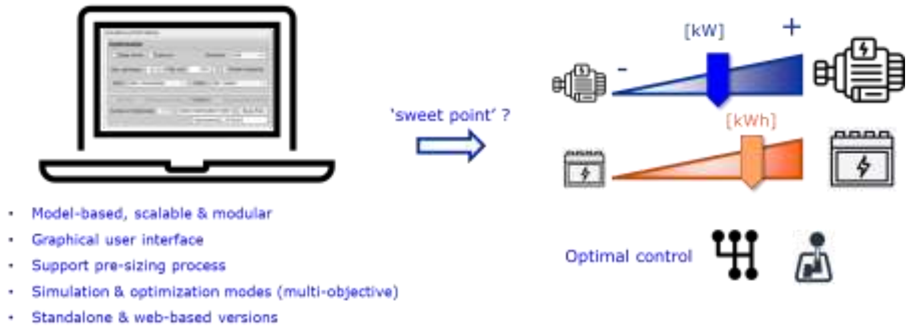


Figure 19. Main features of software for pre-sizing powertrain components.

- Fast screening of architecture solutions – start in the right place and objectively demonstrate a competitive edge and insight with comprehensive preliminary analysis.
- Objectively investigate attribute tradeoffs quickly – e.g. performance versus cost.
- Evaluate "headroom" in current configurations' performance and attributes against the best potential – quantify strategic advantages and limitations.
- Map technology capability walks to future configurations and how they will compare to current performance.
- Build, configure, and customize libraries of modular sub-systems to quickly establish optimal powertrain families.

4.1 RIC AIM App

Addressing the challenges associated with large-scale vehicle simulation and optimization tasks for component right sizing and energy management, Ricardo (RIC) developed the AIM (Architecture Independent Modelling) toolchain. This report outlines the achievements and enhanced features of the AIM toolchain, focusing on its application in the design optimization of flexible and modular powertrains for BEV and FCEV used in long-haul applications. The AIM methodology for architecture definition based on systems engineering approach is shown in Figure 20 [2].

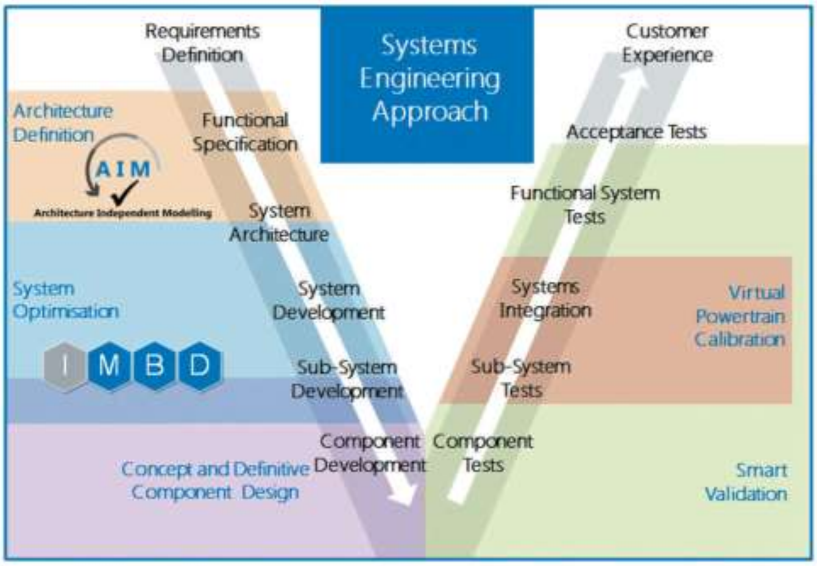


Figure 20. Architecture independent modelling (AIM) methodology for architecture definition.

To meet the specific requirements of long-haul vehicle models generated by project partners, RIC enhanced the AIM toolchain. Notably, these enhancements significantly reduced computational costs, both in terms of time and monetary expenses. The methodology leverages the compilation of vehicle models in MATLAB/Simulink, presenting several advantages as below and its benefits shown in Figure 21.

- License Optimization: Licenses are only required during the model preparation phase, reducing licensing costs. Once compiled, the models demonstrate improved running speeds.
- Cloud Distribution: By eliminating the need for a license check for each simulation, the AIM toolchain enables scalable cloud distribution. This reduces overall task durations and costs associated with large-scale simulations.

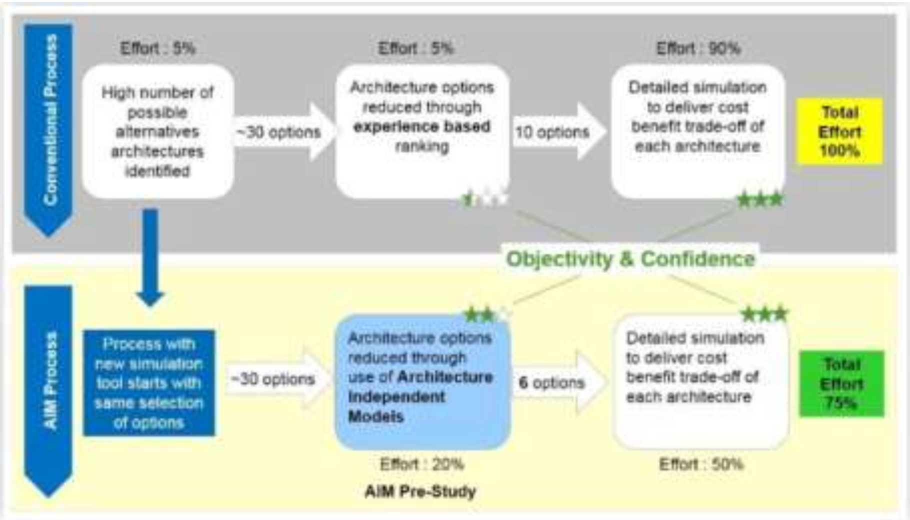


Figure 21. AIM benefits.

For effective component down selection and right sizing, numerous vehicle simulations are required with minimal time and cost overhead. The AIM toolchain achieves this by compiling simulation models before tasks, allowing for faster execution, and removing the need for licenses after compilation. The toolchain is designed to operate on Linux, eliminating the need for operating system licenses or fees. The approach involves several phases.

- Simulink model preparation: Following identified rules ensures the Simulink model can be compiled and accept modified parameter values without additional effort.
- Simulink model compilation: Utilizing RSim and GRT targets in MATLAB/Simulink, the toolchain offers flexibility with advantages and trade-offs for each target.
- Adapting Python scripts: A Python wrapper facilitates parameter modifications, simulation launching, and results reading, requiring minimal adaptation.
- Running models in container: Linux containers with Python installations are employed for GRT and RSim-compiled Simulink models, eliminating the need for a MATLAB license.
- Running DOE/optimization task in parallel compute environment (see Figure 22): Containers are configured to run in parallel compute environments, leveraging cloud computing services.
- The compiled models were rigorously tested for accuracy and CPU time efficiency. Results from both GRT and RSim-compiled models in Linux containers with Python wrappers matched those obtained from native Simulink models, demonstrating accuracy. Additionally, CPU time for simulating compiled models was approximately 10 times shorter than simulating reference models in Simulink, showcasing significant time efficiency.

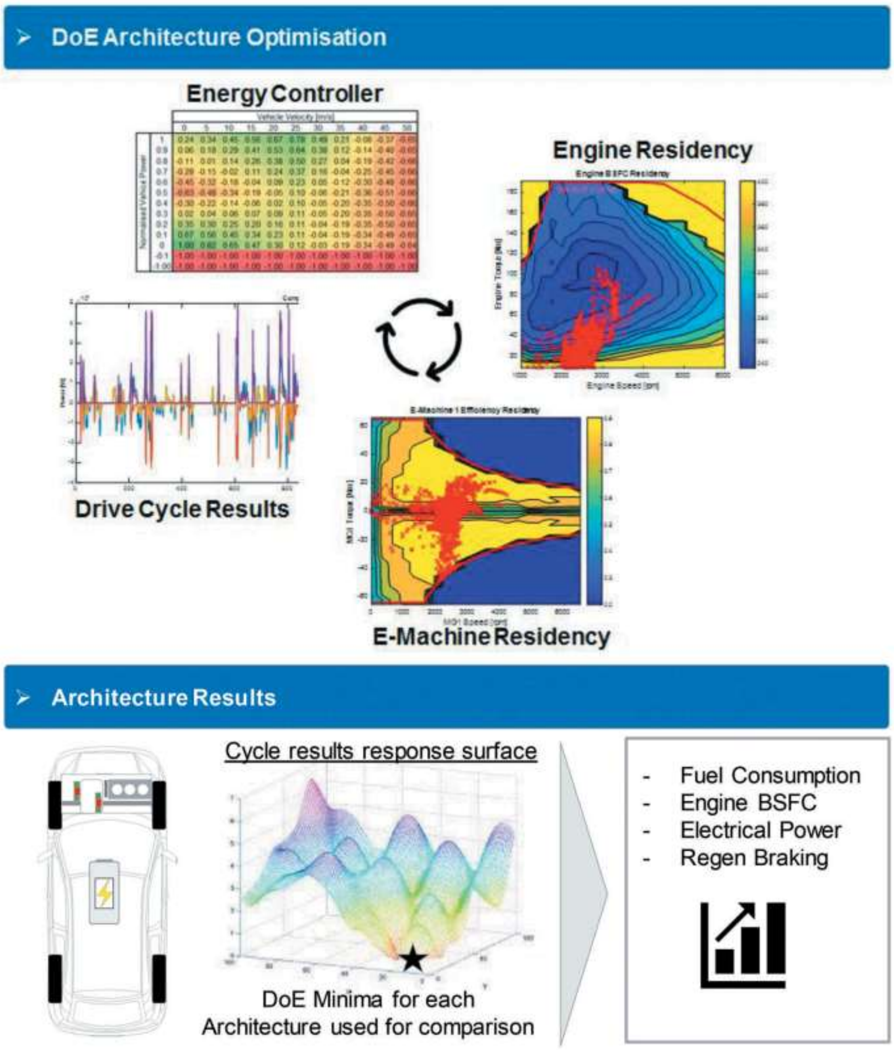


Figure 22. Illustrative AIM process flow.

4.2 FHG IVI App

Fraunhofer (FHG) has developed in-house software called IVI*sion* which is a MATLAB©/Simulink based software tool with a widely universal vehicle model for longitudinal dynamic simulation of different vehicle and powertrain configurations. This simulation takes part in the core element of the tool: IVI*drive*, which is shown in Figure 23 as part of the overall structure of the tool. Most of the components are using characteristic maps which are imported and edited in the IVI*map* module. This also allows component creation by automated scaling. Other relevant inputs for the simulation can be provided by a data processing module, a module which can process real world data like GPS and CAN signals, collected on specific trips, to use this as a scenario or reference for the simulation. Simulation results will be presented in a wide range of configurable plots and tables, which are part of IVI*plot*.

In general, IVI*sion* has been developed to compare and optimise different powertrain configurations as well as auxiliaries and comprehensive operation strategies. Last mentioned especially for the evaluation of the impact on driving dynamics, energy demand and driving range. The results can also be investigated regarding the lifetime of critical components like batteries or fuel cells. Finally, the tool takes recharging along the route into account which makes multiple day operation possible as well as analysis and optimisation of recharge strategies.

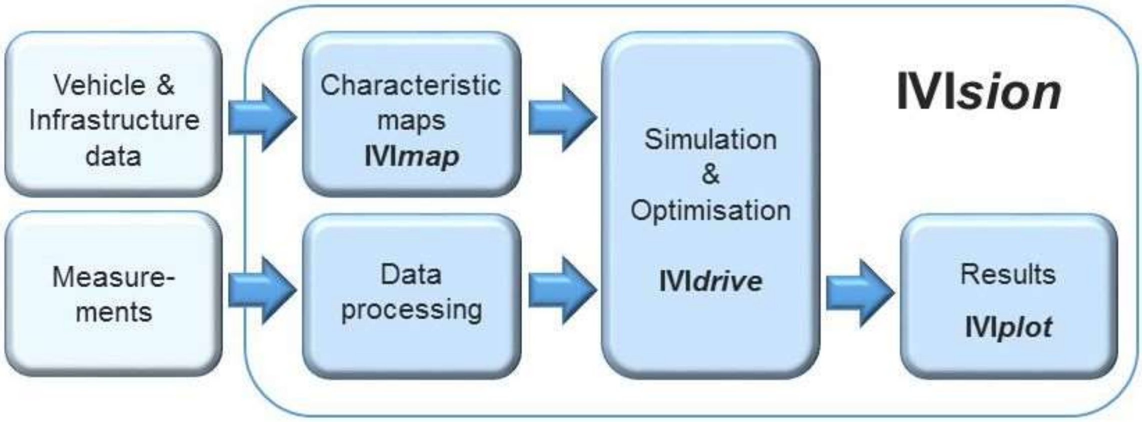


Figure 23. Principal structure of IVIsion.

The IVIsion comes along with a wide range of preconfigured and prepared powertrain system structures, even for extra-long vehicles. The pre-configured powertrain systems are conventional, series and parallel hybrid, pure electric with batteries, super capacitors or fuel cells as well as in depot charging, opportunity charging or trolley bus configuration. Figure 24 Figure 25 show the examples of powertrains included, whereas the combination of letters and signs describes the configuration.

- “E” → electric powertrain
- “xx”→ free axle
- “ed” → electric motor with transmission to the wheel
- “-“ → hinge without vertical force
- “+” → hinge with vertical force

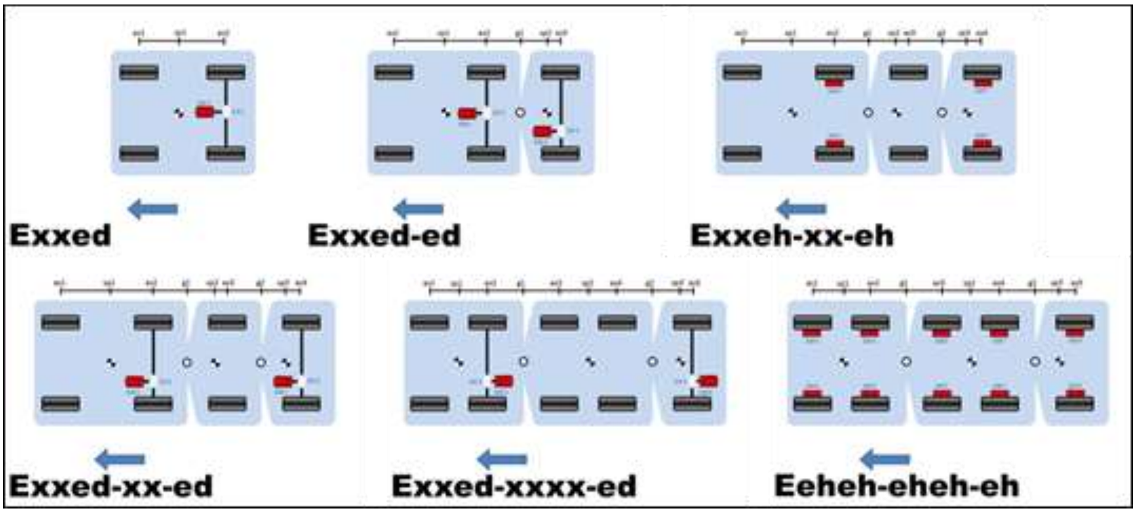


Figure 24. Examples for electric powertrain configurations.

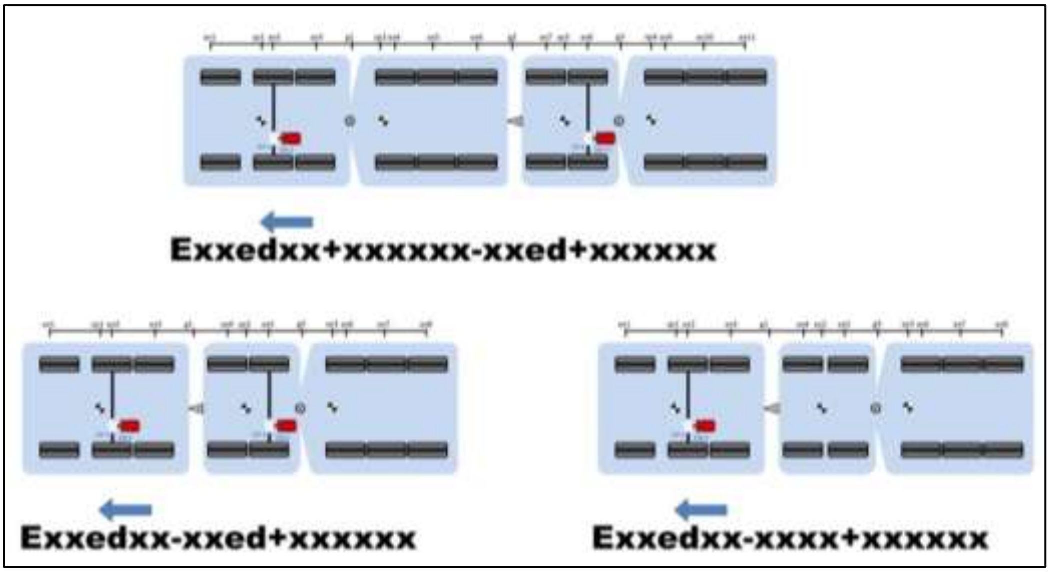


Figure 25. Examples for extra-long electric vehicle combinations.

The tool comes with a comprehensive GUI. The user can set up the vehicle configuration by selecting parameters of drop-down menus as shown in Figure 26.

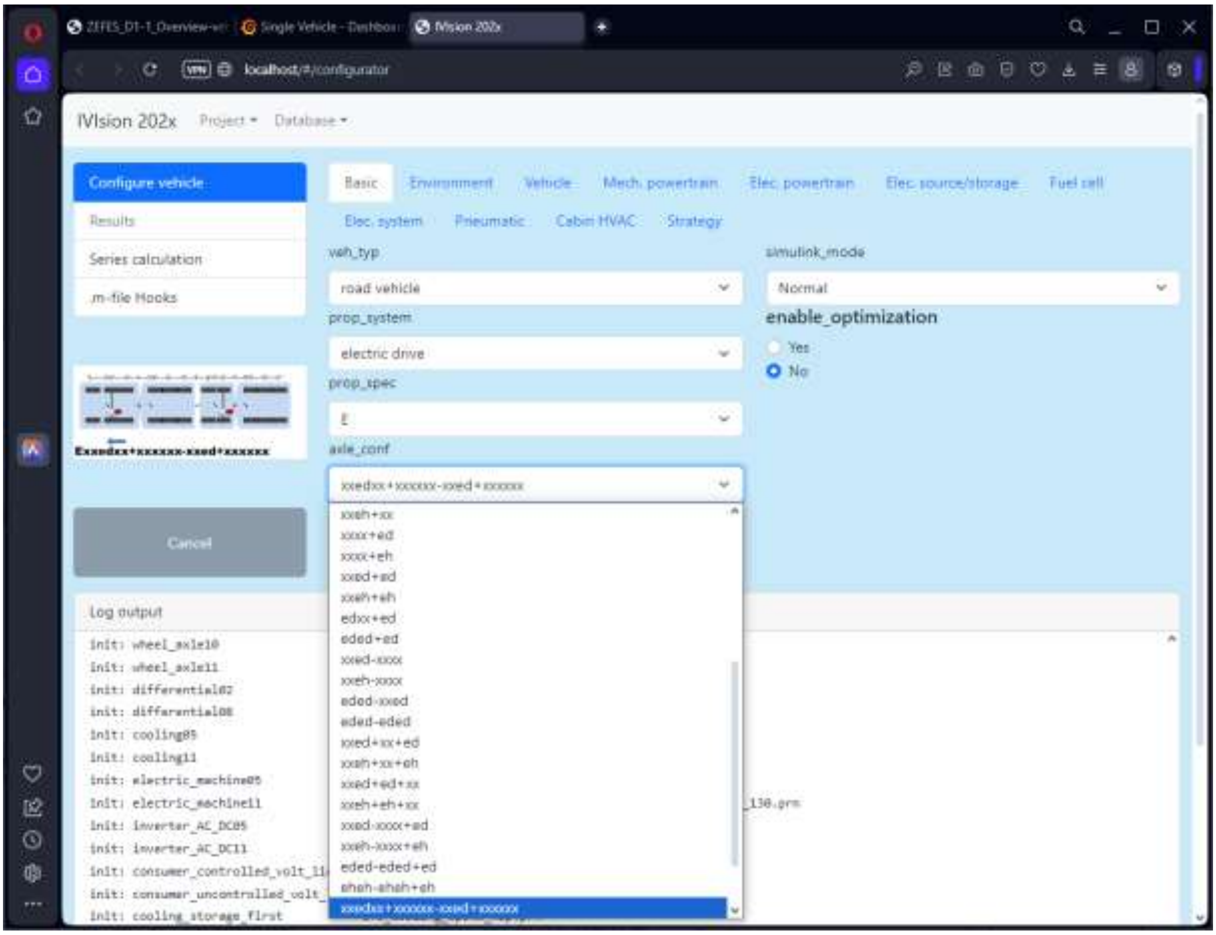


Figure 26. User interface for vehicle configuration.

Furthermore, the selected vehicle configuration can be parameterised with a wide range of parameters for all relevant vehicle components (see Figure 27). An extensive database with various parameter sets and characteristic maps is available for this purpose.

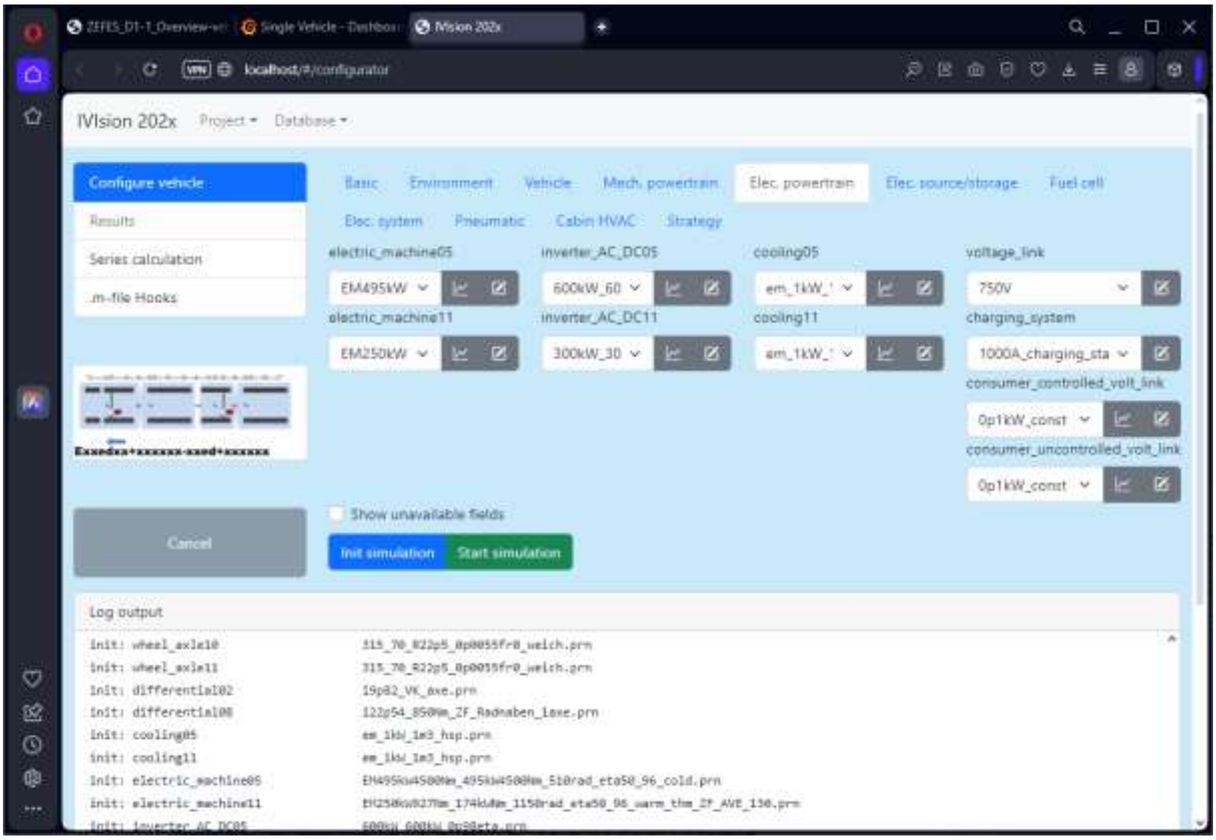


Figure 27. User interface for vehicle configuration.

To find an optimal configuration for the specific purpose it is possible to automate the simulation. One option is to use pre-configured parameter sets, e.g., via Excel files and the other one is to use an interface to optimisation routines, where the next parameter set is created based on the simulation results. Figure 28 shows these two processes in a generic way.

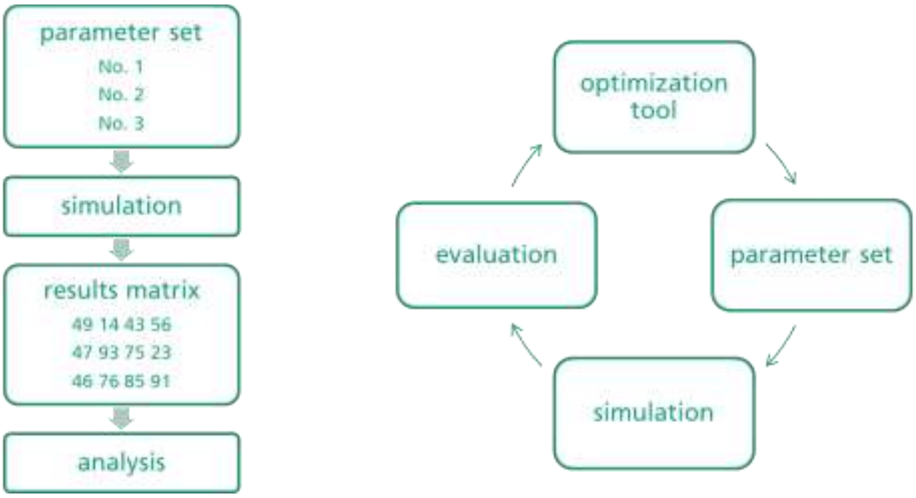


Figure 28. Optimisation loop with automated simulations.

In context of ZEFES, the idea is to simulate the extra-long project demonstrator vehicles in different configurations to evaluate possible component configurations on the one hand and compare it to the real-world driving vehicles in a later project phase.

4.3 VUB EPOWERS App

VUB has developed a software called EPOWERS (**E**lectrified **POWER**train **S**earching). A concise standalone user interface enables users to perform an early screening of the potential, huge design space for an electrified powertrain system that meet a target drive cycle. The EPOWERS App system quickly reviews tens to hundreds of thousands of powertrain combinations against cost, mass, range and efficiency, across different pre-defined driving cycles. Through the analysis, it can objectively pinpoint a highly targeted subset of powertrain configurations that best align with customer requirements. Figure 29 shows the design methodology of the EPOWERS app based on co-design optimization considering the optimal controller is nested inside the sizing optimization loop.

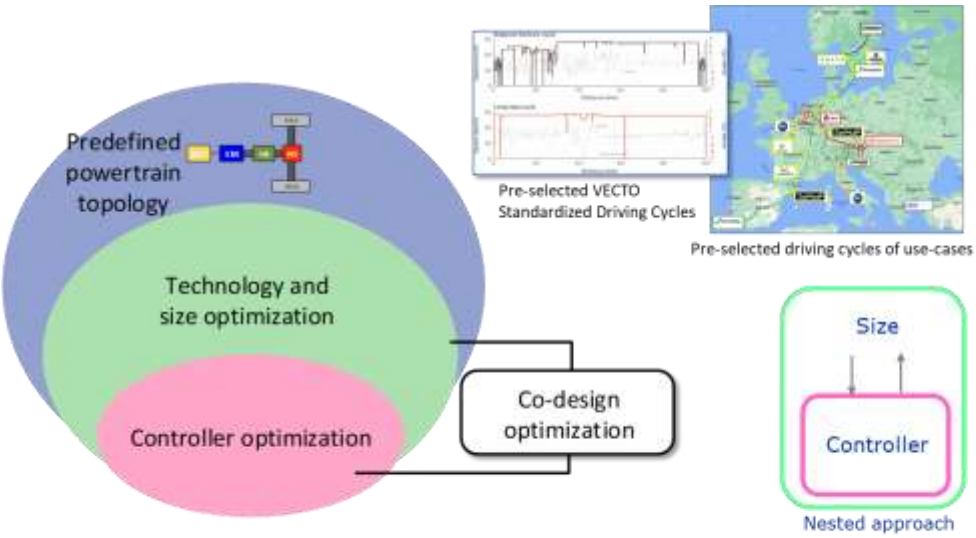
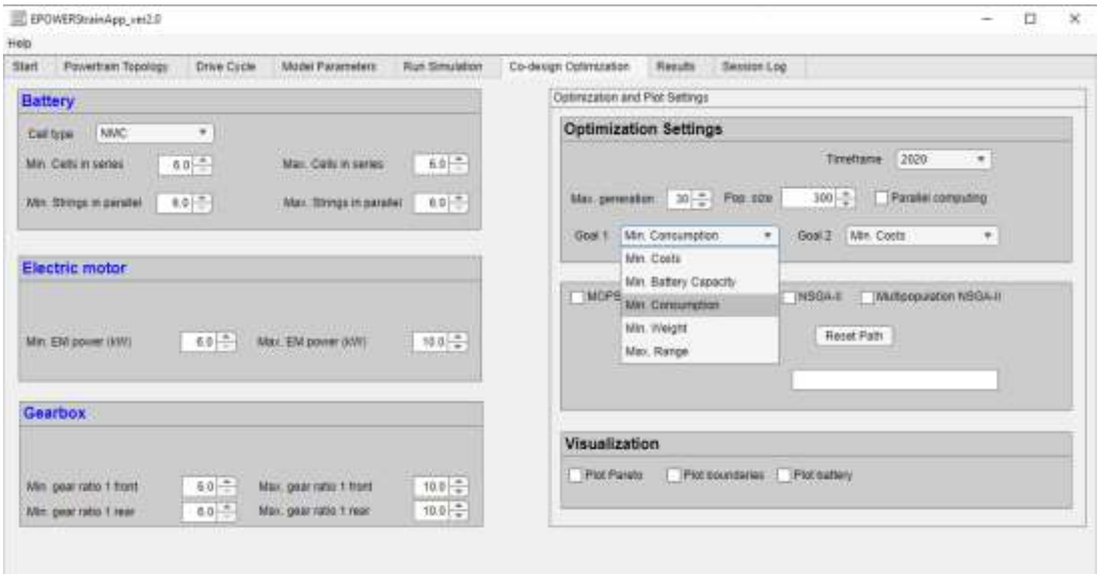


Figure 29. EPOWERS app optimization design approach.

The user interface enables deeper dive capability to plot out various attribute combinations, refine and focus on data inputs giving detailed insight into attribute trade-offs (such as powertrain cost versus battery consumption) and further analyse the most suitable powertrain.

(a)



(b)

Figure 30. Graphical User Interface of EPOWERS app.

5 Conclusion

This deliverable D2.2 reported the outcomes of tasks 2.3 and 2.4 in WP2 to fulfil the needs of objective 1 (i.e., improve modular HD BEVs and FCEVs) – and sub-objective 1.3 (i.e., add functionality to the co-design tool especially for HD, to help to choose the right sizes for components). The achievements are listed below.

- Upgraded the design optimization tool/framework (following the outcomes of previous EU projects, i.e., ORCA, ASSURED, LONGRUN) to make it suitable for HD ZEV so as to optimize the vehicle powertrain with right component size
- This framework considered the modularity and standardization of components to be used in different vehicles or applications, covering the need for price reductions.
- The co-design tool provided the final modular powertrain configurations and selection of technologies with a TCO reduction up to 20%.

6 Deviations from Annex 1

This task has suffered a delay due to the complexity of the development of the simulation platform in the task 2.2.

7 Risks and interconnections

7.1 Risks/problems encountered

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
1	Lack of information/ development of the third-party components	2	2	A simplified model of the component will be developed and used as a placeholder
2	Input data missing or not compatible	2	2	Input system has been developed to ensure lack of data will be completed automatically and will be made compatible with the system

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

7.2 Interconnections with other deliverables

The results obtained from this deliverable, mainly the simulation platform, will be used as the basis for T4.2, and consequently D4.1.

8 References

[1] B. Hussein, S. Arash, and R. Felípe, “Total cost of ownership for tractor-trailers in Europe: Battery electric versus diesel.,” *Int. Counc. Clean Transp.*, 2021.

[2] R. Bao, J. Baxter, and P. Revereault, “Simulation Based Hybrid Electric Vehicle Components Sizing and Fuel Economy Prediction by Using Design of Experiments and Stochastic Process Model,” in *SAE Technical Papers*, Apr. 2019, vol. 2019-June, no. June. doi: 10.4271/2019-01-0357.

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Project partners:

#	Partner short name	Partner Full Name
1	VUB	VRIJE UNIVERSITEIT BRUSSEL
2	FRD	FORD OTOMOTIV SANAYI ANONIM SIRKETI
4	KAE	KASSBOHRER FAHRZEUGWERKE GMBH
5	REN	RENAULT TRUCKS SAS
6	SCA	SCANIA CV AB
7	VET	VAN ECK TRAILERS BV
8	VOL	VOLVO TECHNOLOGY AB
9	ABB	ABB E-MOBILITY BV
9.1	ABP	ABB E-MOBILITY SPOLKA Z OGRANICZONAODPOWIEDZIALNOSCIA
10	AVL	AVL LIST GMBH
11	CM	SOCIEDAD ESPANOLA DE CARBUROS METALICOS SA
11.1	APG	AIR PRODUCTS GMBH
12	HEPL	HITACHI ENERGY POLAND SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
13	MIC	MANUFACTURE FRANCAISE DES PNEUMATIQUES MICHELIN
14	POW	PLASTIC OMNIUM NEW ENERGIES WELS GMBH
15	RIC-CZ	RICARDO PRAGUE S.R.O.
15.1	RIC-DE	RICARDO GMBH
16	UNR	UNIRESEARCH BV
17	ZF	ZF CV SYSTEMS HANNOVER GMBH
18	ALI	ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE
19	DPD	DPD (NEDERLAND) B.V.
20	COL	ETABLISSEMENTEN FRANZ COLRUYT NV
21	GRU	GRUBER LOGISTICS S.P.A.
22	GBW	GEBRUEDER WEISS GESELLSCHAFT M.B.H.
23	PG	PROCTER & GAMBLE SERVICES COMPANY NV
23.1	PGP	PROCTER AND GAMBLE POLSKA SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA
23.2	PGA	PROCTER & GAMBLE AMIENS
24	PRI	PRIMAFRIO CORPORACION, S.A.
25	PTV	PTV PLANUNG TRANSPORT VERKEHR GmbH
26	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
27	HAN	STICHTING HOGESCHOOL VAN ARNHEM ENNIJMEGEN HAN
28	IDI	IDIADA AUTOMOTIVE TECHNOLOGY SA

29	TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
30	UIC	UNION INTERNATIONALE DES CHEMINS DE FER
31	CFL	CFL MULTIMODAL S.A.
32	GSS	Grupo Logistico Sese
33	HIT	Hitachi ABB Power Grids Ltd.
34	IRU	UNION INTERNATIONALE DES TRANSPORTS ROUTIERS (IRU)
35	RIC-UK	RICARDO CONSULTING ENGINEERS LIMITED

Disclaimer/ Acknowledgment

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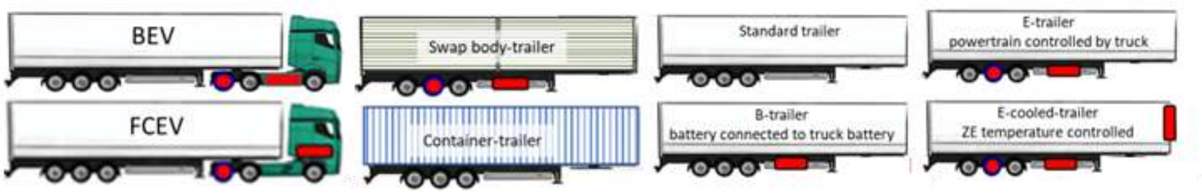
10 Appendix A1. Summary of Vehicle Configurations and ZEFES Use Case Demonstrations

Table 3. Summary table of vehicle configurations and ZEFES use case demonstrations.

	Use Case	Vehicle configurations		Payload	Goods to be transported	Shipper	Battery Electric HDV	Fuel Cell Electric HDV	Rigid Unit (R)	Tractor Unit (T)	Semi-trailer (ST)	Dolly (D)	e-Dolly (e-D)	Semi-trailer (ST)	e-Trailer (e-T)	Cooled e-Trailer (e-reefer)
7.2 VOLVO	7.2.1	FC-1		64t GCW	Steel Scrap	Ovako		X	X		X					
	7.2.2	BEV-1		44t GCW	Automotive parts	Volvo Logistics	X			X	X					
				64t GCW	Automotive parts		X			X	X	X		X		
	7.2.3	BEV-2		64t GCW	Partly Hazardous goods	PG	X			X	X		X	X		
				44t GCW	Temperature-controlled goods	Primafrio	X			X						X
	7.2.4	BEV-3		48t GCW	Parcel distribution	DPD	X		X				X		X	
7.3 SCANIA	7.3.1	BEV-4		44t GCW	Automotive parts	Scania Logistics	X			X					X	
	7.3.2	FC-2		44t GCW	Temperature-controlled goods	GRU		X		X						X
	7.3.3	FC-2		44t GCW	Temperature-controlled goods	Primafrio		X		X						X
		BEV-4					X			X						X
	7.3.4	BEV-5	Low Liner	44t GCW	Automotive goods	GSS	X			X	X					
			Low Liner Low Liner	64t GCW			X			X	X	X		X		
7.4 Renault	7.4.1	BEV-6		44t GCW	Automotive components	Renault + Michelin	X			X	X					
	7.4.2	BEV-6		44t GCW	Parcel distribution	DPD	X			X	X					
				64t GCW			X			X	X			X		
7.6 FORD	7.6.1	FC-3		44t GCW	Automotive components	Ekol		X		X	X					
	7.6.2	FC-3		44t GCW	Parcel distribution	GBW		X		X	X					
	7.6.3	FC-3		44t GCW	Partly Hazardous goods	PG		X		X	X					



11 Appendix A2. Description of UC 7.4.1 and UC 7.6.3

T7.4.1 Renault – Renault (BEV)

REN will lead the demonstrations, make the vehicle combinations (T+ST @ 44t GCW) available for the logistics providers, collect and hand over all necessary data for the evaluation. REN will operate the vehicle for 3-6 months on an existing RENAULT TRUCKS logistic flow, delivering cabs (Blainville sur Orne – 14) to assembly plant warehouse (Bourg en Bresse – 01), a daily distance of 700 km, mainly on French highways.

Starting point address: Renault Trucks, ZI Caen, 63 Rue du Canal, 14550 Blainville-sur-Orne. End point address: Renault Trucks Livraison, Rue Paul Berliet, 01250 Bourg-en-Bresse.

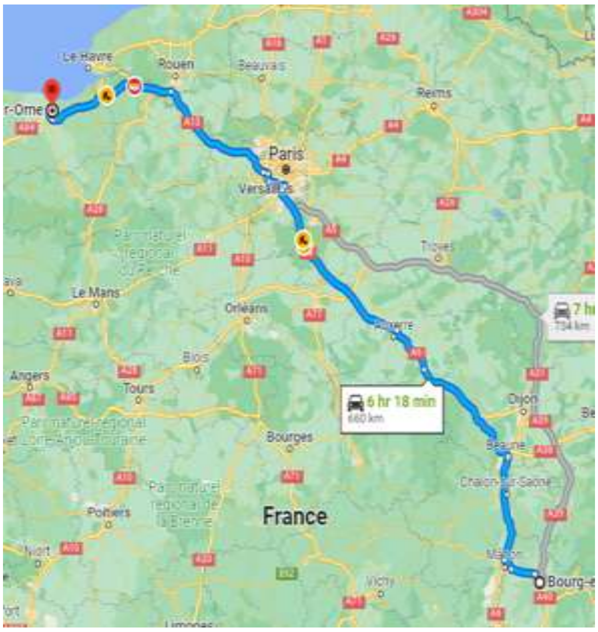


Figure 31. Demonstration route for T7.4.1 REN –REN (BEV 44-ton 750km daily long-haul).

T7.6.3 FORD 44t 700km daily (FCEV)

FRD will lead the demonstrations, make the vehicle combinations (T+ST @ 44 GCW) available for the shipper, collect and hand over all necessary data for the evaluation. PG will act as shipper and a contract carrier will operate the vehicle, as tractor + 45ft container-trailer in a national flow long-haul profile of partly dangerous goods on mountainous terrain and with the use of tunnels, daily ca. 660km for 3 months. The 45ft containers arrived or go to the terminal Zeebrugge by rail, see also ST7.2.3 PG.

USP, FCEV vehicle operating in a hilly national long-haul VECTO mission profile.

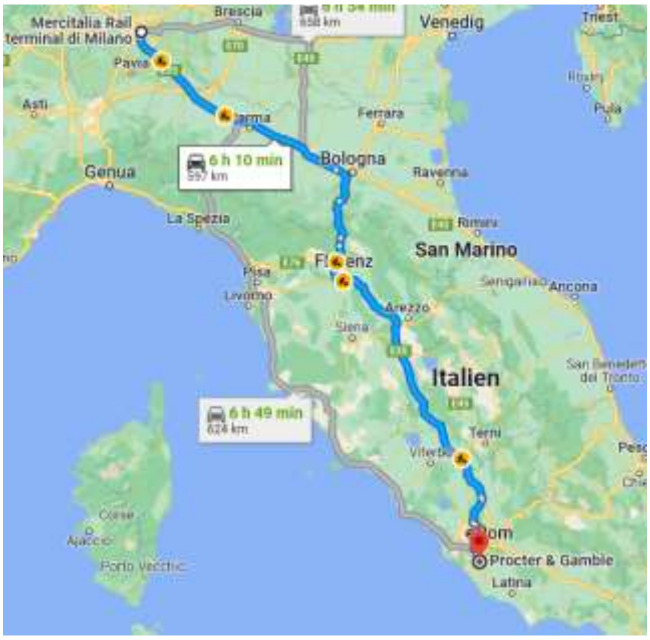


Figure 32. Demonstration route for T7.6.3 FRD –PG (FCEV 44-ton 750km daily long-haul).

12 Appendix A3. TCO formulation

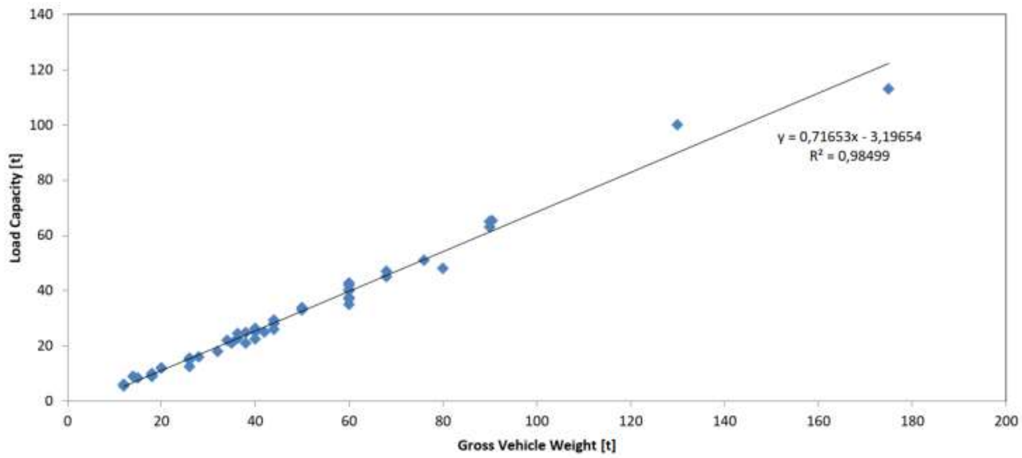


Figure 33. Load capacity as a function of gross vehicle weight.

Table 4. TCO cost formulation.

	Description	Parameter	Unit	Value/Equation
Vehicle	Payload	m_{load}	[kg]	**User input**
	5-year depreciation	Depr_{5y}	[%]	55
	Taxes (Euro 3 or above until 2025)	C_{tax}	[€/quarter]	81-325
	Taxes (Euro 3 or above after 2025)	C_{tax}	[€/quarter]	> 81 - >325
	Administrative costs (Euro 3 or above after 2025)	C_{admin}	[€/year]	926
	Insurance	C_{insu}	[€/year]	-
	Driver salary (Average NL)	C_{wage}	[€/month]	1,600
	Investment	C_{invest}	[€]	110,000-280,000
CAPEX	Life cycle	$Life_{dist}$	[km]	1,450,000
	Annual driving	$Drivg_{ann}$	[km/year]	130,000
	Annual utilization	$Util_{ann}$	[%]	$\left(\frac{Drivg_{ann}}{Life_{dist}}\right) * 100$
	Estimated vehicle service life	$Year_{serv}$	[years]	11.15
	Expected residual value (resale) after 5 years	$C_{residue}$	[€]	$C_{invest} - C_{invest}\frac{\mathrm{Depr}_{5y}}{100}$
	Annual Depreciation	Depr_{ann}	[€/year]	$(C_{invest} - C_{residue})/5$
	Annual CAPEX	$CAPEX_{ann}$	[€/year]	$(4 * C_{tax}) + (12 * C_{wage}) + C_{insu} + \mathrm{Depr}_{ann} + C_{admin}$
	Electricity cost (Oct 2022) (VAT included)	C_{elec}	[€/kWh]	0.2
OPEX	Energy consumed in trip	E_{cons}	[kWh]	**From simulation**
	Trip length	$Dist$	[kms]	**From simulation**
	Tolls and fees	C_{toll}	[€/year]	-

	Repair and maintenance (Incl. tires) per km	C_{repair}	[€/km]	0.1577-0.2123
	Fuel cost per trip	$C_{fueltrip}$	[€/trip]	$C_{elec} * E_{cons}$
	Fuel cost per 1000 kms	$C_{1000kms}$	[€/1000km]	$\frac{C_{fueltrip}}{Dist} * 1000$
	Annual repair and maintenance cost	$C_{repair(ann)}$	[€/year]	$C_{repair} * Drivg_{ann}$
	Annual fuel costs	$C_{fuel(ann)}$	[€/year]	$\frac{C_{1000kms}}{1000} * Drivg_{ann}$
	Annual OPEX	$OPEX_{ann}$	[€/year]	$C_{fuel(ann)} + C_{repair(ann)} + C_{toll}$
TCO	**TCO per year**	TCO_{ann}	[€/year]	$CAPEX_{ann} + OPEX_{ann}$
	TCO per km	TCO_{km}	[€/km]	$\frac{TCO_{ann}}{Drivg_{ann}}$
	TCO per tonne per km	$TCO_{ton.km}$	[€/tonne. km]	$\frac{TCO_{km}}{m_{load}/1000}$

Table 5. Other costs.

Parameter	**Unit**	**Baseline**	**Results**
Chassis costs	€	39,000	
Battery costs	€	144,125	86,851
Vehicle costs (without chassis)	€	10,000	6,000
Lifetime	Year	13	
Mileage over lifetime	km	1,425,000	
Maintenance and repair cost	€/year	12,600	
Vehicle taxes	€/year	573	
Infrastructure costs	€/year	4,000	
Battery mass	kg	6,069	5,033
Energy price	€/kWh	0.20	
Fuel cell unit	€/kW	460	
Hydrogen tank	€/kg	900	
Power battery	€/kWh	370	
Electric drive	€/kW	52	