Graz University of Technology

INSTITUTE OF INTERNAL COMBUSTION ENGINES AND THERMODYNAMICS

VECTO: Extension to hybrids and further technical support

Final Report

Service Contract Number 340201/2018/789690/SER/CLIMA.C.4.

Authors: Gérard Silberholz
Martin Rexeis
Markus Quaritsch
Stefan Present

VECTO: Extension to hybrids and further technical support – Final Report

Date 30.09.2022

Customer: DG CLIMA

Institute of Internal Combustion Engines and Thermodynamics

Head: Univ.-Prof. Dr. Helmut Eichlseder

Inffeldgasse 19, A-8010 Graz, Austria

Tel.: +43 (316) 873-30001

Fax: +43 (316) 873-30002

institut@ivt.tugraz.at

http://ivt.tugraz.at

CONTENT

Abbreviations **5**

1 About this report **7**

2 Task 1: Development and implementation of the extension of VECTO with regards to hybrid technologies **8**

2.1 Introduction 8

2.1.1 Course of the project 8

2.1.2 Structure of the documentation for Task 1 9

2.2 General approach for xEV in VECTO 10

2.3 Electric powertrain components 12

2.3.1 Electric machine 13

2.3.2 Batteries 19

2.3.3 Capacitors 24

2.3.4 IEPC 26

2.4 xEV Powertrain Architectures in VECTO 28

2.4.1 Definitions of parallel-HEV architectures 28

2.4.2 Definitions of serial-HEV architectures 30

2.4.3 Definitions of PEV architectures 30

2.4.4 Powertrain configurations and applicable components 31

2.4.5 Other possible architectures 35

2.4.6 "Micro hybrids" 35

2.5 xEV operation strategies in VECTO 38

2.5.1 Parallel HEV 38

2.5.2 Serial HEV 65

2.5.3 Pure Electric Vehicles (PEV) 69

2.5.4 ADAS for xEV 71

2.6 xEV auxiliaries 74

2.6.1 Power demand for conditioning of electric powertrain components 74

2.6.2 Adjustment of advanced auxiliaries (AAUX) model 76

2.6.3 Handling of Engine-Stop-Start (ESS) in connection with the power requirements of the auxiliary consumers 82

2.6.4 Post-processing methods for balancing energy demands over cycle 84

2.7 Handling of vehicles with off-vehicle charging capabilities 89

2.7.1 External charging and reference point for energy balance 89
2.7.2 Electric ranges 92
2.7.3 Concrete implementation of the method for OVC-HEV (plug-in HEV) in VECTO 95

3 Task 2: Testing, Software Verification and Documentation with regards to hybrid technologies 98

3.1 Working method as applied throughout the project 98
3.2 List of open topics for further consideration 99

4 Task 3: Feasibility assessment and development of a first VECTO forward looking prototype taking into account results from Task 1 102

4.1 Feasibility analysis on changing VECTO to a forward architecture 103
4.1.1 Background to the different model architectures 103
4.1.2 Reflections on a possible change from VECTO to forward architecture 105
4.2 Stakeholder involvement 107

5 Task 4: Technical support for the VECTO tool 109

6 References 112

Annex A: List of meetings with project relevance 113

Annex B: List of tickets associated with point 3. of Task 4 117

Annex C: Relevant application cases for consideration of ESS and auxiliary power demand during ICE-off phases 144

Abbreviations

The abbreviations are listed in alphabetical order.

AAUX	……..	Advanced Auxiliary Model
ADC		Additional driveline component
AMT	……..	Automated Manual Transmission or Automatic Mechanically-engaged Transmission
APT	……..	Automatic Powershifting Transmission
APT-N	……..	APT without torque converter
APT-P	……..	APT with torque converter in parallel arrangement
APT-S	……..	APT with torque converter in serial arrangement
CD	……..	Charge depleting driving mode
CO_2	……..	Carbon dioxide
CS	……..	Charge sustaining driving mode
CVT	……..	Continuous variable transmission
DC	……..	Direct current
DP	……..	Dynamic programming
EAER	……..	Equivalent all electric range
ECMS	……..	Equivalent Consumption Minimisation Strategy
EF	……..	Equivalence Factor
EffShift	……..	"Efficiency Shift" (Generic gear selection algorithm is applied in VECTO)
EM	……..	Electric machine
EMS	……..	Electric machine system
ESS	……..	Engine-Stop-Start
FCEV	……..	Fuel cell electric vehicle
Genset	……..	Generator set (system unit of ICE and generator in a serial HEV)
GTR4 HILS	……..	Global technical regulation no. 4 (Six C. 2014)
HDH	……..	Heavy-duty hybrid
HDV	……..	Heavy-duty vehicle
HEV	……..	hybrid electric vehicle
HVAC	……..	Heating, Ventilation and Air Conditioning
ICE	……..	Internal Combustion Engine
IEPC	……..	Integrated Electric Powertrain Component
IHPC	……..	Integrated HEV powertrain component

OCV	……..	Open circuit voltage
OEM	……..	Original equipment manufacturer
OVC	……..	Off-vehicle charging
PCC	……..	Predictive Cruise Control
PEV	……..	Pure electric vehicle
R_{CDA}	……..	Actual charge depleting range
REESS	……..	Rechargeable electric energy storage system
ToR	……..	Terms of Reference
UF	……..	Utility Factor
VECTO	……..	Vehicle Energy Consumption Calculation Tool
xEV	……..	“any” kind of vehicle with an electrified powertrain
ZCER	……..	Zero CO_2 emissions range

1 About this report

This document is the final report of Service Contract Number 340201/2018/789690/SER/CLIMA.C.4. ("VECTO: Extension to hybrids and further technical support").

The scope of the project consisted of three different topics:

(1) Extension of VECTO to cover hybrid electric heavy duty vehicles

   a. Task 1: Method development and software implementation (documented in chapter 2)

   b. Task 2: Testing, Software Verification and Documentation with regards to hybrid technologies (documented in chapter 3)

(2) Feasibility assessment and development of a first VECTO forward looking prototype taking into account results from Task 1 (Task 3, documented in chapter 4)

(3) Technical support for the VECTO Tool (Task 4, documented in chapter 5)

The second key deliverable of this project is the software version 0.7.9.2741 including User Manual as uploaded to CITnet JIRA on 4 July 2022.

2 Task 1: Development and implementation of the extension of VECTO with regards to hybrid technologies

2.1 Introduction

2.1.1 Course of the project

With the extension of the VECTO approach to electrified powertrains, as it was the main scope of this contract, a completely new territory was entered. Where the journey in this regard was actually going only became really clear in the course of the project.

In the original project planning, which was mainly based on the outcome of the "Feasibility study" (Silberholz G. 2017), it was envisaged that the methodology to be developed should focus on hybrid electric vehicles (HEV) and aim at a simple and quickly implementable approach, which would be realistic to be finalised within the given time frame (less than two years). A distinction should only be made between essential "archetypical" power train architectures (parallel hybrid, serial hybrid, possibly also third "power-split" hybrid variant). Pure electric vehicles (PEV) should only be included "as far as possible" in order to enable an estimation of the electric range (CO_2 emissions would be zero anyway). Concerning component testing it was originally assumed that the methods, if at all necessary, can be based on the procedures already developed for GTR4 HILS[1].

Due to the steep learning curve regarding HEV and PEV technologies in the period since early 2019 that has taken place among all participants (industry, consultants, Commission) and also due the significantly changed political framework conditions regarding alternative powertrains ("Green Deal"), a significantly more complex path had to be taken with regard to the coverage of xEVs[2] in VECTO. Anything else would have been negligent, as the methods developed now will certainly represent the backbone of Regulation (EU) 2017/2400 and VECTO in the next 10+ years. The following major changes in the basic concept have resulted from the developments in the project:

1) A strong simplification of hybrid powertrain architectures is assessed as not possible due to the high variance of systems realised on the market in the meantime and taking into account the high accuracy requirements established in Regulation (EU) 2017/2400. Therefore, distinction between more than ten separate different powertrain architectures for HEVs have now been considered for the second amendment, with even more possible configurations considering combinations with different transmission technologies and auxiliary system configurations (the latter is only relevant for buses).

[1] (Six C. 2014)

[2] "xEV" is used as a summary term for vehicles with electrified powertrains

2) A detailed assessment of the electric energy consumption of PEVs has become a central element in the methodology. For PEVs, three different powertrain configurations have been foreseen which can be each combined with three different transmission technologies.

3) The approaches to component testing for electric powertrain components (Electric machine system (EMS), Battery system, Capacitor system) were designed at least as complex as the test methods developed over almost a decade for conventional powertrain components. Specifics such as continuous power vs. peak power and voltage dependency of the efficiencies (EMS) or, for example, modular scalability of battery systems are covered with specially developed approaches. It can be assumed that the methods developed in this project will soon become an internationally established standard approach for the measurement and simulation of electrified powertrains.

4) Going beyond the above-mentioned methods and degrees of freedom the new elements “Integrated Electric Powertrain Component” (IEPC) and “Integrated HEV powertrain component” (IHPC) have been defined. Such components are characterised by an integrated functionality of several "conventional components" (electric motor, gearbox, differential) into a single unit and thus go beyond the classical component scheme in Regulation (EU) 2017/2400 and VECTO. Thus, they need to be represented in the component test as well as in VECTO with their own methods.

The significantly increased scope of work compared to the original project plan was made possible in accordance with the Commission's decisions in such a way that:

1.) The project duration was extended by 8 months, whereby the completion of Task 1 and Task 2 was postponed until the very end of the project.

2.) Resources were shifted from Task 3 to Task 1.

3.) Part of the support contingent (Task 4) was also used for Task 1.

4.) The work on IEPC and IHPC as well as the required extension of the Factor Method[3] to xEV powertrains was outsourced to a separate contract.

This report provides full documentation of the resulting approach for xEV in Regulation (EU) 2017/2400 and in VECTO, whereby for details on the implementation of IEPCs and IHPCs, reference is made to the documentation to be prepared in 2023/2024 in the relevant contract.[4]

2.1.2 Structure of the documentation for Task 1

The ToR suggested a division of the development of xEV features into three steps based on the process designed in the feasibility study. Two of those steps were allocated to Task 1:

Task 1.1: Development of methods and software based on generic component data

[3] The „Factor Method“ (FM) is a calculation method in VECTO that makes it possible to split the calculation process for the characteristic values of the final vehicle configuration over several manufacturer levels and without having to pass on confidential data (e.g. engine maps). The FM was developed in a separate project from 2018 to 2020 and will be used for the VECTO application for heavy buses.

[4] VECTO Extension to Cover Electric Vehicles and Additional Powertrains, Specific Contract No 090203/2021/863026/SER/CLIMA.C.4

Task 1.2: Extensions of methods and software in order to take specific component properties (especially efficiency data) into account.

In the course of the project, the development of software and component test methods was actually largely completed in an integral development process, which is why the following documentation of Task 1.1 and 1.2 is provided together and sorted by technical functionality.

2.2 General approach for xEV in VECTO

Section 2.2 shall provide a general overview of the methods that have been developed to cover HEV and PEV through Regulation (EU) 2017/2400 and VECTO and the structure of the related documentation in this report.

The established approach consisting of the two steps “component certification” and “application of the standardised simulation model VECTO” is also followed for HEV and PEV. The following xEV specifics are applied:

- For component certification, specific standardized test procedures for **electric powertrain components** are to be applied resulting in specific sets of input data for VECTO. Using this data, the related component models in VECTO as developed in this contract model the energy consumption-relevant behaviour of the components in the simulation.
- For the simulation of xEV in VECTO typical **powertrain architectures for HEV and BEV** are defined and implemented in the simulation model.
- For HEV it is required to determine the split of propulsion power either between the different propulsion energy converters for parallel HEV or between propulsion energy converter and storage for serial HEV. This function is accomplished by a **generic HEV control strategy** implemented in the simulation tool.
- In order to adequately map xEV, specifics regarding the **xEV related auxiliary consumers** need to be taken into account.
- For hybrids with the possibility of external charging (OVC-HEV, "plug-in" hybrids) and for PEVs, VECTO needs also to provide **results for electric ranges and electrical energy consumption**.

Electric powertrain components

The following components relevant for HEV and PEV were introduced:

- Propulsion energy converters
    - Electric machine system (EMS)
    - IEPC
    - IHPC
- Rechargeable electric energy storages
    - Battery system
    - Capacitor system

Section 2.3 describes the principles of the developed component test procedures and the component models implemented in VECTO. A full description of the component tests can be found in Annex Xb of the second amendment of Regulation (EU) 2017/2400.

Powertrain architectures for HEV and BEV

The elaborated approach covers the following main powertrain configurations:

- HEV parallel:
  - Five basic powertrain architectures that include an ICE that powers a single mechanically connected path between the engine and the wheels of the vehicle (section 2.4.1).
  - An additional special variant of parallel hybrid with a fully integrated powertrain component is depicted by an IHPC.
- HEV serial:
  - Three powertrain architectures that include an ICE that powers one or more electrical energy conversion paths with no mechanical link between the ICE and the wheels of the vehicle. (section 2.4.2)
  - An additional special variant of serial hybrid with a fully integrated powertrain component is depicted by an IEPC.
- PEV:
  - Three powertrain architectures for PEV with a single powertrain (section 2.4.3).
  - A special variant of PEV with a fully integrated powertrain component is depicted by an IEPC.

Generic HEV control strategies

To determine the split of propulsion power either between the different propulsion energy converters for parallel HEV or between propulsion energy converter and storage for serial HEV the following generic control strategies have been implemented:

- Parallel HEV: It was decided to implement a strategy based on the ECMS (Equivalent Consumption Minimisation Strategy) approach. The principle of this strategy is to optimise the total energy consumption of fuel and electrical energy in the battery for each time step. The crucial point is the selection of the correct equivalence factor (EF) for the weighting of fuel and electric energy cost, which depends on the vehicle configuration and cycle (section 2.5.1).
- Serial HEV: A strategy was implemented that selects five different operating states of the GEN set (maximum efficiency and maximum power, respectively for normal EM operation and EM operation in de-rating as well as engine off). These operating states are selected by the strategy depending on the state-of-charge of the battery (section 2.5.2).

xEV related auxiliary consumers

xEV related specifics regarding auxiliary consumers considered in VECTO are:

- Simple models to allocate typical power demand values required for conditioning of electric powertrain components.
- For heavy buses additionally modelling of “micro-hybrids” (special case of a parallel hybrid using the alternators for recuperation) and xEV specifics regarding HVAC configurations need to be taken into account. Those were implemented within this contract into VECTO resulting in a significantly updated “Advanced Auxiliary Model” (AAUX).

Details are provided in section 2.6.

Results for electric ranges and electrical energy consumption

For OVC-HEV and for PEV VECTO calculates a set of three different “electric ranges”:

- Actual charge depleting range
- Equivalent all electric range
- Zero CO_2 emissions range

For OVC-HEVs, furthermore methods are required, which determine the driving shares in electric driving mode (“charge depleting mode”, CD) and in pure hybrid mode (“charge sustaining mode”, CS) depending on the vehicles characteristics and the mission profile. This is expressed by the “utility factor” (UF, ratio between daily kilometres driven in CD and total daily mileage). The utility factor is used to calculate the cycle-specific energy consumption and CO_2 emissions from the sub-result for CD and CS mode. The details are documented in section 2.7.

For providing results for electrical energy consumption a meaningful system boundary is required, i.e. a definition which part of the losses from the grid to the vehicle should be included and which not. As a basic definition for VECTO, it was decided after extensive analyses and discussions with stakeholders that the system boundary should be set to "battery terminals". This means that only the charging losses of the battery itself but not the losses in the charging infrastructure (off- and on-board charging unit) are included in the energy consumption figures as calculated by VECTO. The reasons for this decision and the specific implementation in VECTO are documented in section 2.7.1.

2.3 Electric powertrain components

For all the electrical powertrain components implemented into VECTO in this project, the basic VECTO modelling conventions were applied: Each powertrain component is represented by a sub-model, whose input signal in the simulation loop is the demanded power at the output side ("downstream" in the drivetrain towards the wheels) of the component. The powertrain is simulated going backward from the vehicle-road-interaction at the wheel upstream to the very last powertrain component in the supply chain. For electric components this is typically the electric storage as source/sink of power, except for serial HEVs where the GEN set can also act as source of power.

Internally, the specific equations defined at component level are solved for each component to provide the demanded power at the output taking all component limitations into account (e.g. current limitation of battery). Component limitations interact again with the assumed power demand on vehicle level defined at the wheel which might need to be reduced accordingly to meet the respective component limitations applicable in the current time interval. For components where the actual operation is dependent on the rotational speed (i.e. EM in this context), the applicable operation point is defined by the internal control logics of each component under the given boundary conditions defined by the vehicle speed and the total transmission ratio from the wheel up to the respective powertrain component.

The convention for all component input files is that positive torque values propel the vehicle, while negative torque values apply an additional braking force to the powertrain and generate electric power. Whereas, the VECTO internal convention for the simulation is that positive torque adds additional braking to the powertrain and vice-versa. Thus, if for example the EM propels the vehicle it applies negative torque in the simulation.

The details of each individual electric powertrain component implemented in this project are explained in the subsequent chapters.

2.3.1 Electric machine

The electric machine[5] (EM) is modelled through a quasi-stationary map considering the electrical power consumption or output of the component as a function of the mechanical power consumed or absorbed and the speed of rotation. Furthermore, the machine's rotational inertia as well as a de-rating behaviour (reducing the available power after a certain period with high average loads depending on the actual load history in the cycle) is also considered. All component parameters are determined for two different voltage levels reflecting the DC input voltage to the EM's power electronics which would be available from the linked REESS in the vehicle. All data determined in the component test reflects not only the efficiency of the actual EM, but also includes the efficiency of the power electronics being an integral part of the testing.

Basically, the EM is depicted by the following equation:

$$T_{EM,map} = I_{EM}\,\dot{\omega} + T_{EM,out}$$

where:

$T_{EM,map}$	torque used for determining the electrical power demand of the EM in the map [Nm]
I_{EM}	moment of inertia of the EM [kg m²]
$\dot{\omega}$	first derivative in time of the EM rotational speed (i.e. the angular acceleration) [rad/s²]
$T_{EM,out}$	torque demand at the output of the EM [Nm]

The electric power demand is then interpolated from the stationary map depending on the rotational speed of the EM, the torque $T_{EM,map}$ and the DC input voltage.

2.3.1.1 EM connection to powertrain and loss calculations

The VECTO component for the EM contains the electric machine itself which is connected via a transmission stage with a fixed gear ratio to the main powertrain. This transmission stage may be used as an optional component to correctly define the connection from the EM to the powertrain (e.g. single gear stage or belt drive) without having to include this transmission stage directly at the EM component test. The actual data of the additional gear stage might be determined in accordance with the adapted procedures for transmissions defined in Annex VI of Regulation (EU) 2017/2400 or standard values may be used.

[5] For the explanations in this report focussing on functional principles of VECTO, the term "electric machine" is used for simplification purposes as opposed to the term "electric machine system" in Regulation (EU) 2017/2400 defining the component testing (which mandatorily includes all power electronics)

This combination of EM and transmission stage is modelled as a single component in VECTO, thus a set of dedicated rules were defined on how the internal signals given in the vmod output of VECTO are interrelated:

- The naming convention for the signals is that ‘X’ denotes the position of the EM in the powertrain and the architecture of the xEV powertrain – i.e. positions 1, 2, 2.5, 3 and 4 and architectures P, S, E (e.g. P2, S3, E4; see chapter 2.4 for detailed definitions)
- ‘n_X’ defines the speed of the main powertrain at the connection point of the EM component
- ‘n_X-em’ defines the speed of the electric motor output shaft
- ‘P_X_…’ / ‘T_X_…’ define the respective power and torque signals referring to the main powertrain speed, while ‘P_X-em_…’ / ‘T_X-em_…’ refer to the electric motor output shaft.

Figure 1 illustrates this convention in a graphical way.

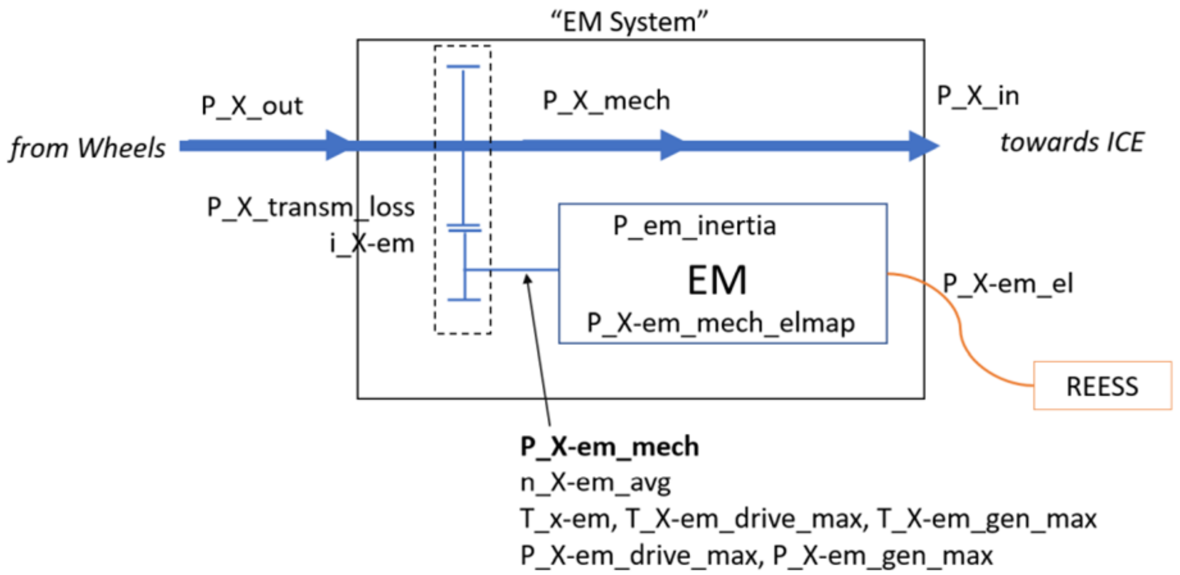


Figure 1: Naming convention of EM component in VECTO

The following equations define the interrelations of all the signals of the combined EM component in detail and correspond to Figure 1 above:

- P_X_in = P_X_out + P_X_mech
- P_X_mech = P_X-em_mech + P_X_transm_loss
- P_X-em_mech = P_X-em_mech_elmap + P_X-em_inertia
- P_X-em_mech_elmap = P_X-em_el + P_X-em_loss
- P_X-em_mech_elmap = n_X-em * T_X-em_map
- P_X-em_el = PowerMap(n_X-em, T_X-em_map)
- P_X_loss = P_X_mech - P_X-em_el

In the actual implementation there are two basic operation modes of the EM: either it is on actively contributing with positive or negative power or it is completely off. During the actual simulation when the EM is on, the maximum drive torque, maximum generation torque and the electric power map are interpolated at each time interval from the data for both voltage levels depending on the current internal voltage of the REESS. The drag curve of the EM (defined as drag torque over speed) is only applied in case the electric motor is turned off in the simulation leading to some additional mechanical drag applied to the vehicle's powertrain.

The electric power demand of the EM is not directly interpolated in the provided power map. Due to the characteristic of this map (increasing electric power with both dimensions, torque and speed) the resulting Delaunay map may cause deviations from the assumed electric power demand depending on how the triangles are actually added to the Delaunay map. Therefore, a new method was defined where the electric power map is converted to a "virtual torque loss" map similar to the transmission loss maps. For every entry in the electric power map, the virtual torque loss is calculated as follows:

$$T_{loss,em-map} = \frac{P_{el}(\omega_{em},T_{em}) - \omega_{em}\,T_{em}}{\omega_{em}}$$

where:

$T_{loss,em-map}$	virtual torque loss of the EM [Nm]
P_{el}	electric power of the EM [W]
ω_{em}	rotational speed of the EM [rad/s]
T_{em}	torque of the EM [Nm]

From the tuple (ω_{em}, T_{em}, $T_{loss,em-map}$) the Delaunay map is created and in the simulation the actual electric power is then calculated as follows:

$$P_{el,act}(\omega_{em,act},T_{em,act}) = Delaunay(\omega_{em,act},T_{em,act})\,\omega_{em,act} + \omega_{em,act}\,T_{em,act}$$

where:

$P_{el,act}$	actual electric power of the EM [W]
$\omega_{em,act}$	actual rotational speed of the EM [rad/s]
$T_{em,act}$	actual torque of the EM [Nm]
Delaunay()	is the Delaunay interpolation routine giving the actual loss torque for the specified operation point of the EM [Nm]

This newly introduced method lead to a significant improvement of the interpolated results for electric power of the EM for operation points located further away from the actual grid points measured in the component test.

2.3.1.2 Overload characteristics

EMs can be operated at a significantly higher power than the long-term maximum for a certain period depending on their specific cooling system setup and dimensioning. This overload performance needs to be reflected in the simulation accordingly, thus in addition to the limitations for maximum propulsion and braking torque being determined in overload condition in the component test, some elements reflecting the overload performance in a realistic way needed to be determined. Due to the existing interrelation between component test and simulation regarding this data, a generic method was defined with the simulation model corresponding to the actual test design for determining the overload characteristics of the EM.

The basic idea is that a certain “buffer” for the heat losses of the EM to be dissipated is existing and the capacity of this buffer is linked to the characteristics of the machine and the cooling system (i.e. thermal inertia due to physical mass of the EM as well as the amount of cooling fluid with their respective specific heat capacities). Thus, it is determined in the component test how long the EM can hold a certain overload point at maximum power until the power is decreasing to a certain extend (i.e. the EM is going into “de-rating operation”). Then, in a second run a certain continuous power point is measured at which the EM can stay for a very long period (at least 30 minutes) without the need to reduce the power. The torque at the continuous power point is now considered as the torque where all heat losses can be directly dissipated to the environment by the EM’s cooling system in the long-term without leading to an increase in cooling system temperature (i.e. without making use of the buffer). Whereas, for the overload point the cooling system temperature is continuously increasing until the de-rating occurs because the heat losses are too high to be directly dissipated by the cooling system. Now the duration of the overload measurement as well as the difference in EM losses between the overload and the continuous point define the capacity of the overload buffer in terms of loss energy.

The implementation of the thermal de-rating in VECTO looks as follows: During the simulation the difference between the current losses in the EM and the losses at the continuous power operating point are integrated over time. Since the magnitude of the electric current is mainly responsible for the losses in the EM and since there is an approximate linear relation between electric current and torque of the EM, the concept for the overload model in VECTO is that the torque is limited to the torque available in the continuous point as soon as the overload buffer is full. Once the buffer is depleted below a certain threshold (to integrate a hysteresis element for preventing cyclization between overload and de-rating operation) again due to operation in points with lower losses, the overload torque is available again. The following equations are used for the thermal de-rating model of the EM:

$$E_{th,buf} = \left(P_{loss,ovl} - P_{loss,cont}\right) t_{ovl}$$

$$P_{loss,ovl} = P_{map,el} \left(\omega_{ovl}, T_{ovl}\right) - \omega_{ovl} T_{ovl}$$

$$P_{loss,cont} = P_{map,el} \left(\omega_{cont}, T_{cont}\right) - \omega_{cont} T_{cont}$$

$$E_{ovl,i} = E_{ovl,i-1} + \left(P_{loss,i} - P_{loss,cont}\right) dt$$

$$P_{loss,i} = P_{map,el} \left(\omega_{act,i}, T_{act,i}\right) - \omega_{act,i} T_{act,i}$$

where:

$E_{th,buf}$	capacity of the overload buffer of the EM [J]
$P_{loss,ovl}$	loss power at the overload point of the EM [W]
$P_{loss,cont}$	loss power at the continuous point of the EM [W]
t_{ovl}	maximum duration of the overload point of the EM [s]
$P_{map,el}$	electric power of the EM interpolated from the map for a certain operation point [W]
ω_{ovl}	rotational speed of the EM at the overload point [rad/s]
T_{ovl}	torque of the EM at the overload point [Nm]
ω_{cont}	rotational speed of the EM at the continuous point [rad/s]
T_{cont}	torque of the EM at the continuous point [Nm]
$E_{ovl,i}$	actual level of the overload buffer of the EM in the current timestep [J]
$E_{ovl,i-1}$	level of the overload buffer of the EM in the previous timestep [J]
$P_{loss,i}$	loss power of the EM in the current timestep [W]
dt	duration of the current timestep [s]
$\omega_{act,i}$	rotational speed of the EM in the current timestep [rad/s]
$T_{act,i}$	torque of the EM in the current timestep [Nm]

In a pre-processing step, the overload buffer is calculated by VECTO for both voltage levels of the EM. Both, the overload buffer and continuous losses used in the simulation are then interpolated with the voltage level of the REESS at the average of the usable SOC level leading to fixed values for all these characteristic overload parameters in the actual simulation loop.

2.3.1.3 EM component tests

Table 1 gives an overview of all EM parameters determined in the different component tests.

Table 1: Overview on component testing for electric machines systems

Test name	Purpose	Description of testrun	Reference in Annex Xb	Input data for vehicle simulation
Torque limits	Derive power limitations for the EM for propulsion and for braking/generating	Unit is run at full positive (i.e. driving) setting of the power controller and in a second run at full negative (i.e. braking/generating) power setting of the power controller. The torque limitations are measured at several different rotational speeds (≥10) to define correctly the torque limitations between zero and the highest motor speed. Defined preconditioning is performed before each run. To be measured at two voltage levels.	Point 4.2.2	Maximum propulsion and maximum braking/generating torque as function of the rotational speed
Drag curve	Derive drag losses (i.e. the torque necessary to spin the EM at a certain speed with zero power delivered by the machine)	The unit is driven at a certain rotational speed and torque and electric power are measured. Defined preconditioning is performed before the actual test.	Point 4.2.3	Drag torque as function of the rotational speed (applied if EM power is zero in VECTO)
Maximum 30 minutes continuous torque	Derive torque that can be constantly delivered by EM	Operating point declared by manufacturer upfront must be kept for 30 minutes, Otherwise test needs to be repeated with lower power. Defined preconditioning is performed before the actual test.	Point 4.2.4	Continuous maximum torque required for simplified thermal derating model (i.e. reduction of maximum power depending on EM load profile over time)
Overload characteristics	Derive torque that can be delivered by EM for a defined short period	Operating point declared by manufacturer upfront must be kept for a declared period of time, Otherwise test needs to be repeated with lower power. Defined preconditioning is performed before the actual test.	Point 4.2.5	Energy buffer is derived from short-period maximum torque and respective duration required for simplified thermal de-rating model (i.e. reduction of maximum power depending on EM

Test name	Purpose	Description of testrun	Reference in Annex Xb	Input data for vehicle simulation
				load profile over time)
Electric Power Mapping Cycle (EPMC)	Derive power losses of EM	Electric power to or from the inverter is measured for different steady-state operating points of the EMS (≥100 theoretically) with a dedicated sequence of testing to define thermal boundary conditions. Defined preconditioning is performed before the actual test. To be measured at two voltage levels.	Point 4.2.6	Electric energy consumption of EM as function of the operating point (rotational speed and torque)

2.3.2 Batteries

The battery is modelled by a zeroth order equivalent circuit model consisting of an ideal voltage source in series with an ohmic resistance. The characteristics of the voltage source (i.e. voltage as function of SOC) are given by the open circuit voltage curve determined in the component test. The characteristics of the battery's internal resistance are defined dependent on the length of the pulse duration in the component test, but are constant for one simulation time step.

The battery is depicted by the following equations, the basic schematics of the battery model are shown in Figure 2 below. The convention of the algebraic sign of current/power in the simulation model is positive for charging and negative for discharging.

$$U_{term} = U_{OCV} + R_i \, I_{bat}$$

where:

U_{term}	voltage at battery terminals [V]
U_{OCV}	open circuit voltage of battery [V]
R_i	internal resistance of the battery [Ohm]
I_{bat}	battery current [A]

$$I_{bat} = -\frac{U_{OCV}}{2R_i} \pm \sqrt{\left(-\frac{U_{OCV}}{2R_i}\right)^2 + \frac{P_{req}}{R_i}}$$

where:

I_{bat}	battery current [A]
U_{OCV}	open circuit voltage of battery [V]
R_i	internal resistance of the battery [Ohm]
P_{req}	power requested at battery terminals [W]

From the last equation one can deduct that the power at the battery terminals is limited to $P_{req,max} = U_{OCV}^2 / (4R_i)$.

The battery SOC is calculated according to the following equation:

$$SOC_t = SOC_{t-1} + \frac{I_{bat}}{Cap \times 3600} \Delta t \times 100$$

where:

SOC_t	SOC at current time step [-]
SOC_{t-1}	SOC at previous time step [-]
I_{bat}	battery current [A]
Cap	capacity of battery [Ah]
Δt	duration of current time step [h]

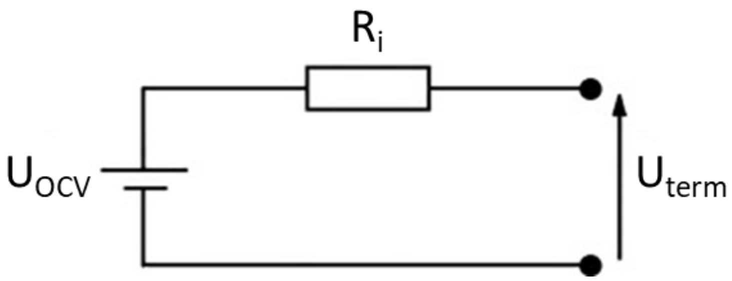


Figure 2: Schematics of the battery model

Since the internal resistance of the battery is determined dependent on the duration of a current pulse in the component test, the actual internal resistance for a specific time step in the simulation is linearly interpolated between the provided resistance values based on the current pulse duration. There no extrapolation is performed but for very short or very long pulses the boundary values of the internal resistance data are used. The pulse duration is simply integrated over time and reset every time the current changes its sign.

During the simulation the battery's SOC must always be between the minimum and maximum SOC threshold determined in the component test. Also the maximum charging and discharging current is limited in the model in accordance with the values determined in the component test.

2.3.2.1 Modular battery system

A method for combination of several batteries with different component characteristics was implemented in VECTO following the request by industry to depict the system design in real vehicles, where several battery elements are combined in a modular way depending on the desired capacity of the energy storage.

Thus, VECTO allows to connect multiple batteries together to a single big battery system. Therefore, every battery is assigned a string identifier. All batteries within the same string identifier are connected in series. All battery strings are then connected in parallel. Figure 3 shows this setup exemplarily for three different batteries arranged in two parallel strings.

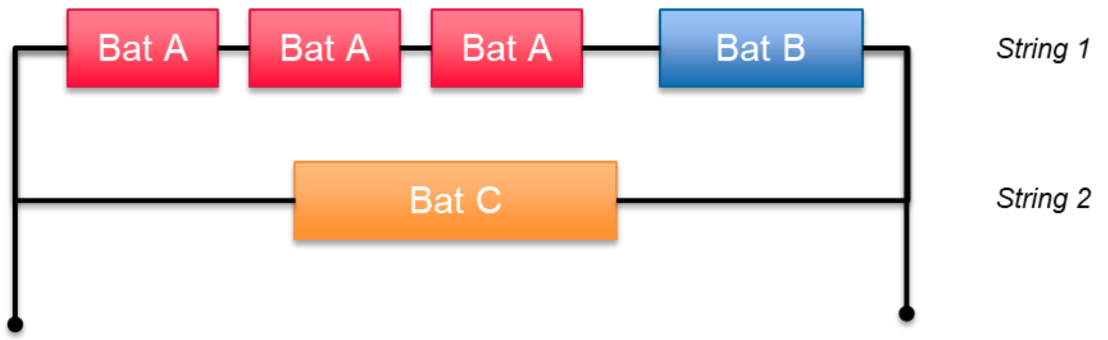


Figure 3: Arrangement of three different batteries in two strings (exemplary)

All batteries of one string of the modular battery system are aggregated to a single "BigBattery". In the example above, BigBattery1 consists of (Bat A, Bat A, Bat A, Bat B), and BigBattery2 consists of (Bat C). Nevertheless, the SOC is calculated for each battery module independently.

The capacity of a BigBattery is the capacity of the smallest of all modules in one string. The maximum current of a BigBattery is also the lowest maximum current of all modules in one string. The open circuit voltage as well as the internal resistance are calculated as the sum of all modules in one string.

The maximum charging and discharging power of the whole battery is the sum of the maximum charging/discharging power of all BigBatteries in the system.

The actual power demand is distributed between the BigBatteries as follows:

$$P_i = \frac{C_i}{\sum C_j} \delta_i \, P_{tot}$$

where:

P_i	power of BigBattery string i [W]
C_i	capacity of BigBattery string i [Ah]
C_j	capacity of each BigBattery string j over all BigBatteries [Ah]
δ_i	compensation term for SOC deviations of BigBattery string i (see below)
P_{tot}	total power demand [W]

$$\delta_i = 1 - sgn(P_{tot}) \frac{SOC_i - SOC_{average}}{SOC_{average}}$$

where:

sgn()	Signum function gives the sign for the given value. For values greater than zero the output is +1, for values smaller than zero the output is -1 and for values equal to zero the output is zero.
SOC_i	SOC of BigBattery string i (see below) [-]
$SOC_{average}$	average SOC over all BigBattery strings (see below) [-]

$$SOC_{average} = \frac{\sum (SOC_j \cdot C_j)}{\sum Cj}$$

where:

$SOC_{average}$	average SOC over all BigBattery strings [-]
SOC_j	SOC of BigBattery string j over all BigBatteries [-]
C_j	capacity of each BigBattery string j over all BigBatteries [Ah]

$$SOC_i = \frac{\min\limits_{B \in BB} (SOC_B \cdot C_B)}{C_i}$$

where:

SOC_i	SOC of BigBattery string i [-]
SOC_B	SOC of single battery module within BigBattery string i [-]
C_B	capacity of single battery module within BigBattery string i [Ah]
C_i	capacity of BigBattery string i [Ah]

In case a BigBattery reaches its maximum power, the power for this BigBattery is limited to its maximum power and then the power distribution is re-calculated with the remaining power demand.

The SOC of each battery module is then calculated according to the standard equations defined for the single battery model using the current for the specific BigBattery string computed by solving the following equation:

$$P_i = (U_i + R_i \cdot I_i)I_i$$

where:

P_i	power of BigBattery string i [W]
U_i	voltage of BigBattery string i [-]
R_i	internal resistance of BigBattery string i [Ohm]
I_i	current of BigBattery string i [A]

2.3.2.2 Battery component tests

The following Table 2 gives an overview of all the parameters of the battery determined in the component test:

Table 2: Overview on component testing for battery systems

Test name	Purpose	Description of testrun	Reference in Annex Xb	Input data for vehicle simulation
Rated capacity	Derive total energy content of the battery	Battery is preconditioned, fully charged and rested for a defined period. Then the actual measurement is performed by discharging with a defined current. Integration of current over time gives the energy content of the battery.	Point 5.4.1	Energy content of battery (actual usable energy restricted by SOC limits – either generic as function of cell technology or declared and verified in VTP)
Open circuit voltage	Derive battery voltage for different levels of energy content	Battery voltage is measured at different SOC levels after discharging with a defined current and a defined resting time.	Point 5.4.2	Battery voltage as function of the level of energy content (SOC)
Internal resistance	Derive parameter that defines internal losses of battery	Battery is operated in a specific cycle of discharging and charging current pulses. This is done for different currents at several SOC levels. Defined preconditioning is performed before each testrun.	Point 5.4.2	Internal resistance for battery model as function of SOC and current pulse duration (internal losses in the simulation are calculated as a function of this parameter and actual battery current)

Test name	Purpose	Description of testrun	Reference in Annex Xb	Input data for vehicle simulation
Current limits	Derive power limitations for the battery for charging and discharging	Declared values by battery manufacturer are verified in test for internal resistance	Point 5.4.2	Maximum and minimum allowed current of the battery

2.3.3 Capacitors

The capacitor is modelled by a zeroth order equivalent circuit model consisting of an ideal capacitor in series with an ohmic resistance. The characteristics of the capacitor model are given by the capacitance and the internal resistance determined in the component test which are both constant scalar values.

The capacitor is depicted by the following equations, the basic schematics of the capacitor model are shown in Figure 4 below. The convention of the algebraic sign of current/power in the simulation model is positive for charging and negative for discharging.

$$U_{term} = U_C + R_i I_{cap}$$

where:

U_{term}	voltage at capacitor terminals [V]
U_C	internal voltage of capacitor (see below) [V]
R_i	internal resistance of the capacitor [Ohm]
I_{cap}	capacitor current [A]

$$U_C = \frac{I_{cap}}{C} \Delta t + U_{cap,_{t-1}}$$

where:

U_C	internal voltage of capacitor [V]
I_{cap}	capacitor current [A]
C	capacitance [F]
Δt	duration of current time step [h]
$U_{cap,t}$	capacitor voltage at current time step [-]

$$I_{cap} = -\frac{U_C}{2R_i} \pm \sqrt{\left(-\frac{U_C}{2R_i}\right)^2 + \frac{P_{req}}{R_i}}$$

where:

I_{cap}	capacitor current [A]
U_C	internal voltage of capacitor [V]
R_i	internal resistance of the capacitor [Ohm]
P_{req}	power requested at capacitor terminals [W]

From the last equation one can deduct that the power at the capacitor terminals is limited to $P_{req,max} = U_C^2 / (4R_i)$.

Since for a capacitor the SOC is directly proportional to the capacitor internal voltage, the SOC is calculated by linear interpolation between maximum and minimum voltage based on the actual capacitor voltage U_{cap}. The capacitor SOC is calculated according to the following equation:

$$SOC_C = \frac{U_C - U_{C,min}}{U_{C,max} - U_{C,min}} \times 100$$

where:

SOC_C	SOC of the capacitor [-]
U_C	internal voltage of capacitor [V]
$U_{C,min}$	minimum voltage of capacitor [V]
$U_{C,max}$	maximum voltage of capacitor [V]

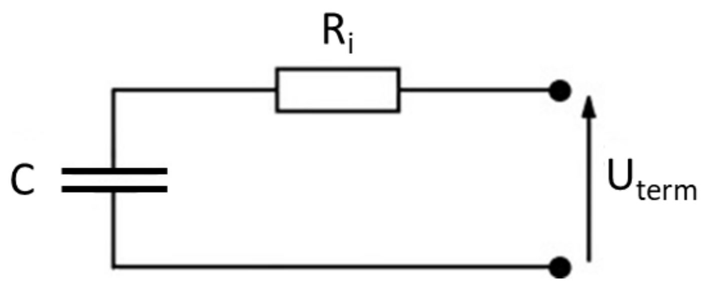


Figure 4: Schematics of the capacitor model

During the simulation the capacitor's SOC must always be between the minimum and maximum voltage threshold determined in the component test. Also the maximum charging and discharging current is limited in the model in accordance with the values determined in the component test.

2.3.3.1 Capacitor component tests

The following Table 3 gives an overview of all the parameters of the capacitor determined in the component test:

Table 3: Overview on component testing for capacitor systems

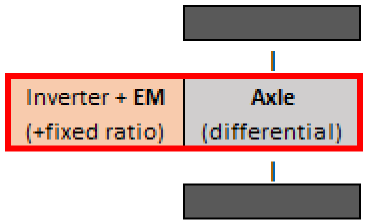
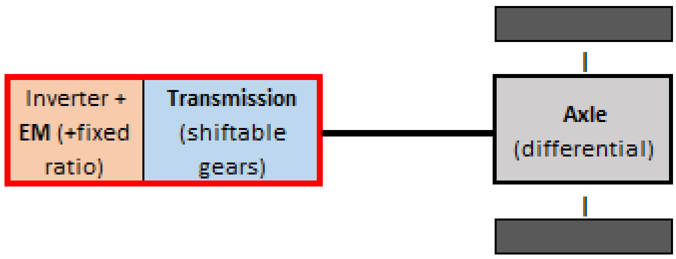
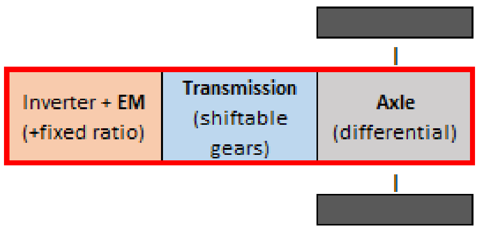
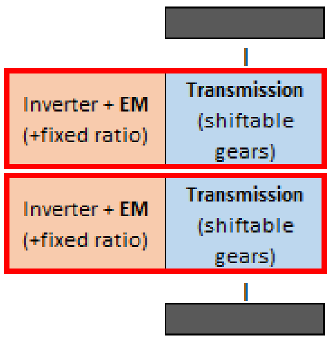
Test name	Purpose	Description of testrun	Reference in Annex Xb	Input data for vehicle simulation
Capacitance	Derive parameter that defines correlation of integrated capacitor current to energy stored	Single testrun consisting of a charging and discharging cycle with defined resting periods in between.	Point 6.3	Capacitance for capacitor model (integration of ratio of current divided by capacitance gives delta energy from/to capacitor)
Internal resistance	Derive parameter that defines internal losses of capacitor	Combined single testrun with capacitance	Point 6.3	Internal resistance for capacitor model (internal losses in the simulation are calculated as a function of this parameter and actual capacitor current)

2.3.4 IEPC

As explained in the introduction, the need to develop this completely new type of powertrain component for xEV vehicles was identified over the course of the project. Thus, related methods for simulation as well as component testing were developed. Such components are characterised by an integrated functionality of several "conventional components" (electric motor, gearbox, differential) into a single unit. Separate testing of these “classic” VECTO components is on the one hand hardly possible - as it would require demounting of the single parts and setting up special housings for testing of each single part - and would on the other hand not give representative performance data due to decomposing the integrated system into several individual sub-systems with tailor-made hardware for testing purposes only.

Table 4 gives an overview of all different system configurations of an IEPC that are considered in VECTO.

Table 4: Archetypical configurations of integrated components identified (red bold frame defines boundaries for IEPC)

<table>
<tr><th>ID</th><th>Symbolic picture</th></tr>
<tr><td>“1”
EM plus axle</td><td>
</td></tr>
<tr><td>“2”
EM plus transmission, axle as separate component</td><td>
</td></tr>
<tr><td>“3”
EM plus transmission plus axle</td><td>
</td></tr>
<tr><td>“4”
EM plus transmission per wheel (no axle)</td><td>
</td></tr>
</table>

For component testing, the same basic principles as for EM apply, but depending on the specific system configuration the test setup or the test runs are partly carried out differently.

For an IEPC with shiftable forward gears all testruns listed in Table 1 for EM except the EPMC are only performed in one specific gear. For the EPMC to be measured on all forward gears, the grid of target setpoints determined based on the maximum and minimum torque limits determined in a single gear needs to be converted to the respective equivalent target setpoints for all other gears by following a dedicated set of defined provisions defined in the Regulation.

Based on the respective parameters in the component data describing the layout of the specific system configuration, the correct powertrain architecture and position of the system in the vehicle’s powertrain is allocated by the simulation tool automatically.

The development and implementation of this technology was outsourced to a separate contract and is thus not further documented in this report.

2.4 xEV Powertrain Architectures in VECTO

The following sections give an overview of all the different powertrain architectures that were defined for VECTO following the 2nd amendment of Regulation (EU) 2017/2400. Basically, there are three big groups of powertrain architectures, namely the parallel HEVs, the serial HEVs and the PEVs.

The term hybrid electric vehicle (HEV) means a hybrid vehicle where one of the propulsion energy converters is an electric machine and the other one is an internal combustion engine. The specifics of the parallel HEV architecture are explained in chapter 2.4.1, those for serial HEV in chapter 2.4.2.

The term pure electric vehicle (PEV) means a vehicle equipped with a powertrain containing exclusively electric machines as propulsion energy converters and exclusively rechargeable electric energy storage systems as propulsion energy storage systems and/or alternatively any other means for direct conductive or inductive supply of electric energy from the power network providing the propulsion energy to the motor vehicle. The specifics of the PEV architecture are explained in chapter 2.4.3.

Chapter 2.4.4 explains all powertrain configurations covered in the course of this project and defines in detail which different powertrain components are applied for each specific architecture.

2.4.1 Definitions of parallel-HEV architectures

A parallel HEV is defined as a powertrain architecture of the type HEV that includes an ICE that powers only a single mechanically connected path between the engine and the wheels of the vehicle. A special variant of parallel hybrid with a fully integrated powertrain component is depicted by an IHPC (see chapter 2.4.5).

Figure 5 illustrates the possible parallel HEV standard architectures implemented in VECTO (except for IHPC).

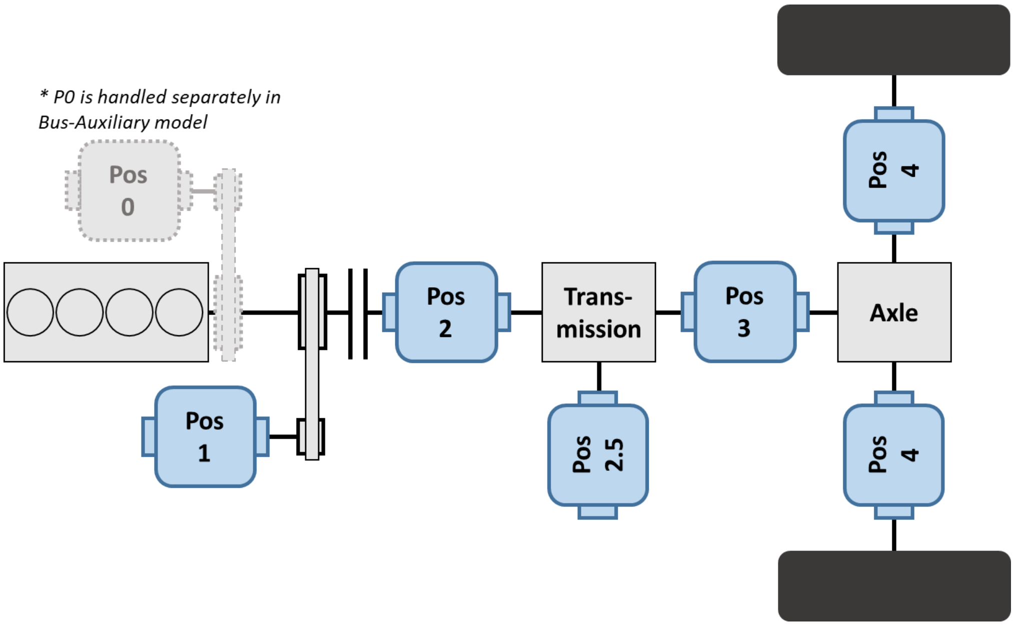


Figure 5: Powertrain architecture and position of EMs for a HEV parallel configuration

Based on the demand raised by industry, there was a special variant of a parallel HEV configuration implemented with the EM located at position 2.5. This P2.5 architecture is characterized by the following points:

- The EM is connected to the powertrain via a specific shaft inside the transmission (e.g. layshaft) somewhere between the transmission input and output shaft.
- Since the inner structure of the transmission is not known by VECTO, this system needs to be modelled in a simplified way. In order to handle all possible connection points of the EM to the transmission, the EM is virtually moved to the input side of the transmission and the P2.5 system is modelled as a P2 system with different transmission ratios of the EM to the main powertrain for each gear of the transmission. This conversion is done automatically in VECTO, the component input data only needs to be provided as for a regular EM.
- Thus, a specific transmission ratio for each mechanical gear in the transmission needs to be provided. This ratio is defined as either “n_{GBX_in} / n_{EM}“ for an EM without additional ADC or “n_{GBX_in} / n_{ADC}“ for an EM with additional ADC.[6]

[6] n_{GBX_in} is the rotational speed at the transmission input shaft

n_{EM} is the rotational speed at the EM output shaft

n_{ADC} is the rotational speed at the ADC output shaft

ADC (additional driveline component) is a transmission stage with a fixed gear ratio between EM and main powertrain (refer to chapter 2.3.1.1 for details)

For the 2nd Amendment, only configurations with one or more identical EMs at one of the positions 1 to 4 are accepted in VECTO. Parallel HEV configurations with EMs at several different positions were identified as not relevant in the working groups and would require a significantly more complicated procedure in VECTO (especially with regard to the generic operation strategy).

2.4.2 Definitions of serial-HEV architectures

A serial HEV is defined as a powertrain architecture of the type HEV that includes an ICE that powers one or more electrical energy conversion paths with no mechanical link between the ICE and the wheels of the vehicle. A special variant of serial hybrid with a fully integrated powertrain component is depicted by an IEPC (see chapter 2.3.4).

Figure 6 illustrates the possible serial HEV architectures implemented in VECTO (except for IEPC). As for parallel HEVs only configurations are allowed, which have EM(s) located at a single position in the mechanical powertrain (right part of the figure).

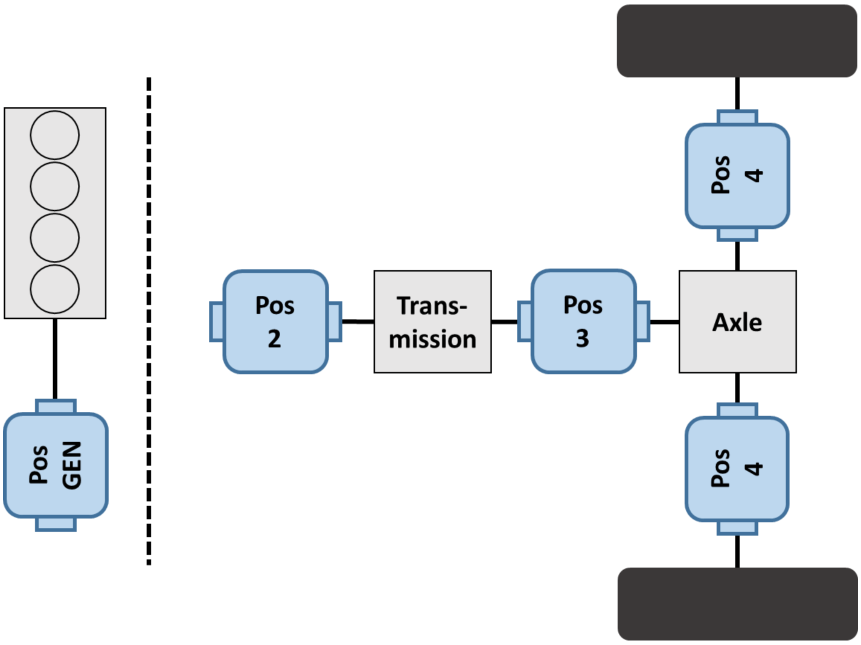


Figure 6: Powertrain architecture and position of EMs for a HEV serial configuration

2.4.3 Definitions of PEV architectures

A PEV is a pure electric vehicle, commonly referred to as “battery electric vehicle”. For the second amendment of Regulation (EU) 2017/2400 only vehicles with a single powertrain are covered.[7] A special variant of PEV with a fully integrated powertrain component is depicted by an IEPC (see chapter 2.3.4).

[7] Vehicles with multiple permanently mechanically independent powertrains are exempted from VECTO for the time being (see chapter 3.2).

Figure 7 illustrates the possible PEV standard architectures implemented in VECTO (except for IEPC).

As with the hybrid electric powertrain configurations, only those PEV configurations are currently covered in VECTO where the EM(s) are installed in one of the defined positions.

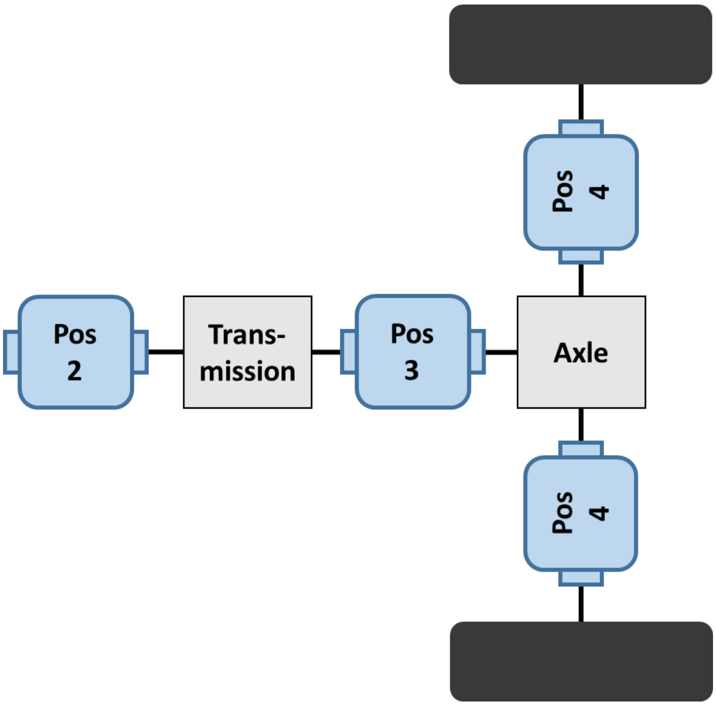


Figure 7: Powertrain architecture and position of EMs for a PEV configuration

2.4.4 Powertrain configurations and applicable components

Table 5 gives an overview of all powertrain configurations covered in the course of this project and defines in detail which different powertrain components are applied for each specific architecture. Based on this characterisation of the vehicle's powertrain configuration on the top level, a clear set of rules was elaborated in order to define the applicable standard architecture to be used for the simulation of a specific vehicle. Based on two parameters, namely the vehicle's powertrain configuration and - for powertrains not containing an IEPC or IHPC - in addition the position of the electric machine in the vehicle's powertrain, a certain powertrain architecture ID is assigned for each specific vehicle. This powertrain architecture ID is used as input to the simulation tool in order to characterize the applicable standard architecture for the simulation. Table 6 gives a detailed explanation on how to derive the correct position of the electric machine in the vehicle's powertrain.

This means that a total of 19[8] new standard powertrain architectures were implemented into VECTO, where so far only one was existing (i.e. the conventional ICE-only powertrain).

[8] Table 5 specifies only 13 different types of standard powertrain architectures, but for both E-IEPC and S-IEPC there are 4 specific sub-variants existing respectively (according to chapter 2.3.4), thus it is resulting in a total number of 19 different standard powertrain architectures

Table 5: Valid inputs of powertrain architecture into the simulation tool

Powertrain type	Powertrain configu-ration	Architecture ID for VECTO input	Powertrain component present in vehicle								Comments
			ICE	EM position GEN	EM position 1	EM position 2	Transmission	EM position 3	Axle	EM position 4	
PEV	E	E2	no	no	no	yes	yes	no	yes	no	
		E3	no	no	no	no	no	yes	yes	no	
		E4	no	no	no	no	no	no	no	yes	
	IEPC	E-IEPC	no	no	no	no	no	no	*1)	no	
HEV	P	P1	yes	no	yes	no	yes	no	yes	no	
		P2	yes	no	no	yes	yes	no	yes	no	*2)
		P2.5	yes	no	no	yes	yes	no	yes	no	*3)
		P3	yes	no	no	no	yes	yes	yes	no	*4)
		P4	yes	no	no	no	yes	no	yes	yes	
	S	S2	yes	yes	no	yes	yes	no	yes	no	
		S3	yes	yes	no	no	no	yes	yes	no	
		S4	yes	yes	no	no	no	no	no	yes	
		S-IEPC	yes	yes	no	no	no	no	*1)	no	

**1) "Yes" (i.e. axle component present) only in case both parameters "DifferentialIncluded" and "DesignTypeWheel-Motor" are set to "false"*

**2) Not applicable for transmission types APT-S and APT-P. A vehicle with an IHPC type 1 is configured in VECTO as a special version of a P2.*

**3) In case the EM is connected to a specific shaft inside the transmission (e.g. layshaft) in accordance with the definition in Table 8*

**4) Not applicable for front wheel driven vehicles*

Further details on the powertrain configurations, specifically the positioning of the EM in the powertrain and the compatible transmission types, are defined for each specific architecture in Table 6.

Table 6: Definition of the EM position in the vehicle's powertrain

Position index of EM	Powertrain configuration	Compatible Transmission type	Definition / Requirements*	Further explanations
1	Parallel HEV	AMT, APT-S, APT-P	Connected to the powertrain upstream of the clutch (in case of AMT) or upstream of the torque converter input shaft (in case of APT-S or APT-P). The EM is connected to the crankshaft of the ICE directly or via a mechanical connection type (e.g. belt).	Distinction of P0: EMs which can as a matter of principle not contribute to the propulsion of the vehicle (i.e. alternators) are handled in the input to auxiliary systems. Notwithstanding the previous sentence, EMs at this position which can in principle contribute to the propulsion of the vehicle but for which the declared maximum torque in accordance with Table 9 of Annex III is set to zero shall be declared as "P1" (see chapter 2.4.6.1 for further details).
2	Parallel HEV	AMT	The electric machine is connected to the powertrain downstream of the clutch and upstream of the transmission input shaft.	
2	PEV, Serial HEV	AMT, APT-N, APT-S, APT-P	The electric machine is connected to the powertrain upstream of the transmission input shaft (in case of AMT or APT-N) or upstream of the torque converter input shaft (in case of APT-S, APT-P).	
2.5	Parallel HEV	AMT, APT-S, APT-P	The electric machine is connected to the powertrain downstream of	The EM is connected to a specific shaft inside the transmission (e.g.

Position index of EM	Powertrain configuration	Compatible Transmission type	Definition / Requirements*	Further explanations
			the clutch (in case of AMT) or downstream of the torque converter input shaft (in case of APT-S or APT-P) and upstream of the transmission output shaft.	layshaft). A specific transmission ratio for each mechanical gear in the transmission needs to be provided.
3	Parallel HEV	AMT, APT-S, APT-P	The electric machine is connected to the powertrain downstream of the transmission output shaft and upstream of the axle.	
3	PEV, Serial HEV	n.a.	The electric machine is connected to the powertrain upstream of the axle.	
4	Parallel HEV	AMT, APT-S, APT-P	The electric machine is connected to the powertrain downstream of the axle.	
4	PEV, Serial HEV	n.a.	The electric machine is connected to the wheel hub and the same arrangement is installed twice in symmetrical application (i.e. one on the left and one on the right side of the vehicle at the same wheel position in logitudinal direction).	
GEN	Serial HEV	n.a.	The electric machine is mechanically connected to an ICE but under no operational circumstances mechanically connected to the wheels of the vehicle.	

* The term EM as used here includes an additional ADC component, if present.

2.4.5 Other possible architectures

In the course of the project, further powertrain architectures were announced by vehicle manufacturers and the supplier industry. The related information was partly presented in the public working groups and partly only communicated bilaterally with the Commission and the project team.

Out of the several possible technologies, only one technology has been identified as relevant for series production in the near future (third and possibly fourth amendment of Regulation (EU) 2017/2400) and that is the HEV concept with the Scania "GEM" hybrid gearbox system. For a simplified representation of this technology in VECTO, the element "Integrated HEV powertrain component" (IHPC) was designed that allows modelling of such vehicles via a combination of special variant of a P2 hybrid (electric motor with separate maps for each gear engaged in the transmission) and specially tested “transmission” component. The development and implementation of this technology was outsourced to a separate contract and is thus not documented in this report.

2.4.6 "Micro hybrids"

The term “micro hybrids” is often used for a special alternator operation strategy where the alternator is used to recuperate as much energy as possible during deceleration events. Sometimes also the term “P0” hybrid is used alternatively for such concepts. The decisive characteristic of such systems is that the installed alternators shall only provide electric power to the board net of the vehicle and are not designed to support in propelling the vehicle.

With this system design, micro-hybrids can therefore be considered as a special form of the vehicle's electrical auxiliary consumer system. In VECTO, different modelling depths for auxiliary consumers are applied for lorries (low energy consumption, simple modelling) and heavy buses (significant energy consumption, high modelling depth). Following this approach, micro-hybrids as described in section 2.4.6.1 are modelled in great detail for heavy buses and are neglected for lorries. The background to the latter point is explained in section 2.4.6.2.

2.4.6.1 Heavy buses

For correct modelling it is essential for the VECTO method that a very clear line is drawn between P0 hybrids - which are not really an actual HEV - and a “real HEV” where the propulsion power can be provided by either of the two energy converters (i.e. ICE and EM). Therefore, the definition of an EM as “propulsion energy converter” in Annex III of Regulation (EU) 2017/2400 is key. In addition to that there was a dedicated text included in Annex III where all different supported powertrain architectures are defined. This dedicated paragraph allows for a clear distinction of P0 from P1 HEV, which have the same basic technical arrangement but differ significantly in available power levels: “EMs which can as a matter of principle not contribute to the propulsion of the vehicle (i.e. alternators) are handled in the input to auxiliary systems.”[9]

[9] Furthermore, it is required for the VECTO method to allow to limit the available EM power for driving (even down to zero EM propulsion torque) for regular P1 HEVs since such vehicles, which do not actually use the “boosting” function for are present on the market. Also, for considering these special cases a dedicated paragraph was included in the Regulation: “However, EMs at this position which can in

The P0 functionality which is called “smart alternator” in the VECTO context was already introduced in the original auxiliary model for buses created by in a preceding project (see (Norris J. 2016)).

The basic principles of the original model were overtaken but modified in certain aspects in order to be compatible with expectations from industry regarding specific distinguishing features or characteristics. In order to depict the influence of the capacity of the electric storage linked to the smart alternator, a dedicated storage model was implemented depicting the real capacity to be parameterized via the respective input data defined in the VECTO Regulation. This electric storage is modelled as a simple integrator with an efficiency factor accounting for losses in the storage process. Depending on the type and technology of the storage the capacity is calculated based in standardized formulas. Furthermore, the so-called “result cards” input from the original model were eliminated in order to save the dedicated full vehicle testing effort. These result cards were designed to limit the alternator output power during recuperation events but required a complex dedicated component test with the full vehicle on a test track. The new approach foresees just a declaration of nominal values for maximum alternator power with a reference to an existing standard. This updated approach, based on modelling in VECTO rather than importing measurement results, is compatible with the modelling of all other HEV configurations and is considered to be much more robust and flexible than the test method proposed in the previous project.

The limitation of the actual alternator output power during recuperation events in the adapted model is influenced by two independent parameters: the declared maximum alternator power on the one hand and the current limits for the storage which are generically defined depending on the declared storage type and technology.

When it comes to the interaction with the second smart auxiliary system available, the smart compressor for the pneumatic system, and also to the interaction with the EM as part of the HEV system, there need to be rules defined for the priorities of recuperation behaviour of all the different systems which compete for the same energy. The system priorities for the different smart auxiliaries were taken over from the original auxiliary model: First the compressor off power demand is covered, then the smart alternator may maximize its braking power up to the maximum system limitations, as third element the compressor on power demand is covered. The applicable power limits for the pneumatic system are derived from the generically defined compressor curves, see (Norris J. 2016). In the interaction with an actual HEV system, the EM of the HEV has priority over both smart auxiliary systems (i.e. electric and pneumatic).

The relevant inputs required for the smart alternator system are listed in Table 7.

Table 7: Relevant inputs required for the smart alternator system

System	Parameter name	Allowed inputs	Comments
Alternator	Alternator technology	conventional / smart / no alternator	

principle contribute to the propulsion of the vehicle but for which the declared maximum torque in accordance with Table 9 of this Annex [III] is set to zero shall be declared as ‘P1’.

System	Parameter name	Allowed inputs	Comments
	Smart alternator – maximum rated current	value in [A]	Maximum rated current at nominal speed in accordance with manufacturer's labelling or data sheet, or measured in accordance with standard ISO 8854:2012 Input for each smart alternator separately.
Batteries for smart alternator systems	Technology	lead-acid battery – conventional / lead-acid battery –AGM / lead-acid battery – gel / li-ion battery - high power / li-ion battery - high energy	Input for each battery charged by smart alternator system separately.
	Nominal voltage	value in [V]	Allowed values: '12', '24', '48'
	Rated capacity	value in [Ah]	
Capacitors for smart alternator systems	Technology	with DC/DC converter	Input for each capacitor charged by smart alternator system separately.
	Rated voltage	value in [F]	
	Rated capacitance	value in [V]	

The detailed operation method of such smart alternator systems in the context of the whole vehicle system is explained in detail in a separate chapter on the auxiliary model applicable to buses (see 2.6.2).

2.4.6.2 Lorries

The modelling of "P0" micro-hybrids described above was only implemented for heavy buses within the framework of the "Advanced Auxiliary Model". For lorries, this technology is therefore not eligible under Regulation (EU) 2017/2400 and VECTO. The reasons for this decision are as follows:

1) Due to the significantly lower energy consumption of the electric system of lorries (approx. 1 kW, compared to approx. 5 kW for heavy buses), the technology results in significantly lower savings potentials.

2) The technology is likely to have been state of the art for years in the majority of truck models.[10] If the technology were only now included in Regulation (EU) 2017/2400, this would result in a (small) reduction in fleet consumption compared to earlier years of construction in VECTO, which does not exist in reality.

2.5 xEV operation strategies in VECTO

The decisive feature of HEVs is that they have two sources of propulsion energy, combustible fuel and an electric storage. The energy management strategy determines how the driver demand is split over the different energy sources for each time step in the simulation. These decisions impact both, the instantaneous and the overall fuel consumption over the cycle since the variation in stored electric energy over the cycle needs to be accounted for when correctly assessing the system efficiency.

2.5.1 Parallel HEV

Originally, based on the past discussions with industry as summarized in the outcome of the preceding feasibility study (Silberholz G. 2017), it was assumed that a very simple control strategy could be reasonably used for parallel HEVs in VECTO. Also in the early stages of this project, the goal was still to implement a very simple strategy[11] which captures the main HEV effect of recuperation adequately.

But after some of the first more detailed simulations were performed for development of the simple strategy, this concept showed some significant shortcomings with the most important being:

- By prioritizing the use of (recuperated) electric energy the course of the storage's SOC depends strongly on the vehicle and cycle combination and a charge sustaining operation of the vehicle cannot be reached for all possible configurations. Thus, a significant amount of energy might be corrected for in post-processing introducing a non-negligible uncertainty on the final fuel consumption.
- For HEV concepts with a downsized ICE the vehicle is not able to follow the target speed in the cycle similar as a conventional one since the available propulsion power is too low in case the electric storage is empty. This fact would lead to an unfair comparison between different vehicles (conventional and HEV) depending on the ratio of ICE power to total propulsion power.
- For parallel HEVs, in case of the simple operation strategy separate rules for gear shifting would be required to select an appropriate gear also in situations where the ICE is operated at low loads with the EM assisting or where the ICE is completely off.

[10] The first truck measured as part of the VECTO development (Hausberger S. 2012) already had this technology on board.

[11] The simple strategy aims at recuperating as much electric energy as possible. Furthermore, use of electric propulsion energy is prioritized as long as the SOC is above a certain minimum threshold. Active charging of the storage by the ICE is not allowed.

- A simple method would not be future proof for handling additional degrees of freedom in the HEV system (e.g. splitting power over ICE and multiple EMs)

Based on these shortcomings, a generic control strategy needed to be designed which would work for all possible combinations of vehicles and cycles. Most of today's energy management strategies for HEVs are rule-based control[12] which requires large amounts of calibration work in order to be optimized for a specific vehicle configuration. This approach is not viable for the VECTO method since it would require some flexible elements and parameters allowing the vehicle OEM to tune the model in order to give optimum results. Furthermore, several studies have shown that the performance of rule-based control (especially if designed more generally and not very specifically calibrated for a certain vehicle and use case) is poor in comparison with more sophisticated controls depending on the respective usage profile and the vehicle configuration (Kim N. 2011). Thus, rule-based control would lead to unfair ranking between different vehicles if only generic rules would be applied without allowing any optimization by vehicle manufacturers. There are in fact options available to perform this optimization in an automatized way (presentations were given by Siemens in the respective expert groups during the first phase of this project), but this would require a commercial software package for both, the optimization routine as well as the corresponding vehicle simulation itself. Some other established methods for energy management in HEVs are model predictive control and dynamic programming, which both require estimation of the demanded power in the future and are intractable for real-time applications due to their computational load.

The only candidate for a generic control strategy working for any arbitrary vehicle and mission and also allowing still a reasonable computation time (much faster than real time) – identified after an extensive literature research – was a method from the field of control theory. Such a method allows the definition of an objective optimization criterion, usually the minimization of the integral fuel consumption over the cycle. All details about the chosen method as well as the specific implementation in VECTO are explained in the following chapter.

2.5.1.1 The energy management problem in parallel HEVs

The essence of the HEV energy management problem is the instantaneous management of the power flows from all energy converters to provide the demanded propulsion power and in addition to that achieve the control objectives. The control objectives are in most cases a defined integral over a longer time horizon (e.g. for fuel consumption) whereas the control actions are local in time. Furthermore, the control objectives are often subject to constraints (e.g. maintaining SOC of the electric storage within a defined range). The function describing the dependency of the control objectives on the control actions is in general referred to as cost function.

If focusing on the fuel consumption, which is the relevant objective within the context of VECTO, the energy management problem in a HEV consists of finding the optimal control actions leading to the minimization of fuel consumed over a certain driving distance (i.e. the cost function):

---

[12] The main characteristic of rule-based controls is their effectiveness in real-time implementation. They do not involve explicit optimization, but rely on a set of defined rules to decide the value of the control to apply at each time. Rules are generally designed based on heuristics, engineering intuition or based on the knowledge of the optimal solution generated in offline simulations.

$$u^* = \underset{u}{\operatorname{argmin}} \left\{ \int_0^{t_f} \dot{m}_{fuel}(x,u)dt \right\} \qquad \text{Equation 1}$$

where:

argmin	mathematical operator (arguments of the minima) defining the elements of the domain of some function at which the function values are minimized (i.e. the inputs, or arguments, within a given domain at which the function outputs are as small as possible)
$\dot{m}_{fuel}$	fuel mass flow
t_f	time at the end of the evaluated driving distance
u	vector of control actions (i.e. electric power) with one value for each timestep
u*	vector of optimal control actions
x	state variable (i.e. SOC)

The minimization of the cost function is subject to local constraints related to physical limitations of the actuators (i.e. energy converters and storages), limitation of the storage capacity and the requirement to maintain the SOC within a defined range. The straight forward local constraints are that all admissible control candidates are not allowed to violate any power or speed limit of any powertrain component and that the requested power demand will be satisfied by all admissible control candidates. The following constraints can be formulated by using the state equation of the system which defines the SOC variation as function of the battery power:

$$\dot{x} = -\frac{P_{bat}(x(t),u(t))}{Q_{bat}V_{bat,ocv}} \qquad \text{Equation 2}$$

where (for a zeroth order equivalent circuit model – see chapter 2.3.2):

P_{bat}	battery power [W]
Q_{bat}	battery capacity [Ah]
$V_{bat,ocv}$	battery open-circuit voltage [V]

Local constraint regarding SOC: The value of the state variable x (i.e. SOC) is constrained to be between a lower and an upper limit.

Global (integral) constraint regarding SOC: The final SOC value has to be the same as that at the beginning of the cycle for HEV in a charge-sustaining operation.[13]

Thus, the optimal energy management problem in a charge-sustaining HEV can be summarized as finding the optimal control sequence u* that minimizes the cost function (given in the

[13] In practical application of this energy management problem – as described in detail in the following chapter 2.5.1.2 – a certain small difference of SOC over a simulated cycle cannot be avoided due to discretization with regard to time and controls and applicability of the method. This remaining difference in SOC needs to be accounted for in order to allow a fair comparison between different simulations and

argmin operator in Equation 1) while meeting the dynamic state constraint (given in Equation 2), the global state constraint (final SOC value) and all local state and control constraints.

Pontryagin's Minimum Principle (PMP) is one method to solve this type of problem. As part of the PMP a specific function was developed – the so-called Hamiltonian – used to solve a problem of optimal control for a dynamic system. The PMP defines that a necessary condition for solving the optimal control problem is that the chosen control should minimize the Hamiltonian. Meaning as soon as an optimal solution to the control problem exists, it must be an extremal control leading to a resulting minimum value of the Hamiltonian. But not all extremal controls are necessarily optimal. Typically, the problem can be solved numerically by using an iterative procedure for problems with a single state and where the effect of the co-state on the solution is easily understood.

of different vehicles. Chapter 2.5.1.5 describes a generic method for accounting for this remaining deviation in SOC.

The HEV energy management problem is a scalar problem, both in the state and in the control. The explicit dependence of the control problem on time is defined by the varying propulsion power request from the driver (which is in turn dependent on the driving cycle). Hence, the Hamiltonian for the HEV energy management control problem is defined as:

$$H = \dot{m}_{fuel}\left(u(t), P_{dem}(t)\right) + p(t)\ \dot{x}\left(x(t), u(t)\right) = \\ = \dot{m}_{fuel}\left(u(t), P_{dem}(t)\right) - p(t)\ \frac{P_{bat}(x(t),u(t))}{Q_{bat}V_{bat,ocv}} \quad \text{Equation 3}$$

where:

P_{dem}	demanded propulsion power [W]
p(t)	co-state of the Hamiltonian [g/s]

The second expression is derived by substituting $\dot{x}\left(x(t), u(t)\right)$ by Equation 2.

The principle of PMP now permits redefining the global HEV optimal control problem in terms of local conditions expressed by the above differential equations and by the instantaneous minimization of the Hamiltonian at each time increment (further derivation see chapter 2.5.1.2). Having this said, it is worth noting that the global nature of the problem does not disappear, since the boundary conditions are still given at the initial and final time. Therefore, the problem cannot be solved as a standard dynamic evolution problem but with an iterative procedure. Furthermore, the existence and uniqueness of the solution cannot be proved formally in the general case, but it is reasonable to assume that at least one optimal solution exists for the HEV energy management problem. This is due to the fact that there must necessarily be at least one sequence of controls u(t) giving the lowest possible fuel consumption over a defined optimization horizon.[14]

2.5.1.2 Basics of generic HEV control strategy

The chosen approach for VECTO is based on the concept of the so-called Equivalent Consumption Minimization Strategy (ECMS) which is a well established heuristic method to address the optimal control problem for HEV (Onori S. 2016). ECMS, even though invented based on engineering intuition, can be analytically derived using Pontryagin's Minimum principle (PMP) explained in the previous chapter.

Taking Equation 3 as a basis, it is obvious that $\dot{m}_{fuel}$ is completely independent of the state x(t) (i.e. the SOC) and due to the characteristics of the electric storage also P_{bat} (i.e. due to nearly constant voltage, since power is the product of voltage and current) and $V_{bat,ocv}$ are nearly independent of x(t) as long as the SOC is kept within the defined minimum and maximum limits. Therefore, the derivative of the Hamiltonian equation is approximately equal to zero under these boundary conditions:

$$\dot{p}^* = -\frac{\partial H}{\partial x} \approx 0 \quad \text{Equation 4}$$

[14] For more background information on the PMP please refer to (Onori S. 2016)

This means that the PMP optimal solution of the HEV energy management problem is characterized by a constant co-state. This constant, though, is unknown a prior but it can be found by means of an iterative search procedure as explained further below.

Defining now the so-called equivalence-factor, s_{eq}, as $s_{eq} = - p / (Q_{bat} V_{bat,ocv}(\approx \textit{constant}))$, the Hamiltonian derived above becomes the so-called cost function for the ECMS approach:

$$\dot{m}_{fuel,eq}\big(t, u(t), x(t)\big) = \dot{m}_{fuel}\left(u(t), P_{dem}(t)\right) + s_{eq}\, P_{bat}(x(t), u(t)) \qquad \text{Equation 5}$$

This shows that the ECMS method is intrinsically equivalent to the PMP formulation. The latter equation now corresponds to the minimization of a cost function which depends only on the current driving conditions (via P_{dem}) and on s_{eq}. The principle of PMP now permits redefining the global HEV optimal control problem, the global minimization problem given by Equation 1 $\underset{u}{\operatorname{argmin}}\left\{\int_0^{t_f} \dot{m}_{fuel}(x,u)dt\right\}$ is reduced to the instantaneous (local) problem $\int_0^{t_f} \underset{u}{\operatorname{argmin}}\left\{\dot{m}_{fuel,eq}(x,u)\right\} dt$ to be solved at each instant only using arguments based on actual energy flow in the powertrain. Selecting suitable values for s_{eq} in order to guarantee optimal performance of the controller is now the challenge with ECMS.

Despite of the mathematical formalism to derive the concept of ECMS from PMP, the basic idea of ECMS can be explained from a more practical point of view as follows: In charge-sustaining operation of hybrid electric vehicles, the difference between the initial and final SOC of the storage is negligible with respect to the total propulsion energy over the cycle. This means that the electrical storage system is used only as an intermediate energy buffer and ultimately all energy comes from fuel. Thus, the battery can be seen as an auxiliary, reversible fuel tank where any stored electrical energy used during a battery discharge phase must be replenished at a later stage actively using fuel from the engine (i.e. charging by ICE load point increase) or through regenerative braking.

Two different directions of electric energy flow have to be considered:

1. When discharging the electric storage at the current operation point, it will need to be recharged somewhere in the future resulting in additional fuel consumption at some future time. The magnitude of this future additional fuel consumption depends on the operating point of the ICE at that recharging event and on how much energy can be recuperated over the cycle. Both of these factors are in turn dependent on the vehicle parameters and the driving cycle itself.
2. When charging the electric storage at the current operation point, this stored electric energy will be used to substitute ICE energy (by either lowering the ICE load or completely replacing the ICE with pure electric driving) at some future time resulting in fewer fuel consumption in the future. Here again, the actual fuel saving in the future depends on the vehicle parameters and the driving cycle.

The underlying principle of ECMS is now that the electrical energy is accounted for as virtual fuel consumption in the current time step. The true value of this virtual fuel consumption is obviously unknown, as it depends on future vehicle behavior, but it has been shown that it can be related to vehicle specifications and driving conditions in a broad sense (e.g. inner city versus highway driving). Thus, an approximate mean efficiency is assumed to define the future operating points where the actual fuel usage/saving occurs (i.e. either charging the storage or assisting the ICE) due to the decision taken earlier related to the virtual fuel use. In case the virtual fuel consumption is considered as future saving, the equivalent fuel flow is negative and vice-versa.

The key idea of ECMS is that this virtual fuel consumption related to the electric energy use at the present state can be summed to the present real fuel consumption of the ICE to obtain the instantaneous equivalent fuel consumption. This summation requires the transformation of electrical energy into fuel by application of an equivalence factor, s_{eq}, which differs whether the battery is being charged or discharged. Thus, a certain cost is assigned to the use of electricity where the equivalence factor represents the chain of efficiencies through which fuel is transformed into electrical power and vice-versa. As such, the efficiency of this transformation chain varies depending on the operating condition of the powertrain. In practical application of ECMS, it can be defined as a set of constants (i.e. for discharging and charging separately) which can be interpreted as the average overall efficiency of the electric path for a specific vehicle and cycle combination. Values of s_{eq} above the average tend to penalize the use of the battery as a prime mover, thus the final state-of-charge is too high. Lower values of s_{eq} on the other hand tend to overfavour the use of the battery, thus the final state-of-charge is too low. Determining the optimal equivalence factor for a certain application requires knowledge of the entire driving cycle a priori – which is not typically available.

As opposed to mathematical optimization techniques, which can be applied offline with high computation effort to derive an optimal controller for a certain typical driving pattern known a priori (e.g. urban bus operation), ECMS is a much simpler and more applicable approach. ECMS consists of sub-optimal, real-time controllers, which are based on the minimization of a properly defined cost function which depends only on the actual driving conditions. Even though, optimal control implementation in a dynamic system, whose future is unknown, is necessarily suboptimal, ECMS yields very close to optimal fuel economy provided the battery state of charge does not reach the defined limits[15].

In the very first stage of designing the HEV control strategy in this project, different strategies were analysed in a MATLAB environment. The actual speed trace from a conventional vehicle in VECTO as well as the corresponding gear was taken as a basis for these simulations. A simple longitudinal vehicle model for a parallel HEV was designed in MATLAB and three different HEV controls were implemented to be coupled with this model: dynamic programming, ECMS and a very simple strategy as described in chapter 2.5.1.

Dynamic programming (DP) is a numerical method that finds the global optimal solution for multistage decision-making problems. It is capable of providing the optimal solution to problems of any complexity level (it is only limited by computational capabilities). However, it is non-causal and works only in simulation environment (not in a real control application), because it requires a priori information about the whole optimization horizon. Nevertheless, it can be used to define the benchmark for real controllers, since it finds the overall best solution possible. Very simply put, DP analyses all possible control options at each time increment and builds a network of points linked by segments. Each segment gets assigned a certain cost to get from one point to the next. In a second step all potential solutions outside of the defined limits are sorted out and from the remaining network the path with the lowest overall costs is calculated by operating backwards in time. This calculation backwards in time is starting at the

[15] E.g. long downhill passage at the end of a cycle which necessarily results in a full storage and charge sustainability cannot be reached despite of the setting of the equivalence factor

very end of the cycle at a single point which resulted in the same SOC from the forward calculation of all possible control candidates in the first step (for further details see https://idsc.ethz.ch/education/lectures/optimal-control.html). The implementation in MATLAB was based on the dynamic programming algorithm provided by the Institute for Dynamic Systems and Control of the ETH Zürich.

The two other strategies, namely ECMS and the simple one, were also based on the same HEV vehicle model. This exercise was done in order to get a deeper understanding of the ECMS approach as a basis for the decision to implement it into VECTO and also to allow a comparison of the performance of other strategies against the benchmark result generated by DP. Figure 8 gives an overview of the SOC trend, vehicle speed as well as battery power and Figure 9 shows the same signals in detail for a certain section of the cycle (exemplary for a typical 12 meter parallel HEV city bus in the VECTO Heavy Urban mission profile). It is evident from these figures that with setting the right equivalence factor ECMS nearly delivers the same performance as the absolute optimum possible from DP. The signals for both cases exactly match for the majority of the simulation horizon. The suboptimality of the ECMS implementation compared to DP is only visible in very limited areas, and even there only a slight offset from the overall optimum is seen. Whereas the simple strategy shows a completely different behaviour, leading to a significant disadvantage in energy consumption but still giving a significant saving compared to the conventional basis vehicle (which was simulated in the same MATLAB environment as reference).

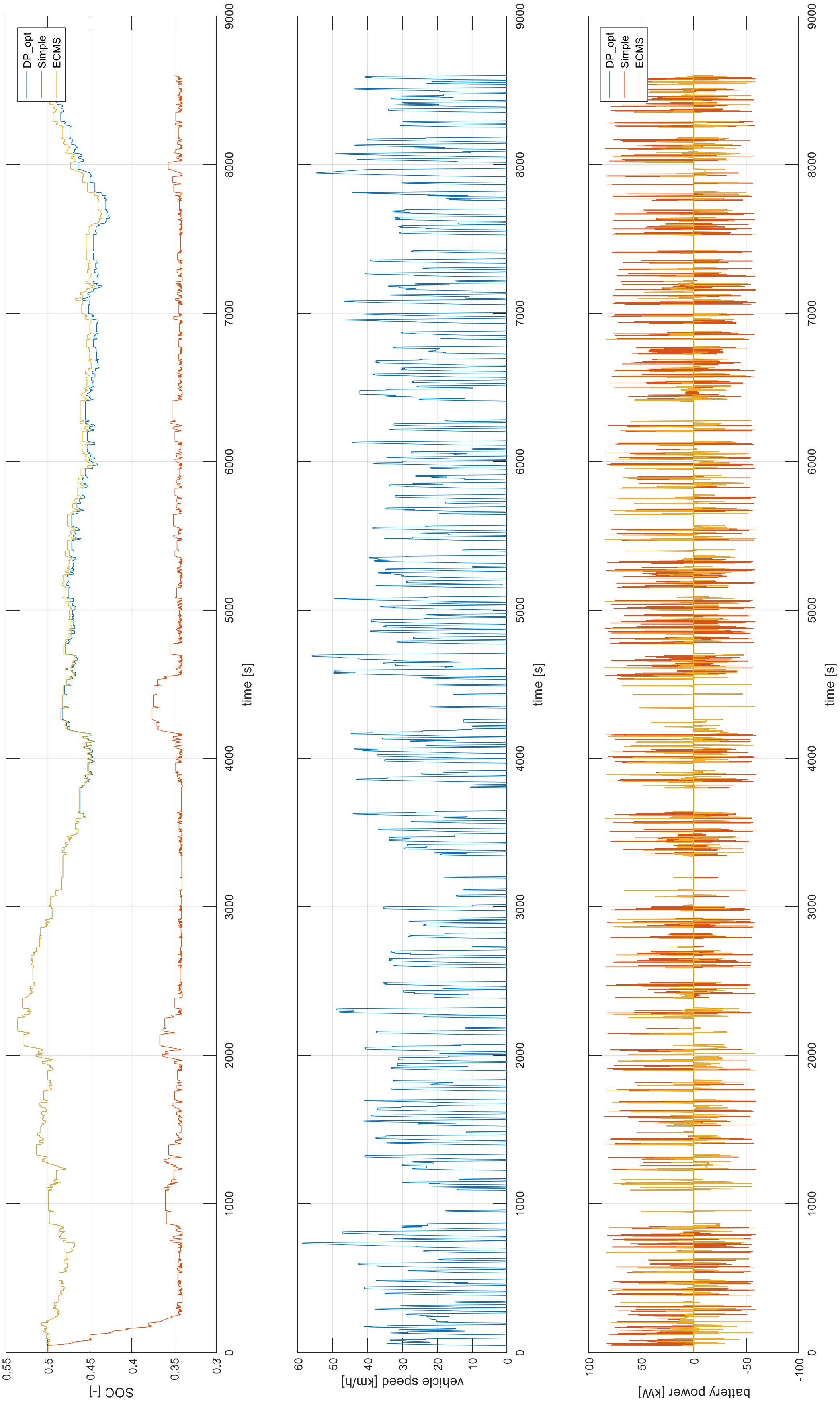


Figure 8: SOC trend, vehicle speed as well as battery power for different control strategies

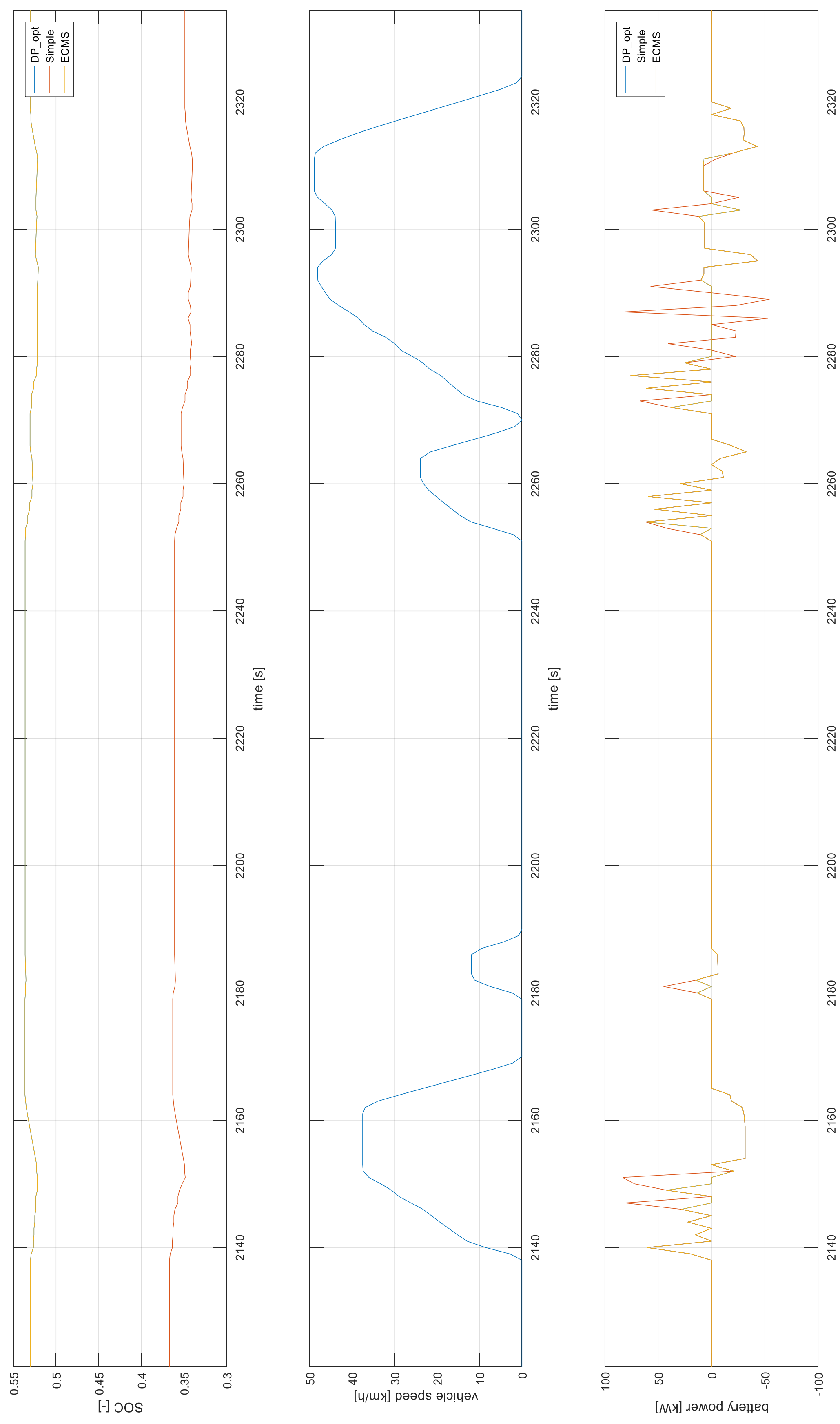


Figure 9: Detail of SOC trend, vehicle speed as well as battery power for different control strategies

Table 8 gives an overview of the performance of the different strategies with regards to fuel savings, again exemplary for the same parallel HEV city bus in the VECTO Heavy Urban mission profile. It is worth noting that ECMS and DP perform equally well, the simple strategy has an absolute 5.5% less saving potential. Furthermore, one can see that over a reasonable range of equivalence factor values, the performance of the ECMS is the same, independent of the exact value of the factor as long as the difference in energy in the REESS over the whole cycle is accounted for to reach charge sustainability.[16]

Table 8: Performance of the different control strategies with regards to fuel savings

HEV strategy	equiv. factor	Δ energy REESS for SOC sustainability [kWh]	Δ fuel mass due to SOC sustainability [g]	original fuel mass [g]	total fuel mass [g]	Fuel saving potential
Simple		0.9653	225.64	7703.0	7928.64	17.96%
	2.500	0.2714	63.44	7330.8	7394.24	23.49%
	2.520	0.1669	39.01	7351.5	7390.51	23.53%
	2.530	0.0362	8.46	7378.0	7386.46	23.57%
ECMS	**2.534**	**-0.0110**	**-2.57**	**7387.6**	**7385.03**	**23.58%**
	2.535	-0.0153	-3.58	7388.5	7384.92	23.58%
	2.540	-0.0661	-15.45	7398.8	7383.35	23.60%
	2.550	-0.1599	-37.38	7418.0	7380.62	23.63%
DP		0.0001	0.02	7388.0	7388.02	23.55%
Conv. vehicle				9664.0	9664.00	

The analysis performed shows clearly, that the concept of ECMS is relying on the necessity of attributing a meaningful value to the equivalence factor. This parameter is representative of past, present, and future efficiency of the ICE, EM and the REESS, and its value affects both the charge sustainability and the effectiveness of the strategy. Research (Rezaei A. 2018) shows that the optimal value of s_{eq} lies within a certain defined range for a specific application case (i.e. combination of vehicle and cycle). However, the strategy is very sensitive to this

[16] Slight deviations between both, the different ECMS settings as well as the DP result are due to the discretisation in the simulation model – both in time as well as in the resolution of potential control candidates in each time increment.

parameter and works well only on cycles very similar to those for which the parameter was optimized. This means that ECMS still implicitly relies on some information about future driving conditions despite its instantaneous formulation. On a driving cycle appreciably different than the one for which the strategy was tuned, the control still works, but the performance does not exploit its full potential.

Based on this knowledge a specific method was developed for VECTO to come up with the optimal value for the equivalence factor for each application case with reasonable computation effort in order to allow a fair comparison between different vehicles. This method will be further elaborated in chapter 2.5.1.4., the concrete implementation of ECMS into VECTO is described in detail in the following chapter 2.5.1.3.

2.5.1.3 Implementation of generic HEV control strategy

In general, the following steps are required to practically apply ECMS in a vehicle simulation approach:

1. Based on the given state of the different powertrain components related to the current vehicle speed and power demand (i.e. rotational speed of ICE, EM, REESS SOC etc.), the acceptable range of controls (i.e. from minimum to maximum allowed battery power) is identified which also satisfies the instantaneous constraints of other power-train components (i.e. power, torque, current limits etc.)
2. The resulting interval of controls from step 1 (i.e. from minimum to maximum allowed battery power) is discretized into a finite number of control candidates
3. Control candidates leading to infeasible operating conditions for a component are discarded (e.g. control within allowed limits but would lead to overcharging the battery).
4. For each control candidate resulting from step 3 the corresponding equivalent fuel consumption is calculated.
5. Based on the results for the equivalent fuel consumption from step 4 the control value leading to the lowest equivalent fuel consumption is selected.

These five steps are performed at each time increment over the entire simulation horizon. In order to make the method generally applicable, the control candidates are defined in a normalized way in VECTO. This is done by dividing the absolute mechanical power of the EM corresponding to a certain control candidate by the total propulsion power demand. Thus, these normalized values of the control candidates run from -1 (i.e. 100% of propulsion covered by EM) to +1 (i.e. full generation of EM). In addition to these basic points, some special points are included explicitly in the analysis:

- The EM maximum propulsion torque exactly in case of high propulsion power demand
- The EM maximum generation torque exactly in case of low propulsion power demand
- The EM maximum torque for completely discharging the battery in the current timestep in case of low SOC

Furthermore, the gear selection routine based on the well-established EffShift principle (Rexeis M. 2019) is also merged into the HEV strategy, expanding the search space with one further dimension. The subsequent paragraphs describe the VECTO implementation of ECMS in full detail.

2.5.1.3.1 Details of VECTO generic HEV control strategy

The basic convention in VECTO is that for all powertrain components (except for the ICE) a positive torque contribution means an additional drag (i.e. braking) while a negative torque contribution means the component supports in propelling the vehicle.

The control candidate u in normalized form is used to identify the different evaluated options. The value of u denotes the factor how much of the torque at the connection point of the electric motor component in the powertrain (which equals the total propulsion torque demand to be provided due to the established standards for component interfaces in VECTO) is applied by the EM. Thus, a value of -1 means the EM provides the full torque demanded at its output shaft and the torque at the EM input side is 0. A positive value of u means that the electric motor acts as generator and applies a braking torque demand.

In case the driver's action is to accelerate the vehicle, the HEV control strategy performs the following steps to obtain a list of potential controls:

1. Issue a "dry-run" request with the currently demanded torque and angular speed

   For this request the EM is completely switched off. The purpose of this request is to get the resulting power demand at the ICE and more importantly, to get the minimum/maximum torque the electric motor can provide and the maximum/minimum torque the combustion engine can provide. This is also a viable configuration and thus added to the list of evaluated configurations as special point.

2. Evaluate options where the EM contributes to propel the vehicle

   i. Iterate over all negative u values with a certain step size (typically 0.1) up to $u_{maxDrive}$. $u_{maxDrive}$ is defined by the torque demanded at the output shaft of the EM and the maximum drive torque of the EM – whichever is lower.

   ii. If the case where the EM applies its maximum drive torque is not already covered by the iteration of u values in the previous step, calculate the u value for the maximum drive torque configuration explicitly.

   iii. If it is allowed to turn off the ICE or the EM can propel during gear shifts, search the torque the EM needs to provide so that the torque at the gearbox input gets 0. This means that the EM may need to provide even more torque than demanded propulsion torque in order to overcome losses of components located further upstream of the EM in the powertrain. If this torque value is within the limits of the EM, calculate the corresponding u value and add this option to the list of evaluated configurations.

3. Evaluate options where the EM acts as generator and applies additional braking torque

   i. Iterate over all positive u values with a certain step size (typically 0.1) up to the EM's maximum generation torque.

   ii. For vehicles of configuration P2, evaluate the configuration where the EM's generation torque equals the torque demanded at the EM output shaft (i.e., the torque at the EM input shaft is 0) if it is allowed to turn off the ICE.

   iii. For vehicles of configuration P3 and P4 search for the torque the EM has to apply as a generator so that the resulting torque at the ICE output shaft is 0. If this torque value is within the limits of the EM, calculate the corresponding u value and add this option to the list of evaluated configurations.

In case of a coast or roll action (e.g. during look-ahead coasting and during traction interruption) the EM is turned off and the EM drag loss is applied to the powertrain.

In case the driver performs a brake action the following options are considered:

1. In case of vehicle configurations P3 or P4 or also vehicle configuration P2 with the gearbox engaged:
    1. If the ICE is on and the torque demand at the ICE output shaft is above the ICE drag curve, switch the EM off.
    2. If the torque demand at the ICE is below the drag curve, evaluate all options as described for the case the driver accelerates (see all steps above).
2. In case of vehicle configuration P2 with the gearbox not engaged, turn the EM off.

For HEV it is not reasonable to decouple the gear selection from the search for EM operating point as in some situations it is more fuel efficient to select the gear not only based on the ICE operation point as done for conventional vehicles. Thus, including the additional degree of freedom of selecting the gear into the HEV strategy might result in an overall more efficient operating point of the hybrid system (considering overall system efficiency of both, EM and ICE). The implemented HEV strategy combines the main ideas of the established EffShift gear selection strategy with choosing the best operating point of the hybrid system. Depending on the subsequent gearshift and the currently active gear, the allowed gear range for upshifts and downshifts is determined. For every allowed gear all possible settings of the hybrid powertrain as describe above are evaluated. The key principle of EffShift that changing a gear needs to improve the overall efficiency by a certain threshold factor (i.e. at least 3% increase in efficiency) is also kept for the HEV implementation in order to prevent gear oscillations.

The following cost function reflecting the ECMS approach is implemented in VECTO and evaluated for each gear within the allowed range:

$$Cost(t,u,x) = \sum_{i \in \, all\, fuels} \dot{m}_{fuel,i}(u)\ \Delta t\ NCV_i + s_{eq}\ (P_{bat}(u,x)\,\Delta t + C_{pen1})\ p_{SOC}(x)$$

where:

$\dot{m}_{fuel,i}$	fuel mass flow with the index i defining the different fuels available (i.e. normally 1, for dual-fuel engines 2)
u	vector of control actions (i.e. electric power)
NCV_i	net calorific value of the specific fuel with index i
s_{eq}	equivalence factor
P_{bat}	battery power (discharge is positive)
C_{pen1}	factor applied when the specific control candidate u requires starting the ICE and it is currently off (see further below)
p_{SOC}	factor depending on the SOC (see further below)
x	state variable of the system representing the SOC

In addition to meeting the standard local and global constraints as explained in chapters 2.5.1.1 and 2.5.1.2, other local constraints were included to further optimize the behaviour of the controller:

- In order to limit the frequency of switching between operating modes, a so-called ICE-start penalty factor, C_{pen1}, was elaborated based on the initial analysis performed with the MATLAB model. It is set to 0.1 times the energy required to ramp up the ICE to introduce a certain additional burden for those control candidates requiring starting the ICE instead of continuing in pure electric driving. The ramp-up energy is calculated in the same way as for the established method for ICE stop/start correction in VECTO (for details refer to the VECTO user manual). If the ICE is currently off and would stay off in the considered control configuration, this factor is set to 0. In case the battery's SOC is below the lower threshold parameterized for the strategy, then this factor is also set to 0 to allow starting the ICE for actively charging the storage.
- The charge-sustaining constraint can be taken into account as a hard constraint (as explained in chapters 2.5.1.1 and 2.5.1.2) by requiring that the energy stored at the end of the mission equals the value at the beginning of the mission. Alternatively, this can be enforced as a soft constraint by penalizing deviations from the initial value of the energy stored at the end of the mission. For such a soft constraint, the cost function needs to be modified with an additional multiplicative term, p_{SOC}, in order to induce the final SOC to be close, but not necessarily identical, to the desired target. This additional element in the cost function helps keeping the SOC cycling around a target value over the course of the cycle. This SOC penalty factor is defined by the following generally valid equation:

$$p_{SOC} = 1 - \left(\frac{SOC - SOC_{target}}{0.5\,(SOC_{max} - SOC_{min})}\right)^{e}$$

where:

SOC	current SOC of the storage
SOC_{target}	desired target value at the end of the cycle (typically the start SOC for real charge sustaining operation)
SOC_{max}	maximum allowed SOC defined as local constraint for the HEV strategy
SOC_{min}	minimum allowed SOC defined as local constraint for the HEV strategy
e	value of the exponent

From the list of possible control candidates with their respective cost value calculated, the best option is selected according to the following list of conditions. If one or more controls match the criteria listed in a specific step, the control with the lowest cost is selected as best option and the next steps are not evaluated. If no control matches the criteria defined in the current step, the next step is evaluated:

1. Select all configurations with a valid cost score (i.e. the score is not NaN[17]).
    a. The resulting vehicle speed is above the gearbox' start speed
    b. If the vehicle speed is below the gearbox' start speed (i.e. the vehicle is accelerating from standstill), the engine speed must be below the maximum allowed engine speed.
    c. Order the viable controls by cost score
2. Select all valid controls resulting in a valid engine speed (i.e. neither too high nor too low and within the shift lines) and order by cost score.
3. If the driver is accelerating and in all evaluated configurations the ICE torque demand is above the ICE maximum torque, filter the possible controls according to the following criteria:
    a. If the EM can propel during traction interruptions (i.e., P4 and P3 configurations) or the gearbox is engaged (P2 configuration), select all controls where the battery SOC is within the allowed range.
    b. Order these control candidates by difference in gear to the current gear and then order the controls by the mechanical torque the EM can provide.
4. If the driver is accelerating and in all evaluated configurations the ICE torque demand is below the ICE drag torque, filter the possible controls according to the following criteria:
    a. If the EM can propel during traction interruptions (i.e., P4 and P3 configurations) or the gearbox is engaged (P2 configuration), select all controls where the ICE speed is valid and the battery's SOC is within the allowed range.
    b. Order these controls by the difference in gear to the current gear and then by the mechanical torque the EM can provide
5. If the driver is accelerating and the gearbox is engaged, filter the possible controls according to the following criteria:
    a. Select all controls where the ICE speed is neither too low nor too high and order these controls by the difference in gear to the current gear.
    b. If no entry in the list matches the previous criteria, order all controls by the difference in gear to the current gear
    c. Order the controls by the mechanical torque provided by the EM.
6. If the driver is braking and the gearbox is engaged, select all controls where the battery SOC is within the allowed range and order by the torque the EM can apply for braking.

After the best candidate was selected in accordance with above steps, the actual simulation is performed for the current time step by application of the specific power requests for each energy converter in the vehicle's powertrain determined based on the selected control value.

[17] Only invalid operation points can result in case the demanded propulsion power is much too high or too low (e.g. high accelerations at high slopes or with fully loaded vehicle).

2.5.1.4 Generic definition of equivalence factor

From the principles of PMP and ECMS explained in chapters 2.5.1.1 and 2.5.1.2, it can be derived that the optimum performance (i.e. energy consumption) of a hybrid system is achieved with the equivalence factor set to a value that ensures a resulting delta SOC of 0 over the whole cycle. Finding the appropriate value could be either done very simple by trial-and-error or by a more sophisticated iterative search method. The iterative search is possible thanks to the fact that there is a direct and bi-univocal relation between the value of the equivalence factor and the value of the SOC reached at the end of the driving cycle. By applying an arbitrary initial guess for the equivalence factor and adapting the value for each consecutive run based on the outcome of the previous run, the iterative search converges in relatively few steps (typically below 10 iterations).

The challenge with the control strategy in VECTO is now finding the suitable value for the factor guaranteeing optimality with the lowest effort possible due to the requirement that computation time shall be rather short (even for complex vehicle systems) as well as transparency and fairness regarding comparability between different vehicles in certification. The iterative search is accelerated by a dedicated method developed in this project described further below. Additionally, instead of applying an arbitrary initial value (i.e. guess) of the equivalence factor for the first simulation run best-guess values were defined for each vehicle and cycle combination.

The first idea was to find a formula defining the optimum equivalence factor based on vehicle parameters and mission profile which would require only one single simulation run for a specific vehicle. Therefore an extensive parameter study was performed in the Engineering Mode of the VECTO HEV model where starting from several base vehicle configurations the following vehicle parameters were varied:

- aerodynamic drag coefficient
- rolling resistance coefficient
- vehicle mass
- ratio of EM power to ICE power
- battery capacity
- EM efficiency
- limits for the total propulsion torque
- different auxiliary configurations

For each resulting single vehicle configuration the following cases were simulated:

- 3 different cycles, each with 2 different payloads
- 3 different usable SOC ranges of the battery
- 3 different exponents in the equation defining the SOC penalty factor (see chapter 2.5.1.3.1)
- multiple equivalence factors for each combination above to identify dependencies

In total more than 10 000 simulations were performed, but contrary to the initial assumption finding a generally applicable formula was not possible due to the following reasons:

- No clear trend could be identified how the variation of a specific parameter affects the optimum equivalence factor (variation can lead to an increase or decrease depending on the base vehicle configuration).
- The risk exists that correlations determined are no longer valid to the same extent when changes are made to the base vehicle.

- Since it is practically not feasible to simulate every possible combination of parameter variation, the effect of certain combinations on the equivalence factor would remain unknown.

Therefore, a different approach had to be elaborated to find the optimal equivalence factor as simple and stable as possible. For this task all the existing results from the parameter study could be re-used and re-analysed where necessary.

One important finding from the data generated in the parameter study was that a value of 1 for the exponent in the equation defining the SOC penalty factor has major benefits regarding the stability of finding the optimal equivalence factor and at the same time generates no systematic disadvantage regarding optimality of the energy consumption compared to other values for the exponent. As shown in Figure 10 exemplarily for one specific vehicle group, the resulting fuel consumption is much less dependent on the equivalence factor for an exponent of 1 (right diagram) instead of 5 (left diagram). This means that the behaviour of the ΔSOC over the cycle can be described as a linear function over the equivalence factor which makes the method of finding the optimum value of this factor much more consistent and stable.

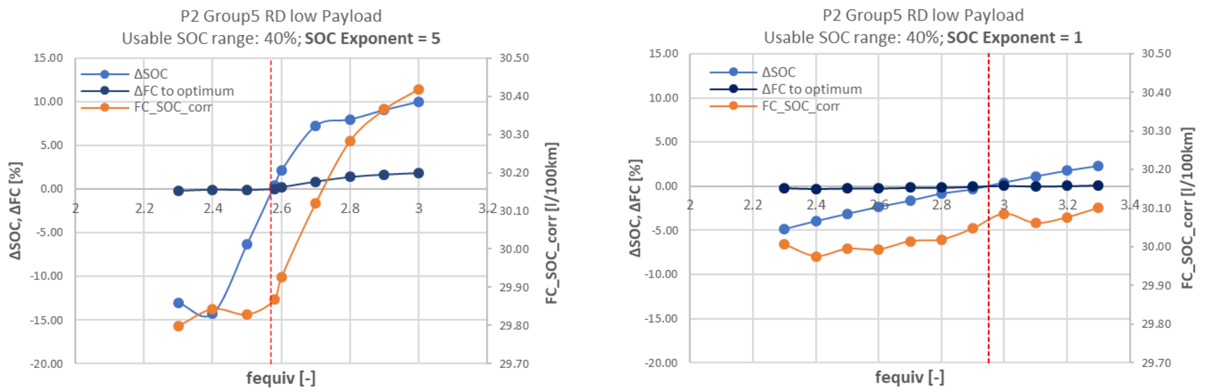


Figure 10: Resulting fuel consumption as function of equivalence factor for different exponents in the in the equation defining the SOC penalty factor

The basic idea of the method designed for determination of the optimum equivalence factor is that the deviation of the SOC at the end of the cycle from the target value (i.e. ΔSOC) is evaluated after a completed simulation run. Based on the linear relation of ΔSOC to the equivalence factor identified, a new value of the equivalence factor is calculated automatically for the next simulation run performed. This procedure is repeated until a ΔSOC of (nearly) 0 is reached. Figure 11 illustrates this basic procedure.

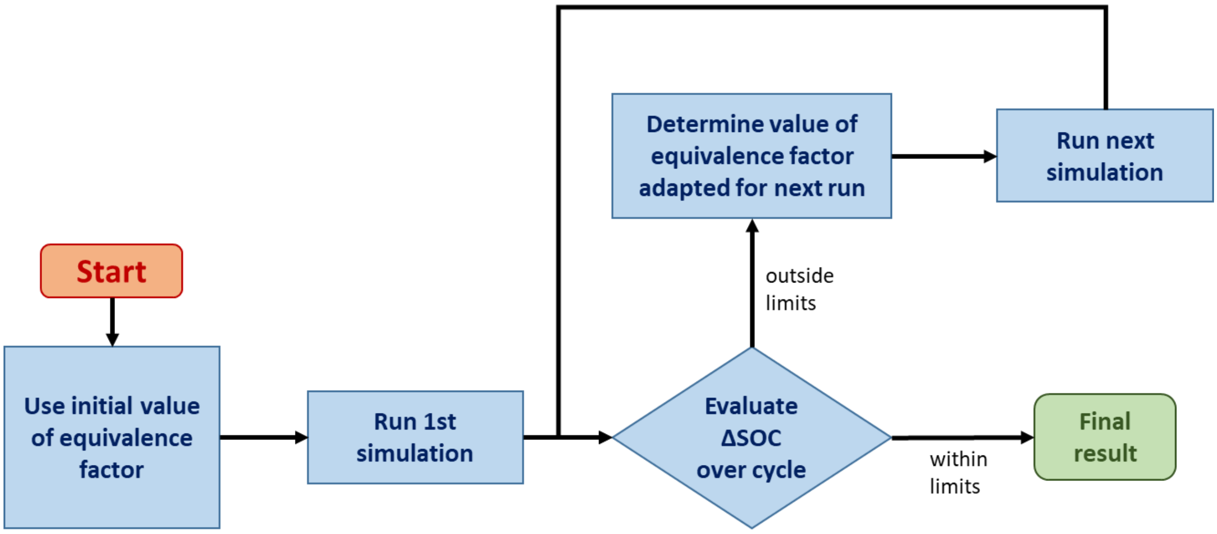


Figure 11: Schematics of method for determining the optimum equivalence factor

Now the crucial element required to make the procedure work is the gradient defining the linear relation of ΔSOC to the equivalence factor for a specific cycle and vehicle combination. Fortunately, the data generated in the parameter study showed that the value of this gradient is rather insensitive to variations in vehicle parameters. Figure 12 illustrates (exemplarily for one specific vehicle) that, despite the absolute level of the values being different, the gradient of the respective regression lines is nearly the same for all different cases of vehicle parameter settings. In the graph each different setting of vehicle parameters (e.g. variation in rolling resistance coefficient) corresponds to a specific colour of the dots. It is evident that the resulting curves are nearly parallel to each other and the gradient of each individual curve is nearly equal to that of the average regression line over all data points (defined by the equation given in the figure and marked with the yellow box).

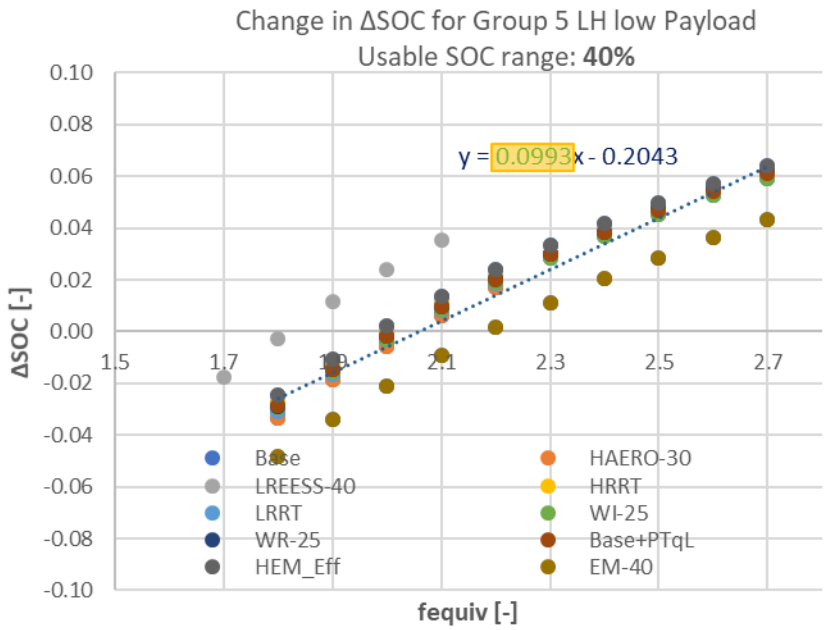


Figure 12: Relation of ΔSOC to the equivalence factor for different vehicle parameter settings (exemplarily for a Group 5 truck with low payload in the Long-Haul cycle)

With all the single values of the average gradient over all vehicle parameter settings as explained above being plotted for each combination of cycle, payload and usable SOC range, the typical behaviour aggregated for one single vehicle group was analysed. Figure 13 illustrates (exemplarily for one specific vehicle group) that, the general behaviour of the gradients for all different combinations within one vehicle group is rather consistent. It is worth noting that Figure 13 – as opposed to Figure 12 from the previous step in the analysis – depicts a completely different fact, namely the aforementioned average gradient dependent on the usable SOC range. So one single value of the average gradient over all vehicle parameter settings derived in the previous step of the analysis is represented by one single dot in Figure 13. But here again, the analysis showed that the resulting curves are nearly parallel to each other (with a bit more variation than in the previous step) and the gradient of each individual curve is nearly equal to that of the average regression line over all data points (defined by the equation given in the figure).

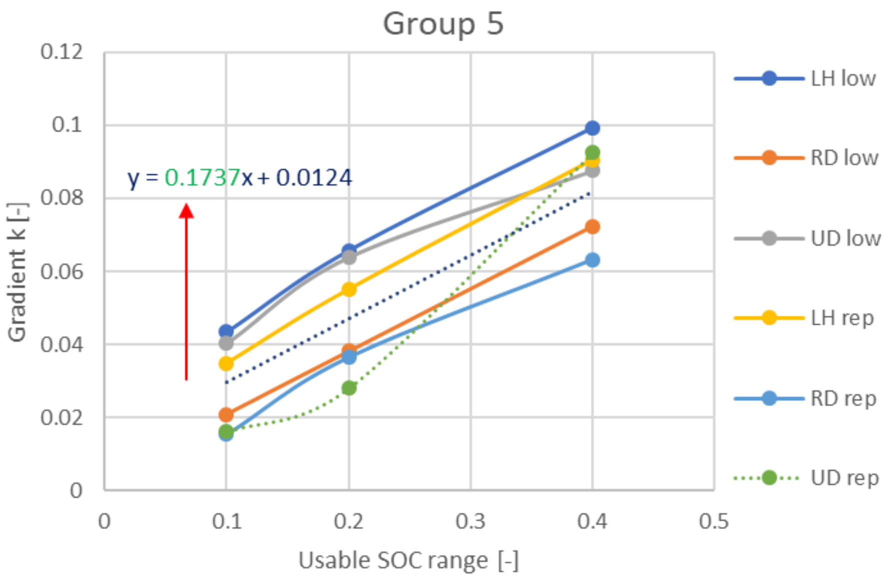


Figure 13: Relation of the gradient for SOC behaviour to the usable SOC range for different cycles, pay-loads and usable SOC ranges (exemplarily for the vehicle Group 5)

The outcome of this analysis over all different vehicle groups analysed led to the conclusion that the general behaviour of ΔSOC depending on the equivalence factor can be approximated by those individual regression lines derived for each vehicle group. To make it even less complex, the individual gradients for each vehicle group being very close to 0.2 were further approximated by a single value of 0.2 for all. Detailed analysis proved that no systematic error is made by using slightly different values across all vehicle groups. Figure 14 illustrates this exemplarily for the vehicle Group 5, where the original gradient for this vehicle group as well as the one determined for a different vehicle group (i.e. Group 2) was used. For both cases, the ΔSOC behaviour in the second simulation run with the adapted equivalence factor is converging in the right direction towards zero compared to the resulting ΔSOC from the initial simulation run. This means that the developed method for iterative search is working properly even with slightly different values for the gradient.

				ΔSOC using suggested start values for the equivalence factor		ΔSOC of the second simulation run using Group 5 correction slope		ΔSOC of the second simulation run using Group 2 correction slope	
	SOC range [-]	Cycle [-]	Payload [-]	fequiv [-]	ΔSOC [%]	fequiv [-]	ΔSOC [%]	fequiv [-]	ΔSOC [%]
P2 Group 5	0.7	LH	low	2	-2.85%	2.19	0.53%	2.17	0.20%
			rep	1.8	-2.34%	1.96	1.04%	1.93	0.48%
		RD	low	2.4	-0.03%	2.40	0.00%	2.40	0.00%
			rep	2.8	-2.10%	2.98	0.09%	2.93	-0.58%
		UD	low	2.1	-4.21%	2.40	0.84%	2.35	0.00%
			rep	2.5	-4.37%	2.80	-0.66%	2.76	-1.16%
	0.4	LH	low	2	-0.15%	2.02	0.02%	2.02	0.02%
			rep	1.8	0.01%	1.80	-0.01%	1.80	-0.01%
		RD	low	2.4	-0.69%	2.50	0.06%	2.48	-0.07%
			rep	2.8	-2.53%	3.20	-0.14%	3.08	-0.83%
		UD	low	2.1	-1.88%	2.32	0.32%	2.30	0.15%
			rep	2.5	-3.91%	2.92	-0.89%	2.91	-0.97%
	0.2	LH	low	1.8	0.51%	1.72	-0.09%	1.69	-0.36%
			rep	1.6	0.19%	1.57	-0.08%	1.57	-0.08%
		RD	low	2.4	-0.01%	2.40	0.00%	2.40	0.00%
			rep	2.7	0.46%	2.54	-1.66%	2.59	-1.45%
		UD	low	2.1	-0.77%	2.25	-0.04%	2.27	0.06%
			rep	2.5	-2.98%	3.02	-1.05%	3.14	-0.66%

Figure 14: Application of different gradients for SOC behaviour for estimation of equivalence factor for the second simulation run (exemplarily for the vehicle Group 5)

All the facts established above are now used to calculate the new value of the equivalence factor for the next simulation run due to the linear relation of ΔSOC to this factor based on the outcome of the previous simulation run. Due to the linearity of the ΔSOC behaviour, a maximum of three iterations is required to determine the optimal value for the equivalence factor. For the detailed procedure, two different cases for determining the new value of the equivalence factor for the next simulation run need to be considered:

1. For the second simulation run

   After the first simulation run with a “best-guess” starting value, a first data point of the characteristic mission specific curve for ΔSOC behaviour is available. Based on this data, the new equivalence factor for the second simulation run needs to be determined according to the following equation:

$$f_{equiv\_2} = f_{equiv\_1} - \frac{\Delta SOC_1}{k}$$

   where:

   f_{equiv_1} equivalence factor used in the first simulation run

   ΔSOC_1 resulting ΔSOC from the first simulation run

   k gradient of the characteristic curve for ΔSOC behaviour determined according to the equation directly below

$k = k_{0.4} + 0.2 * (SOC_{usable} - 0.4)$

where:

$k_{0.4}$ specific value generically defined per vehicle group, mission and payload which defines the absolute level of the characteristic curve for ∆SOC behaviour (i.e. the different dots located at an x-value of 0.4 in Figure 13 (exemplarily for vehicle Group 5 above, but with aforementioned k=0.2 value for all)

SOC_{usable} vehicle specific usable SOC range of the REESS (i.e. difference between maximum and minimum SOC)

2. For the third simulation run

   After the second simulation run, two data points of the characteristic mission specific curve for ∆SOC behaviour are available. Based on these, the new equivalence factor for the third simulation run needs to be determined by linear interpolation according to the following equation:

$$fequiv_3 = \frac{0 - \Delta SOC_1}{\Delta SOC_2 - \Delta SOC_1} * (fequiv_2 - fequiv_1) + fequiv_1$$

   where:

   ΔSOC_1 resulting ∆SOC from the first simulation run

   ΔSOC_2 resulting ∆SOC from the second simulation run

   f_{equiv_2} equivalence factor used in the second simulation run

   f_{equiv_1} equivalence factor used in the first simulation run

The basic relations of the procedure are graphically explained in Figure 15.

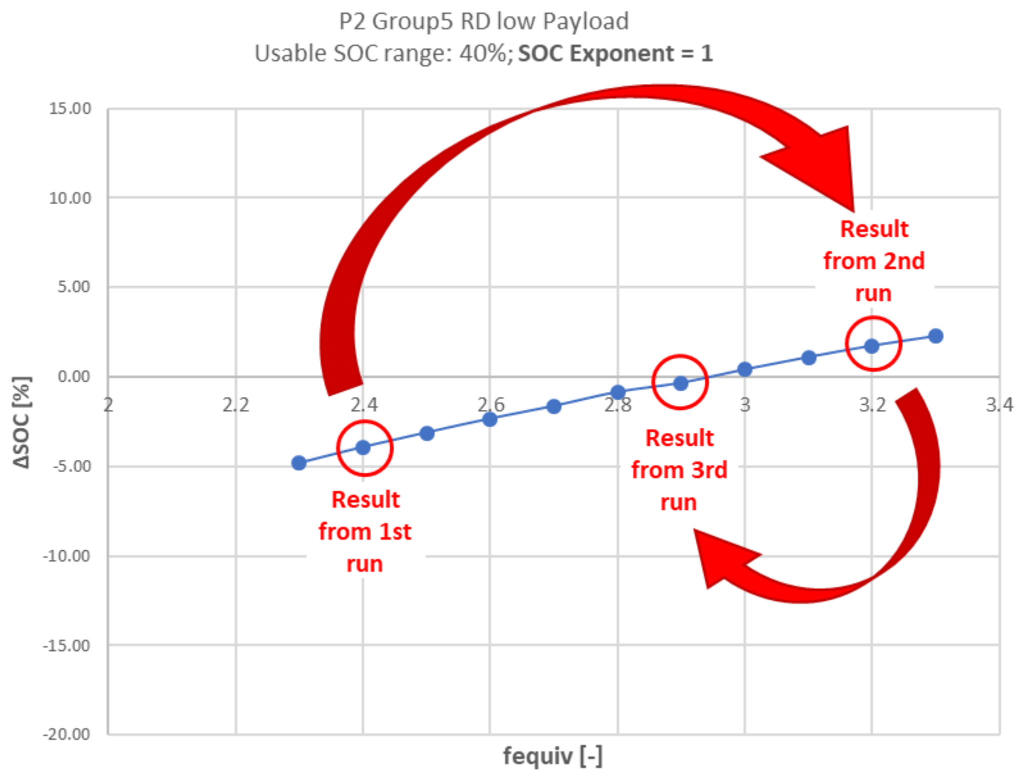


Figure 15: Iterative search method based on linear relation of ΔSOC to the equivalence factor (exemplarily for one specific vehicle, cycle and loading combination)

This procedure of finding the optimal equivalence factor needs to be applied for each single mission profile calculated for a specific vehicle. Even though it is rather quick regarding computational effort taking the complexity of the dynamic problem to be solved into account, it still requires a significant computational effort to find the optimal equivalence factor by the iterative search. In order to reduce this effort, an additional element of defining a termination criterion for the iterative search was developed which would allow stopping after each simulation run if the criterion is fulfilled but at the same time ensuring that the result is very close to the overall optimum solution which is obtained by calculating all three iterations. The termination criterion would keep the allowed deviation in electric energy in the storage over the whole cycle low by limiting the ratio of the delta in electric energy divided by the total fuel energy over the cycle. Thus, the iterative search could be terminated after either the first or the second run for the majority of the vehicles simulated. If this method defining a termination criterion regarding a ΔSOC limit or if a fixed number of three iterations shall be used for the final Declaration Mode is still under investigation by industry using the latest version of VECTO in Engineering Mode for their specific HEVs.

One significant element for reducing the number of iterations as discussed above, is the value of the equivalence factor used in the very first simulation run. The better this value reflects the specific vehicle, the closer the result of the first run to the optimum performance. Therefore, the data generated in the parameter study was used to define “best-guess” instead of arbitrary starting values for the equivalence factor depending on vehicle group, mission, payload and usable SOC range. This element will help even more in accelerating the iterative search method for most mission profiles simulated in case a termination criterion is defined.

For some special configurations of vehicles with a very low capacity of the electric storage there is a specific exception defined as fall-back method in case those vehicles do not show the established linear relation of ΔSOC to the equivalence factor for a specific cycle and vehicle combination. Such vehicles will most likely not exist in reality but were only specifically designed for internal evaluation of the generic method for deriving the optimal equivalence factor. If during the simulation no unequivocal relation between resulting ΔSOC and equivalence factor can be established, the final fuel consumption value will simply be derived by direct linear interpolation between the three individual results of fuel consumption obtained through the iterative search.

2.5.1.5 Correction of SOC variation

In a HEV without the possibility of recharging the storage with energy externally provided, the operation of the vehicle needs to be charge sustaining over a longer time horizon, meaning that the SOC of the storage is fluctuating around a certain value but on average stays at a constant level. Thus, under charge sustaining operating conditions eventually all energy required needs to come from fuel.

In practical implementations an absolutely balanced SOC cannot be achieved over each arbitrary driving cycle, thus a certain ΔSOC difference between beginning and end of the cycle will remain. This also applies to a certain extend to the above proposed algorithm to determine the optimal value of the equivalence factor (see chapter 2.5.1.4) due to discretization in time and search space as well as numerical inaccuracies that occur.

Thus, the deviation in energy content of the storage over the cycle needs to be accounted for to allow a fair comparison between all relevant calculations performed with specific setting of parameters regarding their specific fuel energy consumption. This is done by modifying the original results using a defined method to reflect the perfect charge-sustaining case. The rationale for this is illustrated in Figure 16 which shows the total fuel consumption as a function of the SOC variation over the cycle derived from the data in Table 8, giving a nearly linear correlation within a certain range of equivalence factor used.

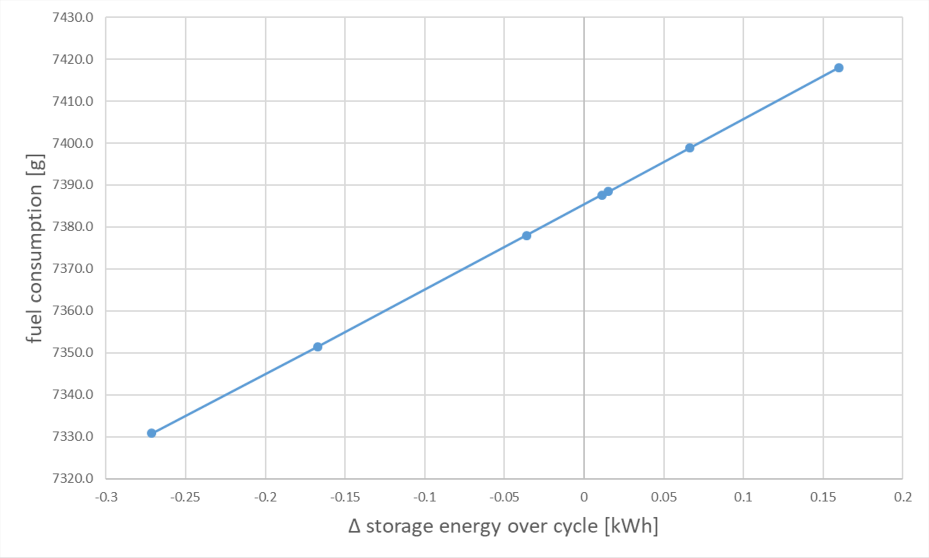


Figure 16: Effect of ΔSOC over the cycle on fuel consumption (not corrected for SOC deviations)

Now, the actual correction could be done with several different methods, where the simplest one is a linear interpolation between two already existing values of fuel consumption (as exemplarily shown by the data in Figure 10 or Figure 16). The simple linear interpolation works well within a defined range where the resulting ΔSOC over the cycle is already close to zero. In case the resulting ΔSOC is far off from reaching charge sustainability a linear correlation cannot be assumed any more for the correction. Also, if only the result of a single simulation run is available, a different method is required to perform the correction.

Thus, for automatically performing the ΔSOC correction over the cycle for each simulation run performed in VECTO – no matter the magnitude of deviation in SOC – a different method was defined based on average component efficiencies over the cycle as well as the well-established Engine Line method (refer to VECTO user manual for more details). The resulting final fuel consumption according to the developed method is defined by the following equation:

$$FC_{SOC_{corr}} = FC_{final} - \frac{\Delta E_{REESS}\ k_{engline}}{d}\ \frac{1}{\eta_{EM,avg}\ \eta_{REESS,avg}}$$

where:

FC_{final}	resulting original fuel consumption from a simulation run [g/km]
ΔE_{REESS}	deviation in energy content of the electric storage over the cycle determined from the difference in energies charged and discharged over the cycle [kWh]
$k_{engline}$	gradient of the Engine Line defining the average increase in fuel consumption for an increase in power for the specific engine in

	this specific application (refer to VECTO user manual for more details) [g/kWh]
d	driven distance over the cycle [km]
$\eta_{EM,avg}$	average EM efficiency over the cycle [-] in case ΔE_{REESS} is negative, the value for charging is used in case ΔE_{REESS} is positive, the value for discharging is used
$\eta_{REESS,avg}$	average storage efficiency over the cycle [-] in case ΔE_{REESS} is negative, the value for charging is used in case ΔE_{REESS} is positive, the value for discharging is used

All values above are directly available in the VECTO vsum file, except for $\eta_{REESS,avg}$ defining the average storage efficiency. This value is calculated from two other existing values from the vsum file according to the following equations:

For charging: $\eta_{REESS,avg} = \frac{E_{REESS\_int\_chg}}{E_{REESS\_T\_chg}}$

For discharging: $\eta_{REESS,avg} = \frac{E_{REESS\_T\_dischg}}{E_{REESS\_int\_dischg}}$

where:

$E_{REESS\_int\_chg}$	total energy charged into the storage counted internally
$E_{REESS\_T\_chg}$	total energy charged into the storage counted at the terminals
$E_{REESS\_int\_dischg}$	total energy discharged from the storage counted internally
$E_{REESS\_T\_dischg}$	total energy discharged from the storage counted at the terminals

2.5.1.6 Boosting limits

Typically HEV have higher total propulsion power than comparable conventional vehicles considering simply the sum of mechanical power which both energy converters could provide at a certain speed. While it is rather common for passenger cars to allow using this combined peak power to generate a very dynamic driving experience (sometimes limited to a user-defined operation mode of the vehicle, e.g. Sport Mode), such operation is not preferable for heavy-duty vehicles due to their much higher mass to power ratio resulting in a significant increase of energy consumption if driven very dynamically. Typically the focus for heavy-duty vehicles is on fuel savings to keep the operational costs low. Thus, many systems limit the sum of available propulsion power to a certain level. Depending on the vehicle group and concept of the HEV system, this limitation might be ranging from allowing not more than the maximum torque of the ICE over the whole speed range, filling up the ICE torque at low speeds, slightly increasing the ICE power over the whole speed range or adding a significant amount of EM torque on top of the maximum ICE torque for concepts with a downsized ICE.

Generally, this real-world limitation of total system power (boosting limits) shall be depicted correctly in VECTO, in order to prevent unrepresentatively high energy consumption values over the cycle due to unrealistically high propulsion power in segments with high accelerations or uphill driving. Another common use case of these limitations is for city buses with a very mild hybridization (i.e. P1 architectures with around 20 kW of EM power). Without applying a limit for the total propulsion torque, these vehicles might in some cases even end up with a higher fuel consumption than their conventional counterpart due to higher accelerations achieved in the very dynamic urban operation.

The vehicle manufacturer may declare limitations of the total propulsion torque of the whole powertrain referring to the transmission input shaft for a parallel HEV in order to restrict the boosting capabilities of the vehicle.

For the VECTO method, the declaration of such limitations makes obviously only sense in the case that the powertrain configuration is a parallel HEV (i.e. classical parallel or IHPC). The limitations are declared as additional torque allowed on top of the ICE full load curve dependent on the rotational speed of the transmission input shaft. Linear interpolation is performed in the simulation tool to determine the applicable additional torque between the declared values at two specific rotational speeds. For the rotational speed range from zero to ICE idling speed the full load torque available from the ICE equals approximately the ICE full load torque at engine idling speed due to the modelling of the clutch behaviour during vehicle starts. The vehicle manufacturer may declare such limitations which match exactly the ICE full load curve by declaring values of 0 Nm for the additional torque. All details regarding the declaration of these OEM specific total propulsion torque limits at transmission input shaft for all parallel HEVs are described in Annex III of Regulation (EU) 2017/2400.

Regarding the implementation in VECTO, the following steps are performed to determine the applicable torque limits per gear used in the HEV operation strategy from the various elements of torque limitations possible:

1. The starting point for determining the applicable boosting limit per gear is the full load curve of the ICE.
2. The data from point 1 above is cropped with the scalar value of maximum ICE torque declared at vehicle level per gear (optional VECTO input parameters P196 and P197).
3. To the data from point 2 above the declared boosting torque on top of the ICE torque is added (optional VECTO input parameters P415 and P416).
4. For all parallel HEV architectures with the EM located upstream of the transmission, the data from point 3 above is cropped with the scalar value of maximum transmission input torque (optional VECTO input parameter P157).

Figure 17 below illustrates the above steps graphically.

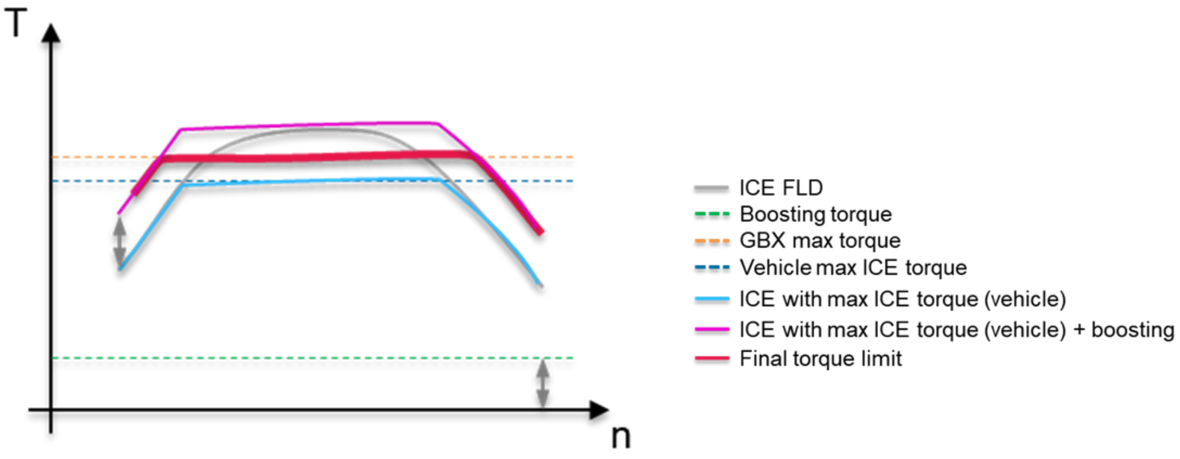


Figure 17: Calculation steps to determine the applicable torque limits per gear used in the HEV operation strategy

2.5.2 Serial HEV

Serial HEV concepts are only of minor importance today, the vast amount of HEV sales forecast by industry for the near future will be belonging either to the parallel architecture or be a more complex system. Over the course of the project only one minor vehicle manufacturer revealed that they have a serial HEV concept planned but with very low units projected to be sold. Thus, serial HEVs have become a niche product due to the high production costs resulting from requiring basically the same components as for a pure electric vehicle and in addition the Genset (i.e. one EM plus one ICE plus the respective peripheral equipment for both systems) needs to be installed with high effort (which represents also a packaging issue for most vehicle concepts). Furthermore, the first generation of serial HEV concept with a very small electric storage where the Genset power needs to follow the propulsion power demand in a damped manner (so that the propulsion power demand is met on average over a longer time horizon) has disappeared from the market. Today's known serial HEV concept have a significant amount of electric storage capacity and can be considered more as a range-extender concept. The designed generic control strategy considers that by operating the Genset in a more static way instead of dynamically following the propulsion power demand.

2.5.2.1 Basics of generic HEV control strategy

Basically, for serial HEV the operation of the Genset converting fuel into electrical energy is completely decoupled from the propulsion power demand since the electric storage serves as buffer. Thus, the generic control strategy for a serial HEV is designed as three-point controller for the Genset which considers the following operation points: off, optimum efficiency, maximum power. The first premise in the strategy is that - if the Genset is on - it shall be operated in the optimum efficiency point whenever possible. The second premise is that if the driving performance requested by the driver cannot be achieved in any other way, the first premise may be violated.

In the algorithm implemented into VECTO, as a first step the relevant operation points for the three-point controller need to be defined in a pre-processing before the actual simulation runs are performed by doing the following operations:

1. Generate a grid of analysed load points by iterating from zero to maximum ICE power and from ICE idle speed to n95h speed (for each dimension with a step size of 20)
2. Calculate the resulting electric power as output from the Genset and the corresponding fuel consumption for all above load points
3. Out of the data from step 2. above the following operating points are selected:
    a. Maximum electric power output (both for the EM being in de-rating and in regular operation)
    b. Optimum efficiency point defined by the lowest ratio of fuel consumption per electric power generated (both for the EM being in de-rating and in regular operation)

This gives in total five possible operating points for the Genset depending whether the generator EM of the Genset is in de-rating or not. Now the logics for operating the Genset during a simulation run is defined as follows:

- The Genset is switched on as soon as the SOC falls below a threshold SOC_min_serial
- The Genset is switched off as soon as SOC reaches SOC_target
- When the Genset is running, the current operation point is selected according to the following rules:
    - SOC_min_serial ≤ SOC < SOC_target: optimum efficiency point (P_opt)
    - SOC < SOC_min_serial:
        - requested electric propulsion power > P_opt:
          maximum electric output (P_max)
        - requested electric propulsion power ≤ P_opt:
          optimum efficiency point (P_opt)

The switching threshold given by the parameter SoC_min_serial needs to be above the battery's minimum allowed SOC and will be defined in a generic way to be determined automatically by VECTO in the declaration mode taking the specific vehicle and cycle characteristics into account (i.e. electric energy required for accelerating from standstill to a certain vehicle speed). Figure 18 summarizes this strategy in a stateflow diagram.

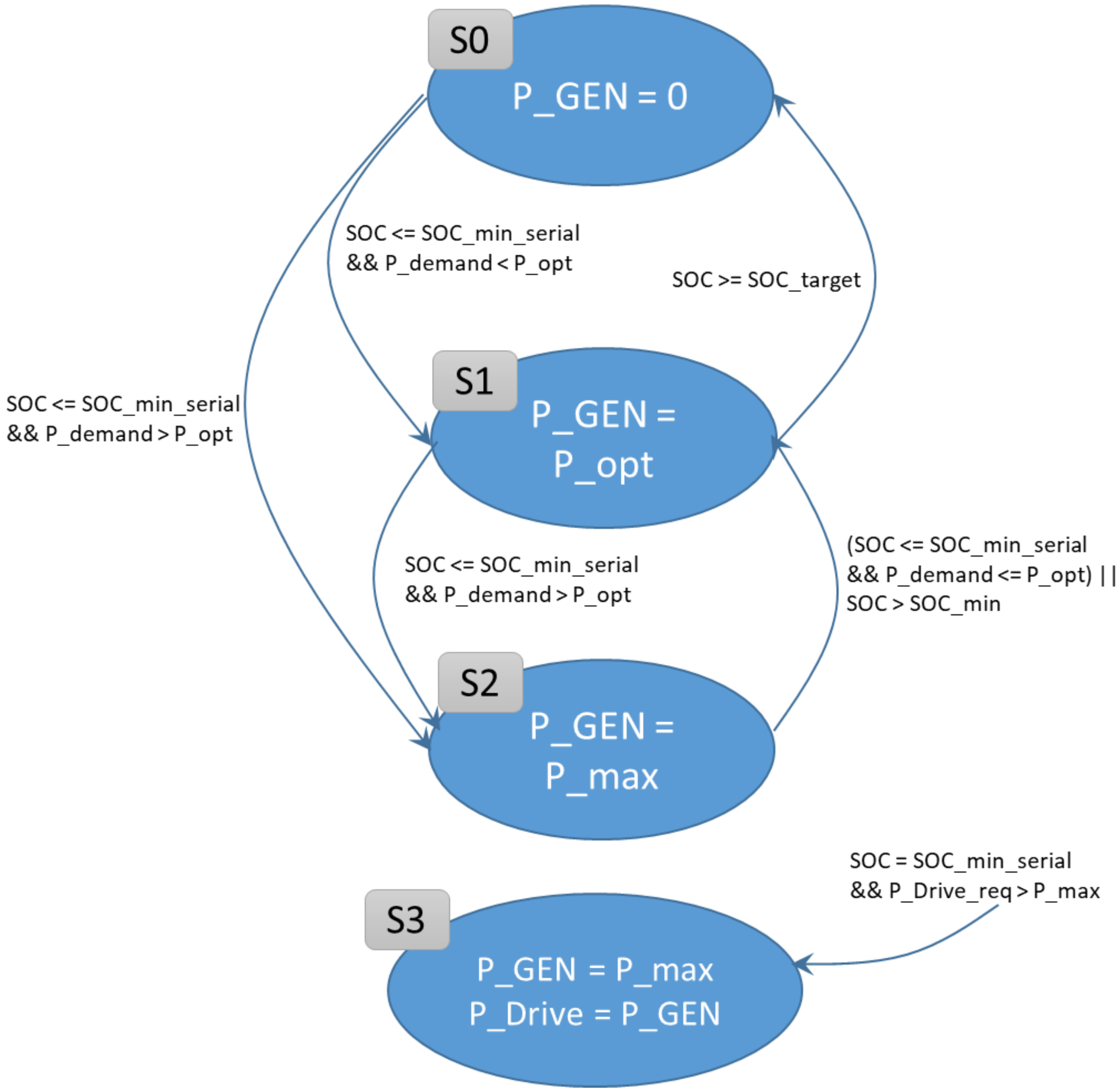


Figure 18: Stateflow diagram of generic serial HEV operation strategy

The basic implementation of the serial HEV strategy during the simulation run for each time interval looks as follows:

1. Calculate the maximum electric power the Genset can provide under the current boundary conditions (e.g. de-rating, ramp-up, regular operation)
2. Calculate the power demand of propulsion EM, assuming the sum of maximum electric power provided by the Genset (as defined in point 1 above) and the electric storage together
3. Depending on the propulsion power demand and current SOC, the Genset may be switched on and is then operated either in the optimal efficiency point or in the maximum power point (always considering the de-rating status of the generator EM)

When switching on the Genset in the current time step, it is often not possible to directly operate it in the desired operating point typically located at moderately high ICE speeds. This fact is resulting from the torque demand for accelerating the ICE being too high to be covered in a single time step due to the high ICE inertia. Thus, first the ICE is ramped up to the desired speed as quickly as possible with the generating EM being switched off (typically for 1 or 2 time intervals) and once the ICE operation point is stabilized the EM is switched to generating mode.

2.5.2.2 Correction of SOC variation

For the designed generic control strategy described in the previous chapter 2.5.2.1 a certain cycling behaviour of charging and discharging the electric storage will occur depending on the vehicle characteristics and the mission. But the actual SOC course over time is not really relevant for the final fuel consumption, since the variation in stored electric energy over the cycle is corrected in a post-processing step (analogous as for the parallel HEV). The correction in the case of a serial HEV is performed by assuming the same average efficiencies as were applied during all events actively charging the storage during the cycle. Since such charging events are mainly performed at the optimum efficiency operation point, it does not really matter if the storage is rather full or rather empty at the end of the cycle – the resulting final SOC is kind of a random outcome depending on the vehicle characteristics, especially the storage capacity and the mission driven.

To account for the variation in stored electric energy over the cycle, a special method was defined for serial HEV in VECTO fitting to the principles of the generic serial HEV control. The difference in fuel consumption due to the SOC correction (this difference can be positive or negative) is calculated according to the following equations:

In case the Genset was running during simulation: $\Delta FC_{SOC_{corr}} = \Delta E_{REESS} \; \frac{FC_{genset,chg}}{E_{genset,el}}$

where:

$\Delta FC_{SOC_{corr}}$	Correction of the simulated fuel consumption to account for the variation in stored electric energy over the cycle [g]
ΔE_{REESS}	deviation in energy content of the electric storage over the cycle [kWh]
$FC_{Genset,chg}$	integrated fuel consumption over the cycle for all operation points where the Genset was providing electric energy [g]
$E_{Genset,el}$	integrated electric energy provided by the Genset over the cycle [kWh]

In case the Genset was never running during simulation (could happen in some rare cases with very large electric storage capacity): $\Delta FC_{SOC_{corr}} = \Delta E_{REESS} \frac{FC_{genset,opt}}{P_{genset,el,opt}}$

where:

ΔFC_{SOC_corr}	Correction of the simulated fuel consumption to account for the variation in stored electric energy over the cycle [g]
ΔE_{REESS}	deviation in energy content of the electric storage over the cycle [kWh]
$FC_{Genset,opt}$	fuel consumption of the Genset in the optimum efficiency point [g/h]
$P_{Genset,el,opt}$	electric power provided by the Genset in the optimum efficiency point [kW]

2.5.3 Pure Electric Vehicles (PEV)

Pure battery electric vehicles, which exclusively have electric machines as propulsion energy converters, as purely conventional vehicles, do not require a control system for the distribution of the drive energy to different sources (ICE, EM). For the simulation in VECTO, however, a separate gear shift strategy had to be developed in this project.

After the release of a first draft version of VECTO capable of handling PEVs it turned out that the existing gearshift model (EffShift + parameterisation for ICEs) did not work particularly well for PEV architectures. Thus, based on the feedback received in the dedicated development workshops a separate gearshift model for PEVs was designed and implemented into VECTO. It eliminated all shortcomings identified by stakeholders as well as strange behaviour identified through an extensive internal testing phase at TUG. The new PEV shift model addresses two particular situations by providing realistic vehicle acceleration behaviour for driving phases and realistic recuperation behaviour through a dedicated operating mode for such phases.

The basic rules for PEV were developed based on the existing EffShift gearshift strategy for AMT and APT elaborated in a preceding project (Rexeis M. 2019). The most important principle is that the gear selection is based on the most efficient gear at the moment. This principle is supplemented, among other things, by rules that prevent gear changes and check the availability of sufficient driving power in alternative gears. The underlying rules and assumptions regarding the EffShift strategy are explained in detail in the referenced report.

These basic principles were adapted so that the ratio of electric EM power over mechanical power at gearbox output is used for assessing the most efficient gear instead of the resulting fuel consumption for conventional vehicles.

There are basically two completely independent factors that can trigger a gearshift in the model:

1. If a gearshift line defined generically in the operation map of the EM is crossed by the actual operation point. Such a crossing event can occur in two directions, either the actual operation point is located left of the downshift line at the low speed region or the actual operation point is located right of the upshift line at the high speed region.
2. For all operation points located between the downshift and upshift lines, the EffShift strategy may choose a more efficient gear to be engaged.

Figure 19 shows the generic definition of the green dot-dashed downshift and upshift lines in the EM operation map (two sets of lines depicted, one dark green for torque and one light green for power). Additionally, there are several parameters marked in bold red which have an effect on the location of the shift lines and other characteristic speeds within the EM map. These bold red figures are at the time being still under discussion with industry and will be fixed for the final Declaration Mode.

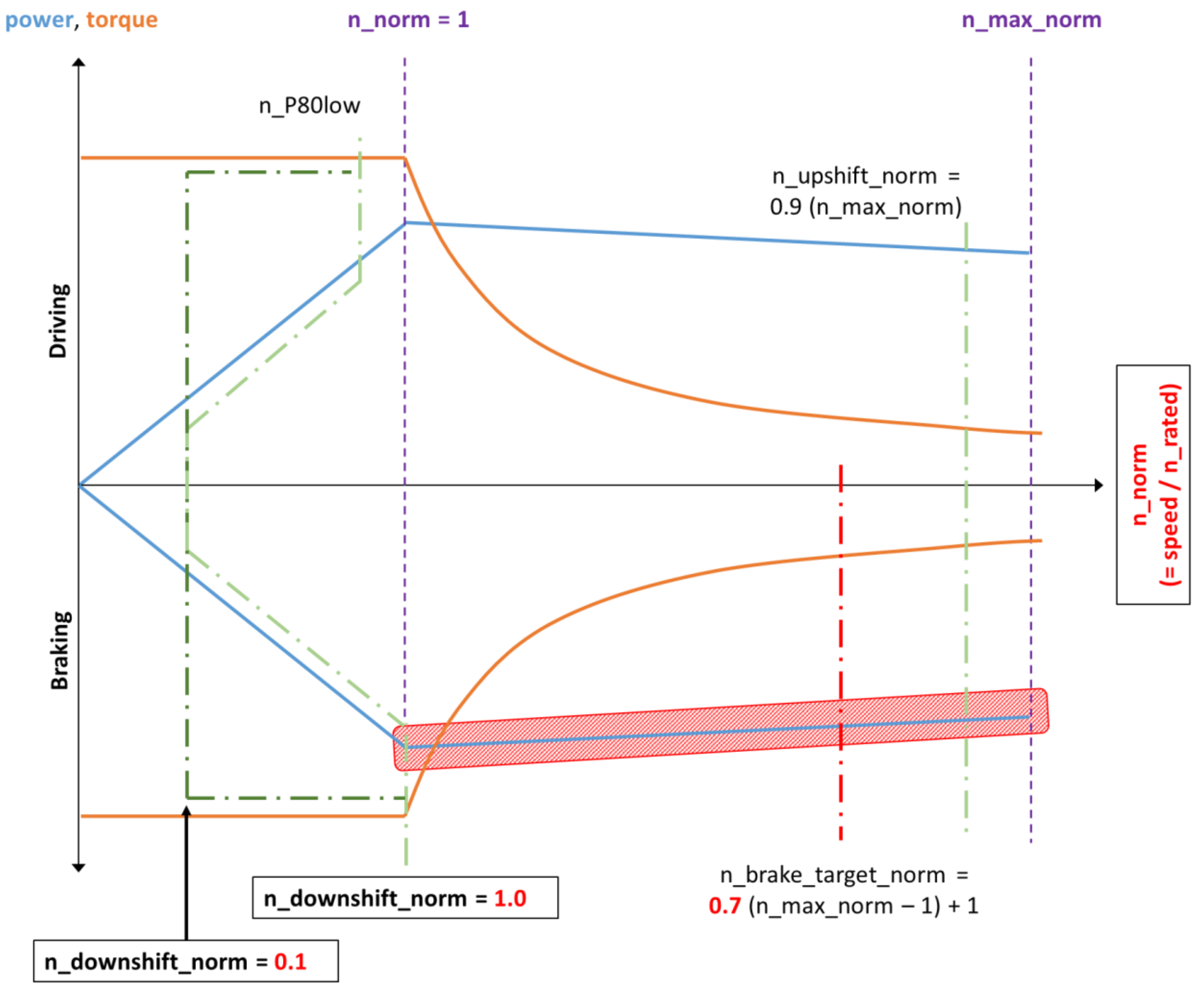


Figure 19: Generic definition of shift lines and parameters in the EM operation map

The shift lines were specifically designed so that their location in the map ensures sufficient power through forced downshifts at low EM speeds and also ensure high EM braking power during recuperation events.

For the EM in driving mode, the maximum downshift speed is located at n_P80low (speed where 80% of the maximum EM power is available). For the EM in de-rating operation, this characteristic speed is calculated from the de-rated power curve.

For the EM in braking mode, EffShift is suppressed for operation points located within the red shaded area (i.e. ≥98% of maximum recuperation power). During braking the new gear after a downshift event is selected so that the resulting speed is equal or higher than n_brake_target_norm (or closest to n_brake_target_norm in case no operation point with higher speed exists).

In addition to these shift lines there are emergency shift speeds defined where a mandatory gearshift is triggered independent of certain limitations being effective in the model (e.g. minimum time between gearshifts). These emergency shift speeds are 0 rpm for a downshift and the minimum of the respective maximum speeds of EM and gearbox upshift.

The only element that was eliminated when adapting the existing gearshift model for PEV was the feature of reducing the required acceleration at very high ICE/EM speeds above the speed at rated power. This element does not make any sense for EMs since the available power is nearly constant at speeds above the speed at rated power.

Table 9 lists all relevant parameters for the PEV gearshift model and the respective default values applied by VECTO. A detailed explanation of all the parameters can be found in (Rexeis M. 2019).

Table 9: Relevant parameters for the PEV gearshift model and the respective default values

Parameter name	Default value	Comment
Rating_current_gear	0.97	Efficiency factor for comparison of different gears
DownshiftAfterUpshiftDelay	6.0	
UpshiftAfterDownshiftDelay	6.0	
ShiftTime	2.0	Minimum time between gearshifts
ATLookAheadTime	1.2	
VelocityDropFactor	1.0	Relevant for upshift for AMT; For APT always 0 since traction interruption is 0
AllowedGearRangeFC	AMT: 2 APT: 1 or 2	For APT with 7 and more gears the allowed range is ±2, for APT with less than 7 gears the range is ±1.
StartTqReserve	20.0	

2.5.4 ADAS for xEV

The existing ADAS in-the-loop model, which is handling Predictive Cruise Control (PCC) events depending on the vehicle configuration and which was developed in a preceding project (Rexeis M. 2019), needed to be adapted for considering also xEVs in the course of this project. The main premise in the extension is the principle that the direct use of kinetic energy ("taking momentum on a downhill gradient") is prioritised over recuperation. Furthermore, in all the defined equations handling the drive cycle pre-processing regarding potential ADAS sections and also the driving actions as well as the different PCC states during the actual simulation run, the effect of the EM needed to be integrated for assessing the respective energy balances triggering a certain PCC event correctly.

The detailed boundary conditions for xEV in combination with PCC are shown in the state-flow diagram in Figure 20.

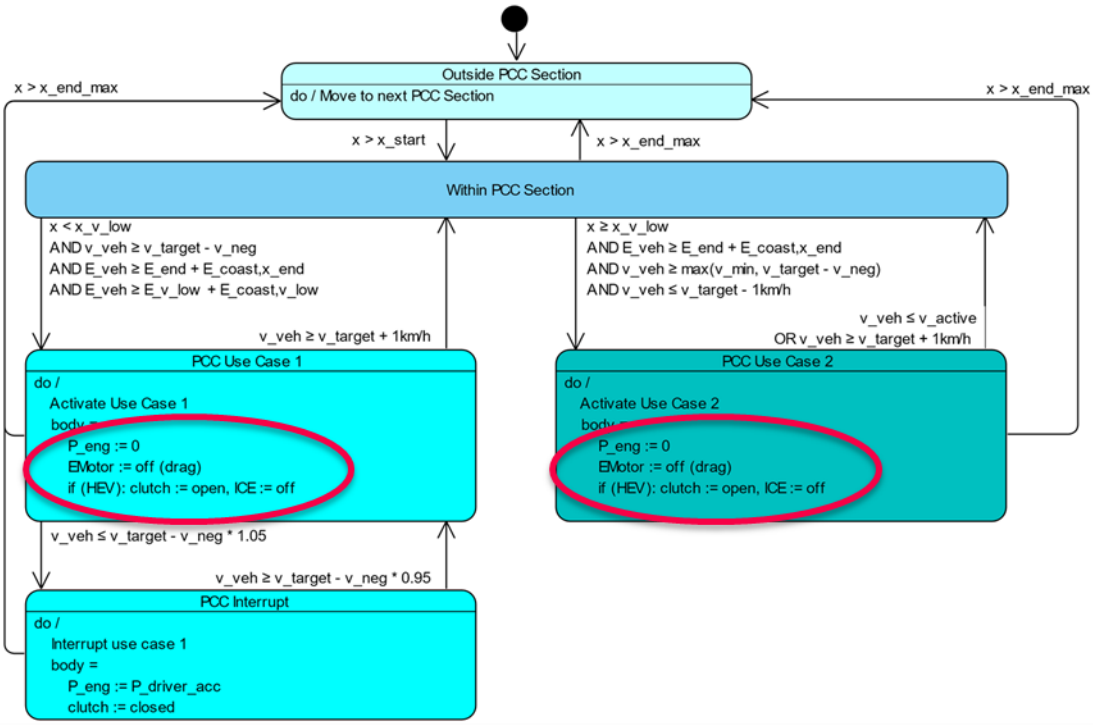


Figure 20: State-flow diagram for PCC model

For the ADAS function "PCC", the following special rules apply for xEV:

- A PCC event for HEV is always done with the ICE off and decoupled from the powertrain via the clutch as well as the EM being off (no separate input required in accordance with the VECTO Regulation).
- For PEV the Eco-Roll feature of decoupling the EM from the powertrain is not foreseen, since no clutch for disconnecting the EM is present (no separate input required in accordance with the VECTO Regulation)

With regard to the Engine-Stop-Start (ESS) feature, the following conventions were defined for HEV after consultation with the stakeholders and in accordance with the implementation in the 2nd Amendment:

- ESS during driving is set to true by default
- ESS during vehicle stop is to be declared in the vehicle input

The background for the rules on ESS is that basically all mild and full HEVs have the capability to (automatically) switch off the engine while the vehicle is in operation under specific boundary conditions. However, there are some mild HEV concepts existing which do not have this feature due to limitations on the ICE side. In this case the input parameter "ESS during vehicle stop" needs to be declared as "false" resulting in the ICE not being turned off in the simulation during PCC events (ICE stays connected to the powertrain and goes into motoring) and during vehicle standstill.

2.6 xEV auxiliaries

For new auxiliary technologies relevant for xEV several elements needed to be added in order to consider these technologies adequately in the Declaration Mode. Generic values for the power demand required for conditioning (i.e. cooling or heating) of electric power-train components needed to be elaborated and adjustments to the original advanced auxiliaries model required for buses were necessary in order to be compatible with xEV vehicles. Furthermore, the handling of Engine-Stop-Start and also the methods for balancing consumption and generation of auxiliaries in post-processing needed to be significantly adapted to be compatible. The following chapters summarize the work performed in this context.

2.6.1 Power demand for conditioning of electric powertrain components

For a solid basic assessment of the power demand required for conditioning (i.e. cooling or heating) of the relevant electric powertrain components (EM and REESS) a methodology was developed in this project based on the existing generic power demand values for the ICE cooling fan established for conventional vehicles in Declaration Mode. The existing concept for the ICE cooling fan is a very simple approach which does not consider the actual time-resolved heat loss to the cooling fluid but simply applies fixed (i.e. equals average) mechanical power demand dependent on the mission profile and the technology of fan drive and control.

Based on these existing values an assessment based on basic physical coherencies was performed. It makes some straight forward assumptions about (heat) losses and their dissipation and the basic assumption for the ICE are transferred to other xEV components. Figure 21 shows the principles of this concept.

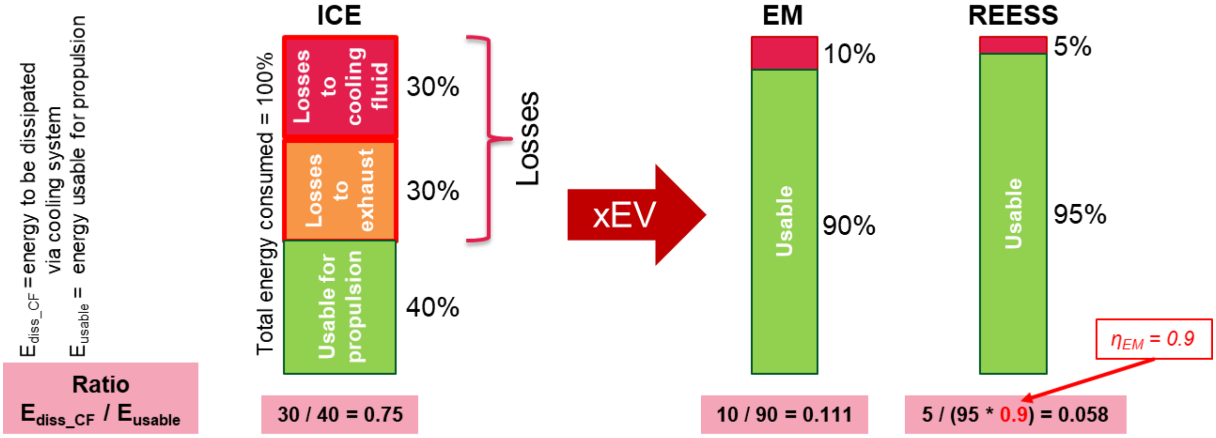


Figure 21: Basic principles of methodology for conditioning power demand of xEV components

Derived from this concept one can obtain factors defining the ratio of the energy to be dissipated via cooling system over the energy usable for propulsion from the respective system. In addition, taking the typical temperatures of the cooling fluid for each system as well as the difference to the ambient temperature into account one can calculate a scaling factor which needs to be applied to the existing mechanical power demand values defined for the ICE fan in order to derive the applicable values for the different xEV components. Table 10 shows these resulting scaling factors for all relevant xEV components.

Table 10: Resulting scaling factors for all relevant xEV components

	ICE	EM	REESS
Ratio E_{diss_CF} / E_{usable} [-]	0.750	0.111	0.053
Typical temperature of cooling fluid [°C]	90	90	40
Delta temperature (ΔT) to 20°C ambient [°C]	70	70	20
Ratio ΔT component to ΔT ICE [-]	-	1.00	0.29
Total ratio component compared to ICE	-	= 0.111 / 0.750 / 1.00 = **0.15**	= 0.053 / 0.750 / 0.29 = **0.25**

The existing power consumption of fully electric fan technology for ICE is then taken as relevant reference value. This reference is defined as mechanical power at the ICE crankshaft, thus a conversion to electric power via the generic alternator efficiency of 0.7 needs to be done. The resulting values are then transferred to other xEV components by multiplying with the respective ratios derived in Table 10. Figure 22 shows the resulting draft values for each different type of xEV component depending on the different mission profiles.

	power demand									
	Buses					Lorries				
	Heavy Urban	Urban	Suburban	Interurban	Coach	Long haul	Regional delivery	Urban delivery	Municipal utility	Construction
	[W]	[W]	[W]	[W]	[W]	[W]	[W]	[W]	[W]	[W]
Reference from ICE	1000	1000	1000	1100	1200	700	800	600	600	1400
Electrical reference	700	700	700	770	840	490	560	420	420	980
EM	105	105	105	116	126	74	84	63	63	147
REESS	189	189	189	208	227	132	151	113	113	265

x 0.7

Total ratio to ICE

Figure 22: Draft values for conditioning power demand of xEV components in different mission profiles

Some generally applicable principles are already currently existing in VECTO for the ICE cooling fan and are transferred to xEV components. These general rules are as follows:

- The fan power demand for ICE is set to 0 when the ICE is off (i.e. due to ESS option), since the assumptions for the basic power demand were based on data without ESS
- The conditioning power demand for xEV components is analogously set to 0 in phases where the respective component is off (no power to/from the component except for electric auxiliaries power demand)

The draft values shown above were then used as a basis for further discussion with industry in dedicated development meetings and served as basis for a plausibility check of values provided by other stakeholders. ACEA also presented preliminary numbers for the conditioning power demand of xEV components in these development meetings which basically match the elaborated draft values quite well regarding the order of magnitude and also include a certain portion of cooling pump drive power. The ACEA values were derived based on available measurement or simulation data and expert judgement at all ACEA members and might thus better reflect reality than the draft values elaborated.

On top of this existing concept for power demand of xEV related auxiliaries there are some special rules required for HEVs, since these vehicles have more than one energy converter installed (i.e. ICE and EMs) but those are not always operated at the same power level as if only one single energy converter would propel the vehicle. Thus, the individual power split needs to be considered for all types of HEV architectures in order not to end up with unrealistically high conditioning power demands.

The basic rules for HEVs are defined as follows:

- The ICE fan power demand is always applied in the simulation when the ICE is on
- In addition to this ICE fan power a certain power demand is added based on the above explained values for EM and REESS (valid for a PEV, $P_{cond,PEV}$) according to the following concept:
    - An electrification factor x is calculated online during each timestep of the simulation defining the electric share of total propulsion power.
    - The applied conditioning power demand for the electric components is then calculated by multiplying the basic value $P_{cond,PEV}$ with the factor x for phases where the ICE is running.
    - For phases where the ICE is off the full amount of $P_{cond,PEV}$ is applied.
    - For serial HEVs also the full amount of $P_{cond,PEV}$ is applied.

2.6.2 Adjustment of advanced auxiliaries (AAUX) model

The basic aim of this subtask was to adjust the original AAUX model created in a former project to cover also the operation of advanced auxiliaries in hybrid or electric vehicles. The original AAUX model that was used as basis for all further work performed in this contract was created by a different contractor and is documented in the respective final report (Norris J. 2016). This model was created specifically to depict the auxiliary loads relevant for buses and coaches.

Already during the preceding project of the “Feasibility study” (Silberholz G. 2017) some incompatibilities of the existing AAUX model for application to xEV vehicles were identified and listed in the corresponding final report.

When a thorough analysis was performed during the actual project, not only incompatibilities but also some methodological errors were identified. The most important ones are summarized in below:

- No documentation of special rules defined in program code for low floor buses regarding HVAC cooling/heating demand

  → discussion with ACEA and contacting the Fraunhofer Institut, which developed the basic quasi-static HVAC model on behalf of ACEA being used as starting point of the original AAUX model, gave more insight

  → only with this support the error in the original AAUX model from the previous contract could be identified and fixed (a wrong parameter was allocated for calculation "FrontRearWIndowArea" instead of "BC_MaxTemperatureDeltaForLowFloorBusses")

- Calculation of total air amount for pneumatic system was based on estimated instead of actual cycle duration (no correction performed in post-processing)
- HVAC mechanical power demand was not corrected for phases of engine stop-start
- Additional fuel consumption due to fuel-fired heater was implemented incorrectly in program code (unit conversion wrongly implemented)
- Pre-existing auxiliary power from regular components outside of AAUX model (e.g. ICE fan) were missing (required engine power too low)

  → leads to incorrect recuperation potential both for smart AUX-systems and also HEVs

- Incorrect method for all corrections regarding fuel consumption corrections in post-processing of AAUX model

  → calculation is done based on absolute fuel consumption values in grams instead of difference in required energy

  → different fuel consumption figures are used as basis for setting up different lines for interpolation, cross influences over different auxiliary systems might not be depicted correctly depending on the specific auxiliary configuration (distortion of benefits of smart AUX systems)

Especially the last point in the above list is very crucial when it comes to correct assessment of the fuel saving potential of smart auxiliaries (also named “P0” or “micro” HEVs) as well as the combined effect of the recuperated energy together with actual HEVs in the context of the VECTO method.

The flaw in this method in the existing AAUX model shall be explained exemplarily for one specific path in the methodology schematics. In module 12, Point 3 and Point 1 for electrical system post-processing regarding true energy demand over cycle include different shares of fuel consumption attributed to the pneumatic system. Thus, they should not be used together to define the basic absolute level of fuel consumption for a certain post-processing method. In more detail, Point 3 includes already the Stop-Start correction for pneumatic system leading to higher fuel consumption contribution from the pneumatic system (originating from Module 10). Whereas Point 1 does not include this contribution but only the required average compressor drive power for phases where the ICE is on leading to a lower fuel consumption contribution from the pneumatic system (originating from Module 3 via Module 11). Thus, the calculated gradient of the correction line is not correct but overestimates the additional fuel consumption per electrical energy generated. Figure 23 gives an overview of the incorrect method for this specific example.

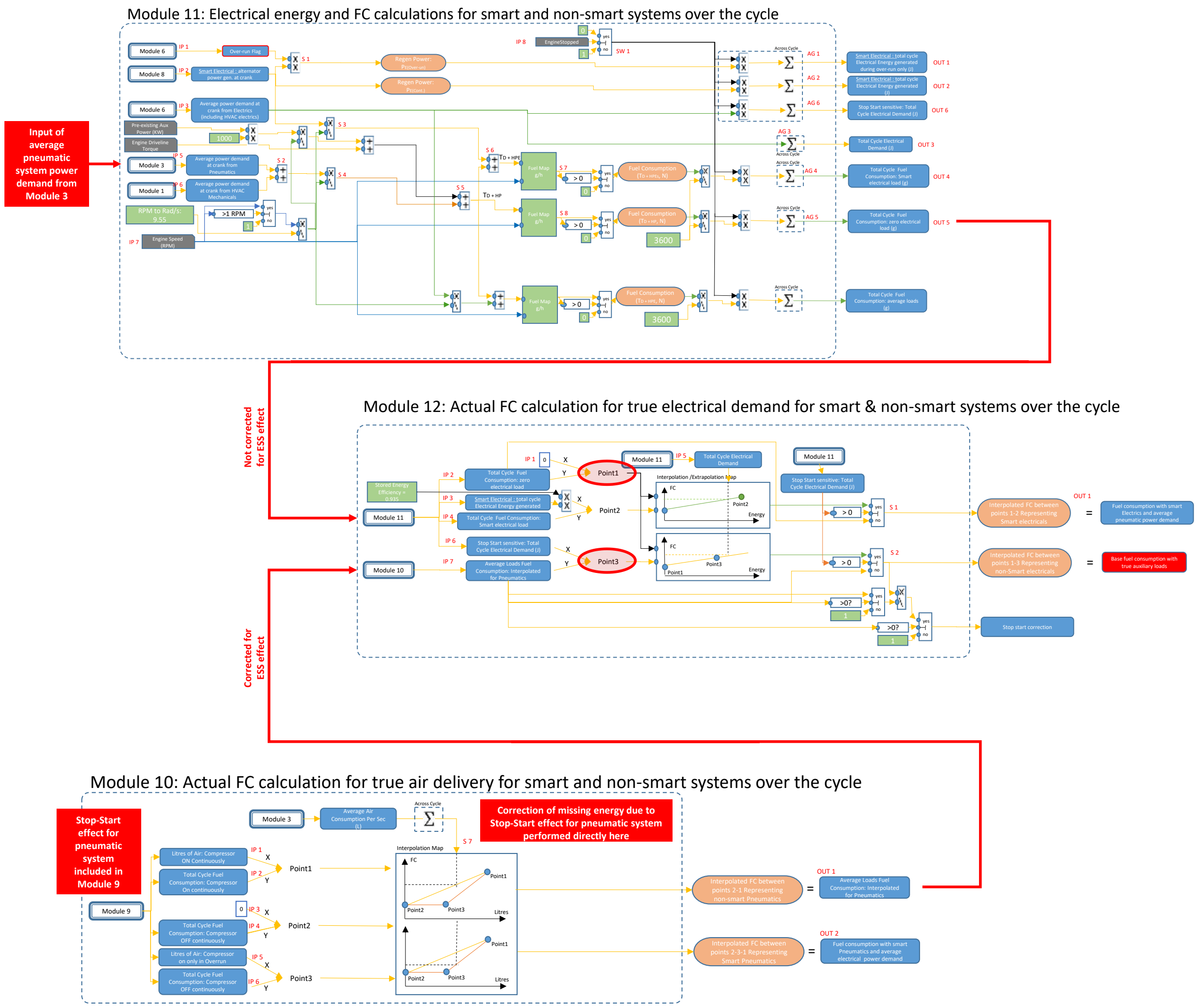


Figure 23: Exemplary overview of the incorrect method for post-processing of fuel consumption correction for one specific path

Based on the incompatibilities of the original AAUX model for application to xEV vehicles and also regarding the structure of the original AAUX model the whole code was completely restructured to fit the needs of the VECTO 3.x architecture and applicability to xEV architectures as well. In the course of the in-depth analysis as basis for implementing all the structural changes, also all identified errors in the model listed above were corrected as well as several minor bugs and faulty test cases. It is essential to mention that the basic methodologies for deriving the power demand of the different auxiliary systems and all underlying assumptions of the original AAUX model are correct and were not changed but completely integrated into the updated code. Regarding the above mentioned deficiencies in the post-processing of fuel consumption correction, the methods were completely revised and based on difference in energy/air demand over the cycle instead of fuel consumption. The resulting difference in energy/air demand over the cycle is then corrected based on the already well-established approach using the slope of the Engine-Line in the VECTO vsum-file (please refer to the VECTO user manual for more details).

The following list gives an overview of the major changes performed according to the in-depth analysis:

- AAUX model now fully merged with all xEV powertrain architectures (was only compatible with pure ICE vehicles so far)
- AAUX model can now be run also in VECTO Engineering mode
- Seven different configurations for electrical auxiliary system modelled for buses

  (configs A to C3.b in Table 11 as discussed and agreed in dedicated development meetings), all definitions are in accordance with the content of Annex IX of the VECTO Regulation
- Implementation of detailed input of auxiliary power demand for all consumer types (electric, pneumatic, HVAC system) possible for all different states of ICE and vehicle (i.e. ICE on/off, vehicle driving/standstill) including updating the GUI as shown in Figure 24
- New approach for engine-stop-start (ESS) (further details in chapter 2.6.3)
  - 2 separate Utility Factors (UF's)[18] for "vehicle stops" and "during driving"
    - Values of UFs can be edited via GUI in Engineering mode, but will be generically defined depending on several vehicle parameters in Declaration mode
    - UF "during driving" is per default always 1 for HEVs
  - ICE always completely off in simulation, corrections performed in post-processing only
- Post-processing of fuel consumption correction completely revised and aligned with existing VECTO approach

[18] The utility factor defines the share of actual "engine off" time during potential "engine off" periods. This value is usually lower than 1 due to influence of not modelled issues in VECTO (e.g. HVAC peaks, PTO etc.). For ADAS for conventional vehicles the UF was defined with 0.8.

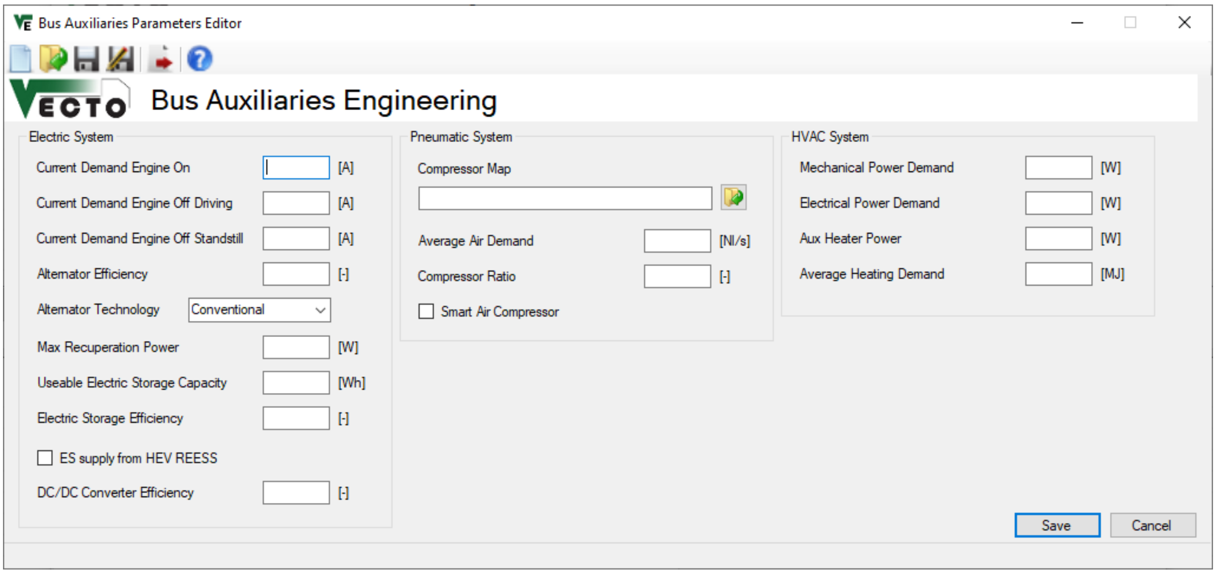


Figure 24: Input of auxiliary power demand for all consumer types in Engineering mode

When it comes to the interaction of the AAUX model with the modules covering the HEV power-train components, there is a careful methodology and a strict definition of boundaries required in order to separate the handling of recuperating energy and not to introduce any double counting of such energy due to improperly defined interfaces between the operation of the main powertrain and the AAUX model. For this reason there were several specific configurations identified in dedicated development meetings together with industry relevant for existing bus concepts on the market. These system configurations define the basis for all further implementation of specific rules for the combined operation of the AAUX model with full HEV functionality of the powertrain. Table 11 gives an overview of all seven system configurations identified and a summary of the handling of the energy consumption for electric auxiliaries.

Table 11: System configurations identified for the operation of the AAUX model in buses

System type (acc. to ACEA definition)	Alternator technology	Full HEV functionality	Supply of electric auxiliaries from HEV REESS possible	Recuperation potential	Fuel consumption allocated to electric energy for electric consumers
A	conventional	no	no	None	Approx. FC = E_el_AUX_ES [kWh] * k_engline [g/kWh] / 0.7 (related mech power is considered in simulation loop, only for ESS post-processing step is applied)
B	smart	no	no	P0	Approx. FC = (E_el_AUX_ES - E_el_rekup) [kWh] * k_engline [g/kWh] / 0.7 (real simulation is "in-the-loop", only missing balances are corrected in post-processing)
C1	none	yes	yes	HEV	1.) E_el_AUX_ES continuously drawn from high voltage SOC (DC/DC eff. = 0.97) 2.) If SOC at min then: post-processing as for A considering eta_REESS ; no turn on of ICE due to SOC min reached (integrator just for aux at standstill)
C2.a	conventional	yes	yes	HEV	1.) E_el_AUX_ES continuously drawn from high voltage SOC (DC/DC eff. = 0.97) 2.) If SOC at min then: post-processing as for A considering eta_REESS ; no turn on of ICE due to SOC min reached (integrator just for aux at standstill) In this configuration the alternator is only installed to cover very high electric loads (i.e. active entertainment system in coaches) which are not applied in the VECTO missions.
C2.b	conventional	yes	no	HEV	1.) E_el_AUX_ES provided by Alternator (handling done as for configuration A)
C3.a	smart	yes	yes	P0+ HEV	1.) E_el_AUX_ES continuously drawn fromP0 storage 2.) If P0 storage at min then: take from HEV-REESS 3.) If both storages at min then: post-processing as for configuration A; no turn on of ICE due to SOC min reached (integrator just for aux at standstill)
C3.b	smart	yes	no	P0+ HEV	1.) E_el_AUX_ES continuously drawn fromP0 storage 2.) If P0 storage at min then: post-processing as for configuration A ; no turn on of ICE due to SOC min reached (integrator just for aux at standstill)

2.6.3 Handling of Engine-Stop-Start (ESS) in connection with the power requirements of the auxiliary consumers

The basic approach regarding power demand of all auxiliaries in VECTO is that a constant power demand over time is specified depending on the specific configuration of the vehicle and the respective mission profile. In order to consider the auxiliary power demand also for phases where the ICE is off due to the Engine-Stop-Start (ESS) feature (declared input parameter), the portion of the auxiliary supply demand that was not provided in these phases needs to be considered. In principle, this could be done quite simply if ESS could be simulated completely "in-the-loop", i.e. the ICE is simply "on" or "off" in the simulation, and the status of the auxiliary consumers could also be set "in-the-loop" accordingly. In VECTO, this simple solution cannot be implemented in this way, because in the modelling of the ESS feature, on the basis of which the engine is switched off according to certain operating conditions (e.g. at standstill after a certain time or during an ADAS event), additional probabilities are defined (Utility factor, UF) for which percentage ESS can actually be used during operation due to other framework conditions.[19] This probability distribution must be taken into account in VECTO in a post-processing step.

There was a simple methodology in place for pure-ICE vehicles at the start of this project which accounted for these "missing" energies partly during the actual simulation and partly in post-processing. This existing methodology proved to be very complicated and complex when it comes to HEVs since a dual-state based weighted superposition of the different ICE operation modes (i.e. once running with a share of 1-UF and once stopped with a share of UF) directly in the simulation does not make sense for such vehicles. Apart from overcomplicating all corrections performed in post-processing, there is also an influence on the actual performance of the HEV system. Meaning once the ICE would be running at a certain vehicle stop, it might not only run in idling to provide the required auxiliary power but on top of that also charge the REESS due to increased overall efficiency. But it is hardly manageable to integrate such a complex methodology into the simulation routine and at the same time to correctly account for all missing shares of auxiliary energy demand in post-processing. Furthermore, the effects of ESS on the total fuel consumption turned out to be completely incomprehensible when looking at the superposed information available in the VECTO output which did not allow for reverse engineering of the individual ICE modes.

Thus, an extensive redesign of the ESS method targeting both, actual simulation and post-processing was developed. In addition there were two instead of only one ESS-UFs introduced to account for the different operation of HEVs as opposed to pure-ICE vehicles during driving and standstill of the vehicle. The basic principles of the ESS approach as well as the new elements introduced are described below:

- The integrated actual supply demand from auxiliaries needs to match the target supply demand over the cycle
- The target supply demand (i.e. mechanical energy, electrical energy or "norm-liters" of compressed air) differs whether the ICE is on or off and whether the vehicle is moving

[19] The utility factor defines the share of actual "engine off" time during potential "engine off" periods. This value is usually lower than 1 due to influence of not modelled issues in VECTO (e.g. HVAC peaks, PTO etc.). For ADAS for conventional vehicles the UF was defined with 0.8.

or not since certain auxiliary systems are deactivated under these circumstances (e.g. steering pump when vehicle is not moving)

- In real on-the road driving there are certain boundary conditions which prevent the ICE to be turned off (e.g. high auxiliary demand, PTO operation, low battery charge etc.). Since those conditions are not modelled in VECTO generic UFs need to be defined.
- The basic method was already implemented in a preceding project during the ADAS in the loop implementation where the generic UF was defined with 0.8 for lorries, in addition to that the ICE is always re-started after coherent off-phases of 120 seconds.
- In the updated approach the ICE is always off in the modal results during an ESS event
- "Missing" supply demands from auxiliaries for both ICE states (i.e. "on" with a share of 1-UF and "off" with a share of UF) are traced separately in dedicated columns in the vmod-file
- In the post-processing target supply demand and actually provided supply are balanced
- In the post-processing the idle consumption of ICE during on phases (i.e. share of 1-UF) and the energy required to start the ICE are accounted for.
- Separate UFs are introduced for "during standstill" ($UF_{standstill}$) and "during driving" ($UF_{driving}$)
    - The $UF_{driving}$ is set to 1 per default for all HEVs, meaning the generic HEV strategy decides whether the ICE is on or off.

      Any further consideration of an UF<1 for HEVs would extremely complicate the cost calculation within the HEV strategy, as well as put into question on/off decisions made retrospectively. This would make the interpretability of the results considerably more difficult and might bias the fuel saving potential between different vehicles.
    - The $UF_{driving}$ for conventional vehicles was already defined with 0.8 in a preceding project during the ADAS in the loop implementation.
    - The $UF_{standstill}$ for lorries was already defined with 0.8 in a preceding project during the ADAS in the loop implementation.
    - The $UF_{standstill}$ for buses was defined in this project in specific development meetings with industry and will be allocated depending on whether the vehicle is conventional (ICE only) or a HEV. Furthermore, for HEVs there will be two different UF values depending on the technology of the air compressor. In case an electrified air compressor is installed, a higher UF will be allocated. All the required numerical values for the Declaration mode are available and can be easily adjusted during the test phase and feedback phase planned in the separate contact (see footnote 4).

Table 12 lists all the relevant application cases for lorries and the seven different system configurations for buses explained in chapter 2.6.2. All the detailed information on how the different auxiliary systems are considered for all of the different application cases is given in the respective figures in Annex C.

Table 12: Relevant application cases for lorries and the seven different system configurations for buses

Application case nr.	Description	
1	Lorries (all)	
	Buses Case A	(conv. vehicle / conv. alternator / no link to HEV-REESS)
	Buses Case 2b	(HEV / conv. alternator / no link to HEV-REESS)
2	Buses Case B	(conv. vehicle / smart alternator / no link to HEV-REESS)
3	Buses Case C1	(HEV / no alternator / link to HEV-REESS)
	Buses Case C2a	(HEV / conv. alternator / link to HEV-REESS)
4	Buses Case C3b	(HEV / smart alternator / no link to HEV-REESS)
5	Buses Case C3a	(HEV / smart alternator / link to HEV-REESS)

2.6.4 Post-processing methods for balancing energy demands over cycle

The resulting difference in supply demand over the cycle as described in the previous chapter is corrected based on the already well-established approach using the slope of the "Engine-Line" in the VECTO vsum-file (see VECTO user manual for more details). The methods developed in this project utilise the same coherent approach for correction in post-processing for all different energies – not only for auxiliary supply demands. The following paragraphs give a detailed overview of the methods used for all individual systems – not only auxiliaries relevant for buses – but also all systems contributing to the energy balance of the whole vehicle implemented in preceding projects – for processing the results in the vmod-files. The formula symbols used here can be found as columns in the vmod file in the case of modal quantities and in the vsum file in the case of integral or cycle-average quantities.

2.6.4.1 ESS

The energies allocated to mechanical auxiliaries during phases of ESS for four different engine states are calculated as follows:

E_aux_ESS_mech_ICEoff_standstill = Σ P_aux_ESS_mech_ICE_off · dt |[20] v_act = 0

E_aux_ESS_mech_ICEoff_driving = Σ P_aux_ESS_mech_ICE_off · dt | v_act > 0

E_aux_ESS_mech_ICEon_standstill = Σ P_aux_ESS_mech_ICE_on · dt | v_act = 0

[20] The operator | stands for "for all time steps in the simulation in which the following condition applies".

$E\_aux\_ESS\_mech\_ICEon\_driving = \Sigma P\_aux\_ESS\_mech\_ICE\_on \cdot dt \mid v\_act > 0$

The energy demand for ramping up the engine is calculated as follows:

$E\_ICE\_start = \Sigma P\_ICE\_start \cdot dt$

The resulting fuel consumption for ramping up the engine is calculated as follows:

$FC\_ICE\_start = E\_ICE\_start \cdot k\_engline$

The total resulting fuel consumption due to ESS relevant for post-processing is calculated as follows:

$$FC\_ESS = FC\_ICE\_start + E\_aux\_ESS\_mech\_ICEoff\_standstill \cdot k\_engline \cdot UF\_standstill + (E\_aux\_ESS\_mech\_ICEon\_standstill \cdot k\_engline + FC(n\_idle, 0) \cdot t\_ICEoff\_standstill) \cdot (1 - UF\_standstill) + E\_aux\_ESS\_mech\_ICEoff\_driving \cdot k\_engline \cdot UF\_driving + (E\_aux\_ESS\_mech\_ICEon\_driving \cdot k\_engline + FC(n\_idle, 0) \cdot t\_ICEoff\_driving) \cdot (1 - UF\_driving)$$

2.6.4.2 Electric system

The energy consumed by the electrical auxiliaries as well as the amount generated are calculated as follows:

$E\_BusAux\_ES\_consumed = \Sigma P\_BusAux\_ES\_consumed \cdot dt$

$E\_BusAux\_ES\_gen = \Sigma P\_BusAux\_ES\_gen \cdot dt$

The difference in energy relevant for correction is calculated as follows:

$\Delta E\_BusAux\_ES\_mech = (E\_BusAux\_ES\_consumed - E\_BusAux\_ES\_gen) / (AlternatorEfficiency \cdot AlternatorGearEfficiency)$

The total resulting fuel consumption due to the electric system relevant for post-processing is calculated as follows:

$FC\_BusAux\_ES = \Delta E\_BusAux\_ES \cdot k\_engline$

There are bus configurations where supply of the electric auxiliaries from the HEV REESS is possible in accordance with Table 11 in chapter 2.6.2. For these vehicles, the case may arise that the electric storage is emptied during long standstill phases of the vehicle as described in the referenced table. In order to maintain the basic approaches described above, in this case the ICE is not started during the standstill phase in the simulation, but the missing electrical energy to be generated is corrected in post-processing:

E_DCDC_missing = Σ P_DCDC_missing · dt

E_DCDC_missing_mech = E_DCDC_missing / (DCDC_ConverterEfficiency · AverageEM-ChargingEfficiency)

The total resulting fuel consumption due to this amount of electric auxiliary demand relevant for post-processing is calculated as follows:

FC_DCDCMissing = E_DCDC_missing_mech · k_engline

2.6.4.3 Pneumatic system

The average amount of compressed air (unit = Norm liters, "Nl") consumed by the pneumatic system in each timestep was determined in a pre-processing step before the actual simulation run based on the actual configuration of pneumatic consumers for the specific vehicle. For some consumers the required amount of compressed air is defined per cycle and not per time (e.g. opening of pneumatic doors occurs a certain number of times in one specific cycle). Thus, the determination of the average amount of consumed compressed air per time requires an estimate for the expected duration of the cycle. Once the real cycle duration is known after the actual simulation is finished, the correct average air demand needs to be calculated once again in post-processing with the actual cycle time. Based on this the correct total air demand over the cycle (CorrectedAirDemand) is calculated and used for all further post-processing steps.

The amount of compressed air generated over the whole cycle is calculated as follows:

AirGenerated = Σ Nl_busAux_PS_gen

The difference in compressed air relevant for correction is calculated as follows:

DeltaAir = CorrectedAirDemand – AirGenerated

The mechanical energy demand for generating this amount of compressed air is calculated as follows:

E_busAux_PS_corr = DeltaAir · k_Air

The factor k_Air defining the average mechanical energy required for generating one unit of compressed air is calculated as follows (for more details of the methodology for the air compressor operation pattern please refer to the dedicated report from the project designing the original AAUX model in (Norris J. 2016):

E_busAux_PS_drag = Σ P_busAux_PS_drag · dt | Nl_busAux_consumed = Nl_busAux_gen (i.e. only operation points in non smartPS phases of the air compressor)

E_busAux_PS_alwaysOn = Σ P_busAux_PS_alwaysOn · dt | Nl_busAux_consumed = Nl_busAux_gen

$Nl\_alwaysOn = \Sigma\ Nl\_busAux\_gen\_max \mid Nl\_busAux\_consumed = Nl\_busAux\_gen$
(i.e. only operation points in non smartPS phases of the air compressor)

$k\_Air = (E\_busAux\_PS\_alwaysOn - E\_busAuxPS\_drag) / (Nl\_alwaysOn - 0)$

The resulting fuel consumption due to the difference in compressed air relevant for post-processing is calculated as follows:

$FC\_BusAux\_PS\_AirDemand = E\_busAux\_PS\_corr \cdot k\_engline$

The resulting fuel consumption due to the compressor drag curve for ESS phases where the ICE would have been running due to the UF (i.e. share of 1-UF) relevant for post-processing is calculated as follows:

$FC\_BusAux\_PS\_Drag\_ICEoff\_driving = P\_PS\_drag(n\_idle) \cdot k\_engline \cdot t\_ICEoff\_driving \cdot (1 - UF\_driving)$

$FC\_BusAux\_PS\_Drag\_ICEoff\_standstill = P\_PS\_drag(n\_idle) \cdot k\_engline \cdot t\_ICEoff\_standstill \cdot (1 - UF\_standstill)$

The total resulting fuel consumption due to the pneumatic system relevant for post-processing is calculated as follows:

$$FC\_BusAux\_PS = FC\_BusAux\_PS\_AirDemand + FC\_BusAux\_PS\_Drag\_ICEoff\_driving + FC\_busAux\_PS\_Drag\_ICEoff\_standstill$$

2.6.4.4 WHR system

The energy generated by the WHR system over the cycle is calculated as follows:

$E\_WHR\_mech = \Sigma\ P\_WHR\_mech \cdot dt$

$E\_WHR\_el = \Sigma\ P\_WHR\_el \cdot dt$

Electrical energy generated by the WHR system is not fed directly to the electrical system, neither to the low voltage auxiliary board net nor to the high voltage HEV-REESS if applicable. Direct feed of electric WHR energy would influence the HEV strategy and the methodology for balancing the SOC over the cycle in a non-controllable way. Direct feed of electric WHR energy to the low voltage board net is not possible for lorries since this element is not modelled for these vehicles and for buses it would overcomplicate the AAUX model. Thus, the electric WHR energy is converted to mechanical energy which leads to the exact same effect as direct feed to the AAUX model due to the specific methodology designed for post-processing.

For all three different application cases the electric WHR energy is converted to mechanical energy according to the following equations:

$E\_WHR\_el\_mech = E\_WHR\_el / AlternatorEfficiency$ (for lorries)
$E\_WHR\_el\_mech = E\_WHR\_el / averageEMChargingEfficiency$ (for buses C3a)

E_WHR_el_mech = E_WHR_el / BusAlternatorEfficiency (for all other buses)

The total resulting fuel consumption due to the pneumatic system relevant for post-processing is calculated as follows:

FC_WHR = - (E_WHR_mech + E_WHR_el_mech) · k_engline

2.6.4.5 REESS energy variation over cycle ("SOC correction")

In the simulations for the charge sustaining mode the balancing of the REESS energy over the cycle is for the most part handled by the HEV strategy if correctly parameterized. For small remaining deviations in REESS energy over the cycle the correction is automatically done in post-processing according to the following equations depending on the direction of the deviation:

In case the SOC at the end of the cycle is lower than at the start:

$$FC_{SoC}[g] = -\Delta E_{REESS}[kWh] * k_{engline}\left[\frac{g}{kWh}\right] * \frac{1}{\overline{\eta_{EM\,chg}} * \overline{\eta_{REESS\,chg}}}$$

In case the SOC at the end of the cycle is higher than at the start:

$$FC_{SoC}[g] = -\Delta E_{REESS}[kWh] * k_{engline}\left[\frac{g}{kWh}\right] * \overline{\eta_{EM\,dischg}} * \overline{\eta_{REESS\,dischg}}$$

2.6.4.6 Final fuel consumption figure

All fuel consumption relevant corrections listed in above paragraphs 2.6.4.1 to 2.6.4.5 are performed automatically and the results are separately listed in the vsum-file. The resulting total fuel consumption for the simulated mission profile (FC_FINAL) is then calculated as sum over the actual, in-the-loop simulated fuel consumption of the vehicle driving the cycle (FC_ModSum) and all individual correction portions follows:

FC_FINAL = FC_ModSum + FC_ESS + FC_DCDCMissing + FC_BusAux_PS +
FC_BusAux_ES + FC_WHR + FC_BusAux_AuxHeater + FC_SoC

2.7 Handling of vehicles with off-vehicle charging capabilities

HEVs equipped with a REESS with larger storage capacity often allow re-charging the storage from an external source. Those concepts are referred to as 'off-vehicle charging HEV' (OVC-HEV) within the context of VECTO. OVC-HEVs are typically able to drive a certain distance (depending on the specific vehicle configuration, mission and individual settings for operation mode by the driver) with the propulsion energy primarily (or even solely) provided by the REESS. To consider the amount of electric energy from external charging utilised for the final energy consumption figures, the basic concept already in place for passenger cars was adopted. Thus, such vehicles are simulated in VECTO in two different operation modes (charge-depleting and charge-sustaining mode) and the final result is then calculated as a weighted average out of the two separate results. All applicable boundary conditions and related methods for VECTO are explained in detail in the subsequent sub-chapters.

2.7.1 External charging and reference point for energy balance

When considering electric energy used for propulsion from an external source two definitions need to be made to allow an unequivocal and comparable assessment of energy consumption between different vehicles:

1. The system boundaries for balancing the amount of electric energy need to be drawn defining which losses in the chain of providing electric propulsion energy shall be considered for the final result.
2. A certain reference point where all the electric energy flows in the vehicle are balanced needs to be defined for correctly considering different paths over which the electric propulsion energy may be provided[21].

Above definitions are applicable for all vehicles which allow charging from an external source, i.e. PEVs and OVC-HEVs.

In principle, there are three reasonable locations where the system boundary for consideration of losses in providing electric energy from an external source could be defined:

1. The connection point to the electric supply grid, taking all losses of required charging components towards the battery and also internal losses of the battery into account.
2. The interface to the charging port of the vehicle, taking only losses of required charging components inside of the vehicle and also internal losses of the battery into account.
3. The battery terminals, taking only internal losses of the battery into account.

[21] This is especially relevant for the upcoming 3rd amendment of the VECTO Regulation which shall consider also feed of electric propulsion energy from an external infrastructure during driving. Due to the fact that electric energy from an external source is not directly considered for the actual simulation in VECTO but only based on a special method defined for post-processing, the losses of all possible pathways need to be reflected correctly (i.e. energy charged into the battery vs. energy provided directly to the EM). Thus, initially all electric propulsion energy for the actual simulation comes from the battery and battery internal losses need to be accounted for correctly in post-processing (meaning either reducing or adding losses depending on whether the energy was fed directly to the EM or stored).

Figure 25 graphically illustrates the possible system boundaries. Based on arguments extensively discussed with stakeholders and given by **Fehler! Verweisquelle konnte nicht gefunden werden.**, the system boundaries were drawn at the battery terminals and also the reference point for balancing the electric energy was defined at the same location as shown in Figure 25.

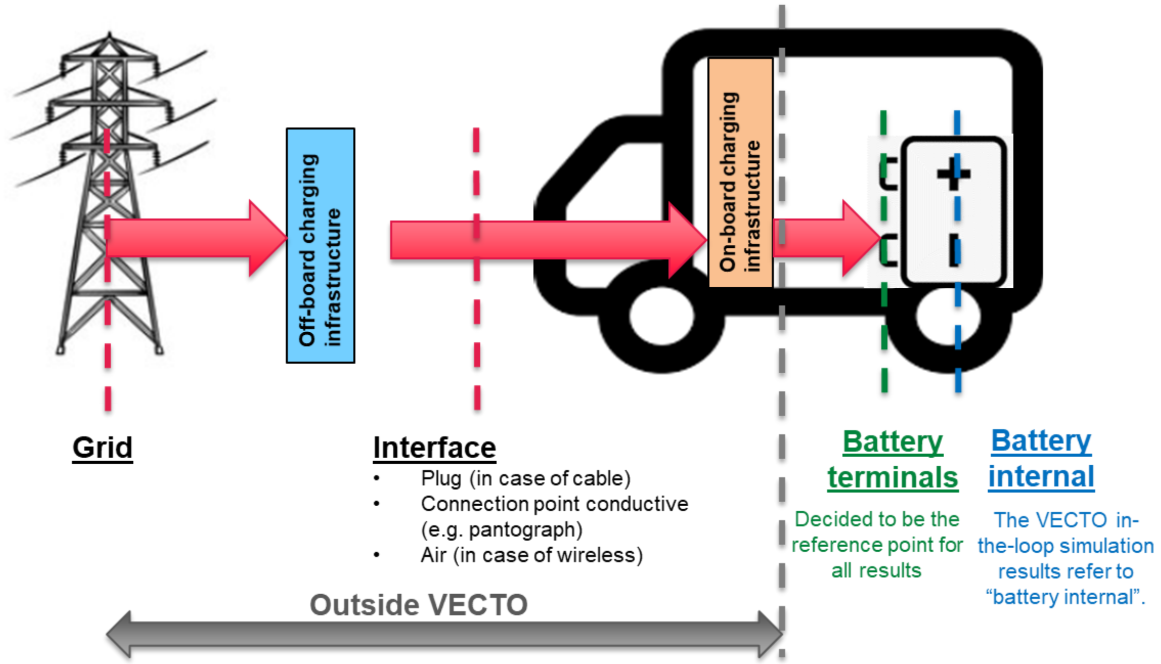


Figure 25: Location of system boundaries for external charging

Table 13: Pros and cons of different locations of system boundaries for external charging

Ref. point	+ / o / -	Argument
Grid	+	This is what counts for society on a total energy consumption perspective
	o	Customer relevance (it depends on the business model of provider and where the meter for charging of fees is located)
	-	An additional industry sector would be touched by the Regulation and may discuss/question the generic parameters (net and charging point providers)
	-	Generic parameters for off-board charging infrastructure will be very uncertain and cannot reflect specific solutions
	-	Makes system for a possible a future certification procedure much more complicated
	-	Results will be more complex to understand for customer
Interface off/on-board	+	This is what counts for society / COM on a vehicle optimisation perspective (a decision between infrastructure type e.g. cate-nary or not will anyway done based on the availability of the infrastructure)
	o	Might be what is relevant to the customer in part of the cases
	+	Most consistent option to TTW approach of VECTO in all other aspects
	+	Comparable to what is reported for LDV / WLTP
	-	Actual level of charging losses depends on individual influencing factors that are not known to VECTO (e.g. fast/slow charg-ing behaviour).
	- -	Unclear how to deal with vehicles with multiple charging technologies (i.e. most of the vehicles). This will add artefacts and and put in question the VECTO results as a whole.
Battery terminals	**o**	**The result does not cover the full picture relevant for customer and society**
	+	**Simple to handle and understand, no artefacts.**
	+	**Compatible with what is asked for in OBFCM**
	+	**Can be compared by the customer with the range relevant electric energy consumption display by the vehicle**
	+	**Clear system boundary to other (future) charging infrastructure standards**

The losses during external charging occurring inside the battery are considered in post-processing as follows:

- The VECTO in-the-loop simulation provides the results for electrical energy consumption referring to “battery internal” balancing of energy.
- In order to account for the losses in the battery that occur during external charging, the electric energy consumption resulting from the VECTO simulation is divided by the battery charging efficiency factor (η_{BAT}).
- η_{BAT} is determined as one single value at the middle of the useable SOC range based on the actual battery component data for internal resistance and a generic value for charging power. This generic charging power is the same for all vehicles and may be further limited by the input parameter of “maximum stationary charging power”.
- η_{BAT} is independent of the actual charging technology in the vehicle, since so far no input to the simulation tool defining a certain charging technology is available.[22]

Thus, the final values for electric energy consumption over a certain mission include not only the required electric propulsion energy per se but also the losses inside of the battery for recharging this amount of electric propulsion energy.

2.7.2 Electric ranges

As explained in the introduction to this chapter 2.7, OVC-HEVs are operated in two different modes in VECTO with one being the charge-depleting and one being the charge-sustaining mode:

- In **charge-depleting mode** (CD) the propulsion energy is primarily (or even solely) provided by the REESS and the SOC decreases on average while the vehicle is driven.
- In **charge-sustaining mode** (CS) the propulsion energy is solely provided by the ICE over the cycle. The SOC of the REESS may fluctuate but, on average, is maintained at a neutral level while the vehicle is driven.

The simulation of both modes results in a representative value for consumption of fuel and/or electric energy over a certain mission for each mode. The final result for the energy consumption is then calculated as a weighted average out of the two separate results, where a so-called utility factor (UF) reflects the share of driving in charge depleting mode typically and thus defines the weighting of each result.

The electrical range for the vehicle in this mission can be determined from the electrical energy consumption in charge depleting mode, taking into account the usable energy content of the REESS. In accordance with the WLTP legislation, this range is also referred to as the "actual charge depleting range" (R_{CDA}).

[22] For the upcoming 3rd amendment of the VECTO Regulation, the battery charging efficiency factor might differ depending on the charging technologies available in the vehicle as well as the charging power level.

An additional output determined from the results of the charge-depleting mode is the range that can be driven without generating any CO_2 emissions (i.e. zero CO_2 emissions range). This quantity has also been adopted from the WLTP legislation and corrects the R_{CDA} value for OVC-HEVs where the ICE also assists in charge depleting mode by the contribution of the CO_2 emissions of the ICE.

Another value that has already been installed with regard to the 3rd Amendment is the Zero CO_2 emissions range (ZCER). This figure takes into account the additional range of other CO_2-free energy sources in the vehicle (specifically hydrogen). For the 2nd amendment - since the use of hydrogen is not yet represented in VECTO - the ZCER will always be identical to the EAER.

Table 14 gives an overview of the exact definitions of all characteristic electric ranges required for the VECTO method and defined in Annex IV of Regulation (EU) 2017/2400.

Table 14: Definition of characteristic electric ranges

Electric range	Definition	Comments
Actual charge depleting range **(R_{CDA})**	The range that can be driven in charge depleting mode based on the usable amount of REESS energy, without any interim charging.	Main relevant information for customer (range from battery, w/o additional infrastructure)
Equivalent all electric range **(EAER)**	The part of the actual charge depleting range that can be attributed to the use of electric energy from the REESS, i.e. without any energy provided by the non-electric propulsion energy storage system. i.e. R_{CDA} mathematically reduced based on fuel consumption in charge depleting mode $EAER = R_{CDA} * ((EC_{fuel,CS} – EC_{fuel,CD})/EC_{fuel,CS})$ Where EC_{fuel} is the fuel consumption of a carbon-containing fuel	Only an interim result for ZCER below
Zero CO_2 emissions range **(ZCER)**	The range that can be attributed to energy provided by propulsion energy storage systems considered with zero CO_2 impact. *For all propulsion technologies defined in the second amendment of Regulation (EU) 2017/2400, the ZCER equals the EAER.* *Only once vehicles using H_2 as fuel are included as relevant technology, the ZCER will extend the EAER by the additional distance enabled by the usable H_2 tank capacity.*	Anchor point for the future “ranking” of a vehicle in the HDV CO_2 standards
Electric range for utility factor (UF)	***Only relevant for OVC-HEV*** The range that can be driven in charge depleting mode based on the usable amount of REESS energy (i.e. R_{CDA}) and additional electric energy available due to stationary charging during mission.	Interim result in VECTO to determine the UF UF = Share of daily distance in charge depleting mode on total daily distance

For PEV, the zero CO_2 emissions range is simply defined by the usable amount of REESS energy. Since for PEV no second propulsion energy storage system having an impact on propulsion energy distribution is available, all three characteristic electric ranges defined in Table 14 above are equal.

2.7.3 Concrete implementation of the method for OVC-HEV (plug-in HEV) in VECTO

As explained in the previous chapter 2.7.2, OVC-HEVs are operated in two different modes in VECTO, namely the charge-depleting and the charge-sustaining mode.

In the charge-sustaining mode the following boundary conditions apply in VECTO:

- The vehicle is primarily powered by the ICE and the energy stored in the REESS may fluctuate but, on average, is maintained at a neutral charging balance level while the vehicle is driven.
- The applied HEV control strategy and the corresponding method result in a neutral SOC over the cycle (for all details regarding the generic HEV control strategy and the charge-sustaining operation mode refer to chapters 2.5.1 and 2.5.2).
- For deriving a representative value for the energy consumption over a certain mission, the target SOC for the HEV control strategy will be defined in the middle of the usable SOC range in order to avoid any “artificial” limitations due to generic REESS boundaries in Declaration Mode.
- Eventually, over the whole cycle the propulsion energy is solely provided from fuel and the electric energy consumption is zero per definition.

In the charge-depleting mode the following boundary conditions apply in VECTO:

- The vehicle is primarily (or in case of a full-hybrid, which has enough propulsion power available from the electric powertrain components to follow the cycle, even solely) powered by the REESS and the SOC may fluctuate but decreases on average while the vehicle is driven.
- For deriving a representative value for the energy consumption over a certain mission, the SOC will be kept “artificially” constant in the simulation (in the middle of the usable SOC range). This is done to guarantee each vehicle being able to drive the complete cycle independent of its electric storage capacity in order to get a representative value for the energy consumption as average over whole cycle.[23] The electrical energy consumed in the cycle is accumulated in a separate counter, independent of the SOC, which is kept virtually constant.
- Also, the constant SOC in the middle of the usable SOC range is representing best the average real-world usage since there is no explicit correlation between actual SOC level and distance in the VECTO mission profiles available (i.e. where are the typical charging points located in the cycle and how much energy can be re-charged at each individual point).
- For parallel HEV, the electric energy from the REESS has priority and the ICE is only used in case the electric propulsion system cannot provide the demanded power.

[23] This ensures the comparability of the results for electrical energy consumption and ranges between all possible vehicle configurations. Otherwise, vehicles with a small battery would not be able to run the full cycle. Thus, the cycle specification implicitly depicted in the result would not be representative.

- For serial HEV, the electric energy from the REESS has priority and the ICE is only used in case the electric storage cannot provide the demanded electric propulsion power.
- Thus, in charge-depleting mode also a certain amount of fuel consumption could occur in addition to the electric energy consumed.

The final result for fuel and energy consumption is then calculated as a weighted average out of the two separate results in post-processing. The detailed method and the underlying boundary conditions are explained in the subsequent chapter 2.7.3.1.

2.7.3.1 Weighting of results from the two operation modes

In order to determine the final result for the energy consumption as weighted average out of the two separate results for charge-depleting and the charge-sustaining mode, a specific weighting factor for each mode is required. This weighting factor should reflect the typical usage pattern of the vehicle. The so-called utility factor (UF) defines the share of the daily distance driven in charge-depleting mode on the total daily distance. Thus, the weighting factor for the charge-depleting mode is defined as UF and the weighting factor for the charge-sustaining mode as complementing counterpart is defined as (1-UF).

Defining the specific UF for a certain combination of vehicle and cycle requires the distance the vehicle is able to drive in charge-depleting mode. This distance depends on the specific electric energy consumption of the vehicle on the one hand and on the usable amount of electric energy from the REESS on the other hand.

For the usable electric energy the following sources are considered for the determination of the UF:

- Useable energy in the battery at the start of mission (assumed to be from stationary charging at depot)
    - This amount of usable energy resulting in the defined range R_{CDA} (refer to chapter 2.7.2) is reduced accordingly by a correction factor smaller than 1 reflecting the real world charging behaviour (i.e. in reality the battery might not always fully charged at the beginning of a mission).
- Energy re-charged into the battery by stationary charging at certain events during the mission
    - Here, the available energy is calculated from tabulated values depending on vehicle group and mission profile. The calculations consider also the limitations by the actual usable capacity of the battery.
    - These tabulated values define the following parameters influencing the amount of available energy:
        - Number of charging events
        - Duration of charging events
        - Available charging power from infrastructure (which is further limited in the calculation by the maximum vehicle capabilities)

- Real world usage factor for stationary charging „$RF_{StatCharge}$" smaller than 1 reflecting the real world charging behaviour (i.e. in reality the battery is not fully charged at each charging opportunity and not each potential charging opportunity is actually used)

From the amount of total usable electric energy (depot plus charging during mission) and the specific electric energy consumption on a certain mission, the resulting daily distance driven in charge-depleting mode is calculated.

The UF is then defined as the daily distance driven in charge-depleting mode divided by the total daily distance. In order to get meaningful results for a particular mission profile, the total daily distance needs to relate to the typical daily mileage in this particular mission for a certain vehicle group and not to an average daily mileage for a certain vehicle group already considering a weighted mission mix.[24] The resulting maximum value of the UF for OVC-HEV is limited with 1.

The final results for a specific mission weighted for charge-depleting and the charge-sustaining mode are determined as follows:

$$RES_{weighted,CDCS} = UF \times RES_{CD} + (1-UF) \times RES_{CS}$$

where:

UF utility factor for OVC-HEV

RES_{CD} result in charge-depleting mode

RES_{CS} result in charge-sustaining mode

The term result in this context applies to average speed, fuel consumption, CO_2 and electric energy consumption.

The values for all generic parameters influencing the resulting UF described above are in the course of the work on the 3rd amendment of Regulation (EU) 2017/2400 still under revision. Due to the huge overlap of this area with additional elements (e.g. external supply of electric energy to the vehicle in-motion) planned to be introduced with the 3rd amendment of Regulation (EU) 2017/2400, a holistic approach is required for the respective methods. Thus, the finalization of the values for these generic parameters is scheduled for Q2/2023, which is in line both with the deadlines for the release candidate version of VECTO for the second amendment and the project end of the "Further Development and update of VECTO with new technologies" covering "Pantograph, catenary and connector systems for electrified vehicles".

[24] The aggregated results for the mission mix for a certain vehicle group are provided by the established weighting of results per mission profile and payload to an overall weighted figure.

3 Task 2: Testing, Software Verification and Documentation with regards to hybrid technologies

Subject of Task 2 was to collect feedback from tests, simulations and analysis carried out by industrial and other stakeholders for demonstrating the validity of the hybrid and electric vehicle simulation approaches to be implemented. Data shall cover both, components and vehicle operation. This information shall be used for demonstrating the good operation of VECTO's updated versions, scan for possible bugs and help establishing an iterating development cycle.

In addition, the following items should be taken care of:

1. Perform a review in order to collect feedback available in literature or from previous projects that could be used for validation purposes within this task
2. Produce the necessary documentation regarding the implemented features including users' manuals, testing guidelines and software changelogs.
3. Support external testing performed by stakeholders and provide instant bug-fixing for released VECTO versions as described in subtasks 1.1 and 1.2
4. Collect and analyse feedback from external testing at vehicle or at component level.
5. Update VECTO accordingly and provide new releases.
6. Create and deliver test cases and other quality control tools for ensuring integrity and VECTO's good operation.
7. Develop inside VECTO generic examples covering all new features and functionalities that will be added.
8. Create a database with list of open issues for further consideration at the end of the contract

3.1 Working method as applied throughout the project

For software development the well-established development, testing, and verification methods as during development of the currently used VECTO version (VECTO 3) have been applied.

All new implemented component models are based on physical laws, well-established mechanical and electrical engineering methods, and where necessary and appropriate, simplified to an extend to achieve an optimal balance between the effort required for component testing and the required computing time on the one hand and the accuracy on the other hand. The related technical methods are fully described in the context of Task 1 in the previous chapter. All methods were extensively discussed and agreed with stakeholders and the Commission in more than 70 meetings (see Annex A).

We have done testing and software verification of the developed simulation tool on multiple levels. Software unit tests build the foundation. The important aspects of all new software components have been sufficiently tested with unit tests. This includes testing that the software component represents the physical model correctly and that the software component fits into VECTO’s architecture. These tests were implemented by TUG during programming.

The second level of testing and software verification are the integration tests. These tests deal with the simulation of a set of connected components or the whole powertrain in different configurations. The purpose of these tests is to ensure that the components “work together” in the simulation and that the simulation results are feasible compared to measurements. For simulations of the whole powertrain, integration tests have been implemented by TUG to ensure a closed power balance.

The third level of testing and software verification was foreseen to be tests by industry and other stakeholders where they parameterize the VECTO hybrid models with their specific vehicle configurations. This has been done in iteration loops where we collected feedback from industry in a structured way, try to reproduce errors as well as to identify wrong or inappropriate simulation behaviour, and update the VECTO models accordingly. To support the tests, TUG provided documentation of the new VECTO models and of the parameters required to OEMs and support them with parametrizing their VECTO models. A series of workshops ("VECTO xEV Workshops") were held, where all new features were explained and discussed extensively and feedback on the model behaviour was collected.[25]

Furthermore, the literature and data from previous projects (e.g. from the feasibility study, projects at TUG) were reviewed to see whether reliable data could be taken for a validation of the methods. Such data could not be found, especially because the few existing data refer to other operating conditions (e.g. specific bus routes or SORT) that are not known in detail and/or not reproducible because the exact vehicle data is not available. However, literature was consulted for method development (see section 2.5.1).

For collecting feedback in a structured and transparent way, we have used the CITnet/Jira platform, whose use is already established among the relevant stakeholders (vehicle manufacturers and component suppliers). To clearly distinguish between issues related to the official VECTO and the issues with the VECTO xEV development we have created a separate area (i.e. using the dedicated component identifiers “VECTO Hybrids” and “VECTO HEV/PEV Development). We have distributed releases of VECTO hybrid versions via the CITnet platform as well, in a clearly separated area such as a separate release announcement page in the Confluence wiki and separate download location. Instant bug-fixing for the released VECTO versions has been managed on this platform.

Furthermore, to enable getting started with the VECTO xEV features and to demonstrate the parametrization of different components and powertrain configurations, we have provided at least one set of input data for every hybrid powertrain configuration supported by VECTO xEV.

3.2 List of open topics for further consideration

Furthermore, as part of Task 2, a list of open topics for further consideration at the end of the contract should be provided. This section gives such a compilation of open issues, in the context of VECTO and xEV.

Due to the close coordination in the project with the Commission, essential contents were already identified in the course of the project, which are necessary for the functioning of VECTO xEV within the scope of the 2nd amendment and which are not included in the present project scope (i.e. IEPC, IHPC, factor method for xEV). These contents, which are already worked on in separate contracts, are not listed below.

[25] This format has proven to be very efficient and will be continued in the course of the other ongoing VECTO contracts under the name “VECTO Development Workshops”.

Topic 1: Vehicles with multiple permanently mechanically independent powertrains

For xEV additional driven axles can be realised in a flexible way through applying additional e-components (“e-axles”). Such vehicle configurations are in particular known to be of relevance for electrified articulated buses (for both HEV, PEV and FCEV).

With the current methods[26] in Regulation (EU) 2017/2400 and in VECTO, such vehicles cannot be represented and modelled. To cover those in a future amendment the following tasks would need to be accomplished:

- Clarification which combinations of powertrain architectures are relevant (i.e. any combination of E2, E3, E4, IEPC1, IEPC2, IEPC3, IEPC4, ICE?; more than 2 powertrains needed?)
- Extensions in Annexes, XMLs schemas, the MRF CIF: Provide component information by powertrain ID
- VECTO simulations: Apply a generic traction force distribution between different axles, apply special rules for gearshift, provide simulation results (e.g. power losses) per component and powertrain ID

With regard to this topic, the priority for implementation is considered to be very high (i.e. ideally still for the 3rd amendment) since a large portion of PEV articulated buses on the market already apply this concept and separate e-axles might also be a topic in the near future for rigid trucks.

Topic 2: Additional, more complex powertrain configurations for HEV

Topic 2 concerns additional, more complex powertrain configurations for HEV as covered by the 2nd amendment. Potential candidates for such technologies are listed in section 2.4.5. However, as also explained in this section, according to the project team's state of knowledge, there is no concrete need for action, since all hybrid electric architectures currently coming onto the market in any significant number should be covered by the current methods. The market situation must of course continue to be monitored. Anyhow, due to the strong development of the market towards fully electric vehicles, it currently seems unlikely that completely new hybrid electric powertrain concepts will be developed to market introduction.

Topic 3: Additional, more complex powertrain configurations for PEV

As with HEV, the methods designed for the 2nd Amendment cannot cover all theoretically possible power train configurations. The clear difference to hybrid electric vehicles is that, due to the general formulation of the definition of IEPCs, the very largest proportion of systems under development for PEVs will be covered by VECTO already.[27]

However, additional relevant PEV powertrain configurations have been announced for the medium-term future. These can be divided into two different groups for the necessary implementation methods for VECTO:

[26] The current system only foresees a single powertrain. An extensions to more powertrain would require a major overhaul of the input and output data structure and also related modifications both in the Articles and the Annexes of Regulation (EU) 2017/2400.

[27] At least until June 2022, no currently relevant PEV powertrain configurations have been reported by manufacturers that cannot be covered in the 2nd Amendment.

1) Extension of the "explicitly" represented powertrain configurations, e.g. an “E23” (a PEV with an EM before and after a transmission unit).
2) Extension of the “blackbox” IEPC concept to cover also systems which without discrete transmission ratios (having either a power-split architecture or a CVT element)

Realistically, such systems cannot be built into VECTO before the 4th amendment. Before any further development of VECTO (and of course of the test procedures linked to it) is undertaken in this direction, in-depth experience and validation of the methods of the 2nd Amendment need to be carried out (e.g. as is currently being done by DG JRC).

4 Task 3: Feasibility assessment and development of a first VECTO forward looking prototype taking into account results from Task 1

The objective of this task was to investigate the feasibility of an updated VECTO version, operating as a fully forward-looking simulator capable of handling software and hardware- in-the-loop (SIL &HIL) simulations. Furthermore a prototype forward looking VECTO demonstrator should be developed on the basis of which future developments and discussions could take place with the relevant stakeholders.

As part of this task, the following work content should be covered:

1. Review the options for implementation of a forward-looking architecture and simulation in VECTO.
2. Collect specifications and requirements from industry and other stakeholders.
3. Review and provide feedback on various possible validation options in particular for hardware and software in the loop applications. Investigate necessary adaptations that need to be made in the existing certification framework.
4. Produce and release a forward-looking VECTO demonstrator based on the most recent and updated VECTO release.

The results of the work on points 1. to 3. are documented in this chapter. As a clear outcome of the related work the conclusion was drawn that a change of the VECTO model to a pure "forward" architecture does not seem worthwile in the foreseeable future. The reason for this fact is that any explicit consideration of OEM-specific control strategies – i.e. the 1-to-1 link to the actual vehicle or component control software - is considered as not feasible within the framework of Regulation (EU) 2017/2400.

This fact also removes any reasoning for a significant modification of the VECTO model architecture, as the currently implemented structure represents a tailor-made approach combining the advantages of both “backward” and “forward” for any application in the calculation of official CO_2 values. This conclusion with the underlying analyses was discussed internally with DG CLIMA and DG JRC as well as subsequently with stakeholders in several meetings, whereby the stakeholder feedback finally confirmed this conclusion.

Based on this situation, the Commission decided to shift the resources allocated for point 4. of this Task to Task 1 in order to support the much more extensive implementation of electrified propulsion systems as described in section 2.1.1.

Following the technical topic of this task, further work was contracted by DG CLIMA already in 2020 within the framework of the contract “Further development and update of VECTO with new technologies”.[28] There the objective was to investigate the feasibility of an updated VECTO version, capable of handling software and hardware - in-the-loop (SIL & HIL) simulations and to provide a technical prototype that allows the use of user-defined control algorithms in VECTO. Due to the extension of the duration of the present contract, the periods of working

[28] Specific contract No 340201/2020/835254/SER/CLIMA.C.4

on these technically related tasks in the two contracts overlapped. The contents of both feasibility analyses are also directly adjacent to each other and are essential for the final conclusions. Therefore, the most important conclusions from Task 5 of the “Further development and update of VECTO with new technologies” contract are also mentioned here.

4.1 Feasibility analysis on changing VECTO to a forward architecture

Before discussing the feasibility and the reasonableness of switching from VECTO to a pure forward architecture, background on the different model architectures is provided.

4.1.1 Background to the different model architectures

Simulation approaches used for analysis of vehicle longitudinal dynamics can be classified into the following two main categories:

i. “Backward” architecture (from wheel to engine)

ii. “Forward” architecture (from driver to the wheel)

“Backward” and “forward” (or sometimes also denoted as “forward-looking”) are referring to how cause and effect of vehicle longitudinal dynamics are depicted inside the model algorithms. VECTO is furthermore based on a tailor-made approach that combines the advantages of both architectures for the specific application. The different model architectures are described below.

4.1.1.1 Forward architecture

In a forward model the chain of cause and effect is depicted like in reality. The simulation of a time step starts with a driver(-control) action, e.g. setting of the throttle pedal calculated from the observed deviation from actual vehicle speed to a target vehicle speed. In a second step, the torque response from engine and powertrain is calculated. In more complex forward models also the interaction of vehicle control systems with the driver request is taken into consideration (e.g. engine torque set to zero triggered by the transmission control system to enable a gear shift). Based on the resulting torque response in the powertrain, the equations of motions are solved to calculate the resulting vehicle operation state (actual speed and acceleration) for this time step, which is then the starting point for driver control in the next simulation time step. Model complexity in forward simulation tools can differ from relatively simple models e.g. designed for analysis of fuel efficiency up to very complex models applied e.g. for design and testing of control systems used in real vehicle applications. In these models, the individual components must be modelled in great detail and parameterised very specifically in order to be able to depict a system that is comparable in detail with the real implementation in the vehicle.[29] A general feature of forward models is the fact, that a target speed cannot be followed exactly, due to the typical oscillations of vehicle speed resulting from the feedback loop between driver control and vehicle reaction.

[29] "Individual components" here also refers to systems that are simply and generically modelled in VECTO (e.g. the start-up clutch) or not at all covered, e.g. certain actuators in a transmission.

4.1.1.2 Backward architecture

As a contrary approach, a backward model uses a pre-defined state of vehicle speed and acceleration as starting point for a simulation time step. Based on this vehicle operation state, the required torques and speeds in the drivetrain and at the engine are calculated taking the vehicle's driving resistances and the efficiency data of the drivetrain components into account. In a "pure" backward model there is no "feedback-loop" between driving cycle and vehicle performance and any functions of driver control are bypassed by the backward approach. Main general features of backward models are rather short computation time and the fact that – if the pre-defined driving cycle is representative for the vehicles simulated – results for different vehicle configurations are directly comparable since per definition no deviation in speed occurs. This feature is not fully the case for forward models, as the vehicle speed oscillations around the target speed are individually pronounced for each combination of vehicle and driver model configuration.

4.1.1.3 VECTO architecture

VECTO in its current model architecture is a "hybrid" between forward and backward architecture as it was specifically designed to combine the main advantages of both approaches for its specific field of application. The VECTO simulation core is based on a backward approach, resulting in the ability to exactly follow a target speed pattern and proving a short computation time.[30] Around this backward core, several "feedback layers" have been implemented into the software, to depict the interaction of driver control and vehicle reaction with the target driving cycles.

Through this approach, the current VECTO architecture is able to:

- simulate full-load and coasting behaviour specifically for each vehicle
- include an adjustable driver model interacting with the target speed cycle
- include "look-ahead" functionalities, e.g. for triggering of brake events or for simulation of functions of advanced driver assistant systems (ADAS)

This modelling approach is, as far as the authors of this report are aware, unique. Since the major evolution of VECTO from version 2 ("demonstrator tool") to version 3 (November 2015, complete redesign of the simulation core), the model architecture was no longer criticised or questioned by stakeholders. However, the wish was expressed, that it should also be possible to take into account OEM-specific control strategies in Regulation (EU) 2017/2400.[31]

[30] However, already the current VECTO software switches from backward to forward in a few simulation conditions, e.g. in the search for operation points for vehicles with hydraulic torque converters.

[31] In this context, the wish was also frequently expressed that Regulation (EU) 2017/2400 should generally be opened up in such a way that individual technologies that are not yet included in VECTO can be assigned individual bonuses in an individually designed process. Such a procedure could not be solved on the software side, but only on the procedural side in Regulation (EU) 2017/2400, e.g. similar to the eco-innovation approach that is used to determine the CO_2 emissions of passenger cars.

4.1.2 Reflections on a possible change from VECTO to forward architecture

From the section above it can be concluded that, purely from the model behaviour of VECTO in a general context, there is no need to make fundamental changes in VECTO in the direction of "forward" architecture. The motivation for such claims originates from the fact that the current VECTO version is technically not capable of linking concrete OEM-specific controllers to the simulation. Part of the necessary measures to make this possible would be a change in the computing algorithm. This conversion will first be analysed here isolated from all other challenges in Regulation (EU) 2017/2400 (e.g. verification, transparency of the process etc.).

As a purely isolated software engineering task, it would in principle be possible to convert VECTO into a forward tool. The interventions required to accomplish this would however be fundamental:

i. A complete new development of component models with the requirement – given by the specific purpose - to add much more (sub-)components as in the current VECTO in order to be as detailed as required to be linked to a real controller

ii. A new implementation of the powertrain builder

iii. A new implementation of a driver model and driver strategy. The driver model is by far the most complex component in VECTO as it handles many different situations that may occur during a simulation step. Moreover, the driver model needs to decide on the actual driving action and consider cycle look-ahead for look-ahead coasting and braking. In the case of a change to pure forward modelling, the driver model would have to be designed in a far more complex way if the requirement is that the target speed should be followed as well and comparably as possible for the most varied vehicle concepts (comparability issue!).

iv. A new development and implementation of a "forward simulation core", i.e. a module which sets up the relevant equations of motion for all powertrain components, combines them and provides the numerical methods to solve the resulting system of differential equations. This is technically and mathematically a very complex task. It seems unrealistic to develop such a system from scratch for VECTO. Therefore, the possibility of using open source libraries for this purpose would need to be examined. Different approaches, i.e. numerical solution methods, would need to be tested for their suitability. This change furthermore results in the need to calculate at a much higher temporal resolution, largely independent of the chosen modelling depth for the components.[32]

v. A rework of all existing generic control features (gearshifts + traction interruption, HEV controller, ADAS) which would still be required to be used by OEMs which would not draw the option to connect their specific vehicle controllers or for VECTO use outside of the official process.

[32] In the current VECTO approach, certain processes, e.g. gear shifting with traction force interruption, are modelled in a very simplified way. This is not possible in a pure forward modelling. In order to be able to calculate the process, which is very complex in reality, but which is not significant in detail for fuel or energy consumption, in a forward model, it must be resolved much more finely.

vi. For heavy buses, it would need to be analysed, whether the “Advanced Auxiliary Model”, which is tailor-made to the current structure of VECTO can be reasonably coupled to a pure forward tool. Presumably there would also be a need for reworking here.

In addition to the purely software-related work, the transition outlined above would require further resources e.g. for:

- Extensive testing whether comparable results can be obtained for the large number of vehicle configurations already covered by VECTO.
- Consultations, support and feedback loops with stakeholders.
- Implementation of a further adjustment procedure for the CO_2 standards
- Significantly higher support and maintenance effort in the official process for the much more complex system

The resources required for this are very difficult to estimate. Under the fictitious assumption that the model architecture of VECTO would not significantly increase (in practise this is in contradiction with point i. above), a work requirement of at least 10 person-years is estimated here. Depending on the additional model detailing to be carried out, the necessary effort is estimated to be even higher.

At this point, item i. of the above list should be addressed further. In this aspect it is obvious that there is no single model setup which makes it possible to link specific control strategies for all types of control algorithms and all manufacturers. Different model setups of VECTO would be required depending on the component(s) or the vehicle level being controlled (vehicle dynamics such as ADAS, powertrain operation such as a HEV strategy, operation of smart auxiliaries, special controls affecting the efficiency of an internal combustion engine etc.). The required model structures would differ by level of detail, time step resolution and interfaces to the controllers, probably also manufacturer or at least controller infrastructure (e.g. Matlab Simulink)-specific.

From these analyses, it is concluded that a changeover from VECTO to a forward architecture does not make sense because the associated effort would be enormous and the intended benefit (consideration of OEM-specific control strategies) could not be achieved in practice.

The fact that the linking OEM specific control strategies to VECTO enabled by Regulation (EU) 2017/2400 is not feasible is also concluded in Task 5 carried out within the framework of contract “Further development and update of VECTO with new technologies”. In the analysis conducted there, a holistic view of such a process was taken. The following points were identified, among others, which suggest that such a procedure should not be aimed for in Regulation (EU) 2017/2400:

- Lack of transparency of the procedure, in which a large number of parameters and assumptions have to be defined individually between the manufacturer and the type approval authority, which stand in the way of comparability of the results at EU level and across manufacturers.

- Lack of possibilities to verify whether the specific control algorithm is actually implemented in a vehicle.

- High costs for the Commission and manufacturers and the associated systematic discrimination against small manufacturers.

4.2 Stakeholder involvement

This topic area was discussed in several iteration loops with stakeholders and manufacturers. The first round of this exchange took place in spring 2019 during the workshop "Long term strategy and future perspectives of VECTO" initiated by the content of this task and organised by the JRC. In this workshop the wish was expressed by both ACEA and CLEPA, that more OEM specifics - not only limited to the controllers used – should be considered by VECTO. One of the options proposed by ACEA to accomplish this was a solution using SIL/HIL in combination with a "totally revised VECTO". CLEPA's slides already address the expected complexity and required flexibility of the solution. It suggests that the necessary approach might require two separate systems:

- The VECTO in its current architecture in combination with an open Eco-Credits process in Regulation (EU) 2017/2400 for the determination of the official results.
- A "forward" HIL/SIL simulation tool in an open / modular platform that can be used individually by manufacturers to determine Eco-Credits.

The issue of the need to switch to a forward model was analysed by ICCT by comparing VECTO with GEM (the US model for calculating HDV CO_2 emissions, which is a pure forward model). The conclusion presented at the JRC workshop in 2019 is that "there is no benefit in moving to a forward looking model".

Further discussions on this topic took place at the VECTO Board in March 2020. TUG presented three theoretically conceivable methods of how VECTO and Regulation (EU) 2017/2400 could more flexibly reflect OEM-specific characteristics of the vehicle. The approaches outlined were:

1) Option "Standard VECTO" in forward architecture with SIL connection (analogous to the solution envisaged in the Task 3 call for tender).

2) Option "Open VECTO" with SIL connection (basically following the CLEPA idea as described above) and in combinations with “Eco-credits” to be accounted in the “Standard VECTO” in combination with a well defined but open process in Regulation (EU) 2017/2400.

3) Option "Vehicle mapping approach". A fundamentally different idea is pursued by this option, based on an extensive measurement of a vehicle in on road operation. This data could then be processed into a kind of "vehicle map"[33], which could then be used to simulate other cycles in a separate VECTO version. However, this idea was rejected after further analysis and discussion with the Commission and stakeholders, as the development effort would be extremely high and the prospects for a robust approach very low.

After the VECTO board meeting in 2020, the exchange on possible approaches and related problems was continued bilaterally with vehicle and component manufacturers.

A very detailed analysis of the feasibility of a direct coupling of the control algorithms actually used in the vehicle was finally presented by TUG in the stakeholder meeting on 8th of June 2021. Based on a number of arguments summarised at the end of section 4.1.2 above, it was

[33] E.g. fuel consumption as a function of vehicle speed, wheel power and SOC; available full-load power as a function of vehicle speed and SOC.

concluded that any explicit consideration of OEM-specific control software (VECTO + SIL/HIL) in the official CO_2 determination is neither practicable nor even desirable. Stakeholder feedback was requested until the next meeting in October 2021. At this meeting, ACEA confirmed this conclusion. No explicit official feedback was received from the other stakeholders or individual suppliers. In bilateral discussions between TUG and suppliers, however, these findings were also confirmed.

5 Task 4: Technical support for the VECTO tool

Scope of Task 4 was:

1. To be responsible throughout the duration of the contract for addressing issues and fixing bugs occurring from the changes performed in VECTO as part of the activities stipulated in this contract.
2. ensure a smooth functioning of the VECTO tool and adjacent software throughout the period of this contract. While VECTO will be downloadable software that shall be run independently by each HDV manufacturer, bugs or inaccuracies shall be corrected.
3. reserve 150 working days, during the duration of the whole contract, for further technical support that might be needed in order to update or develop certain modules of the tool for certification purposes.

The entire work process related to Task 4 was organised via the ticket system in CITnet JIRA. In terms of technical content, the above points 1. and 2. are directly assigned to the method development for xEV to be carried out under Task 1 and Task 2 and were carried out accordingly. Point 3. is clearly separate from this, as the related content is general, i.e. covers maintenance and support needs as well as the implementation of additional technical content not yet known at the beginning of the project. These were carried out by the project team in the course of the project as specified by DG CLIMA. The resources allocated to point 3. (a total of 150 person days) were monitored using a separate export script from CITnet JIRA and subsequent processing in MS Excel, whereby only the work allocated to point 3. was accounted for.

In the following, the work carried out related to point 3 is described. Table 15 gives a breakdown of resource consumption by “JIRA component”, which is an identifier enabling a ticket to be associated with a technical function in VECTO, the VECTO tool family or the official processes (Article 10 Notifications). The entries in Table 15 are sorted in descending order of total amount spent. Most of the work (27%) was done on the component "VECTO Simulation Tool (Certification)". This work covered bug fixes or extensions in the branch of the current tool version, i.e. the one used to calculate the official CO_2 values. The highest number of tickets (247) were processed for Article 10 Notifications[34], which in total account for around 6% of the hours. These two components together comprise the classic maintenance and support needs of the official VECTO following the first amendment of Regulation (EU) 2017/2400, which could be handled with about one third of the resources. The remaining two-thirds could be used for other required extensions of the VECTO functions, which were not covered in other contracts. These extensions are related to the broader scope of the VECTO methodology given by the 2nd Amendment Regulation (EU) 2017/2400, e.g. through additional vehicle categories (medium lorries), the “factor method” for buses, and necessary extensions of the VECTO preprocessing tools.

[34] This is a process in which vehicle data that does not pass through the official calculation of CO2 values in the tool is reported via JIRA. Based on the notification, a classification is made, e.g. whether it is an error in the tool or in the input data, and the next steps are organised,

Table 15: Breakdown of resources from the contingent " for further technical support" by JIRA component

JIRA Component	Count	Time spent [h]	Time spent [-]
VECTO Simulation Tool (Certification)	73	324	27%
AAUX (Advanced Auxiliary Model)	1	251	21%
VECTO Engine	4	140	12%
VECTO Further Development	10	102	8%
not specified	52	94	8%
VECTO Hashing Tool	4	83	7%
VECTO PrimaryBus	11	80	7%
Notification according to Art. 10(2)	247	68	6%
VECTO AirDrag	3	40	3%
VECTO Medium Lorries	3	10	1%
VECTO CompletedBus	7	9	1%
Infrastructure	1	1	0%
Total	**416**	**1200**	**100%**

Figure 26 shows the amount of Article 10 notifications over time. After a more intensive phase at the beginning of the project, coinciding with the start of the application date of Regulation (EU) 2017/2400, the number of notifications, i.e. problems in the official process, has decreased to almost zero. This is an indication that the current official version is already very mature, and above all that the official users are already very experienced in using the methods of the first amendment of regulation (EU) 2017/2400.

With the future expansion of the methodology in the course of the second amendment, rising numbers of Article 10 notifications are to be expected.

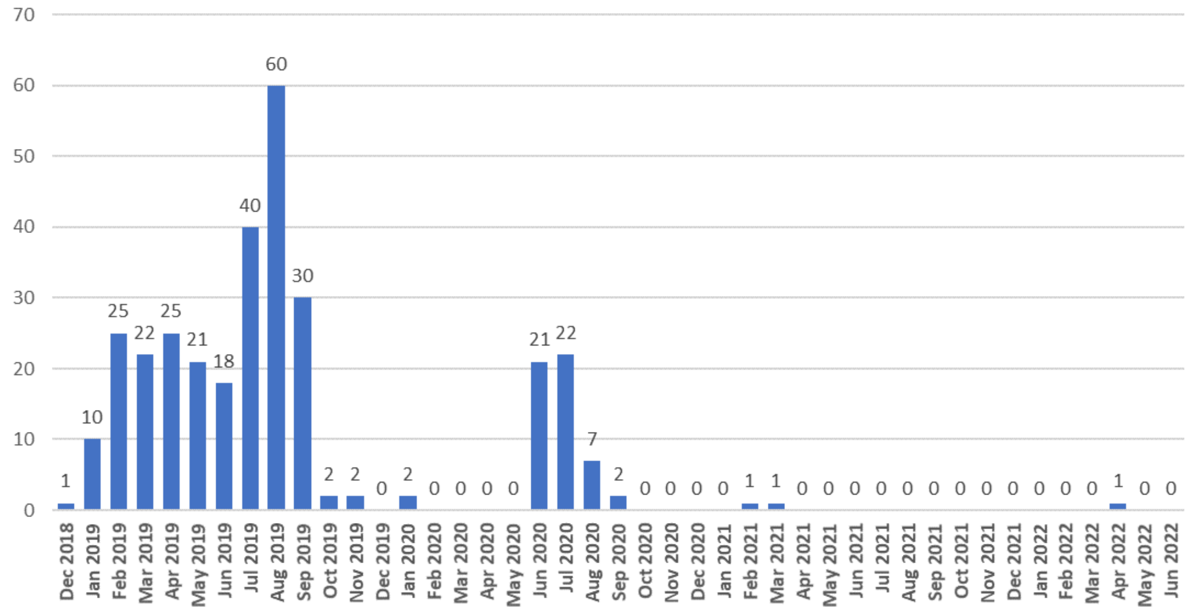


Figure 26: Article 10 Notifications over time

A complete list of the Tickets to which the 150 person days reserved in accordance with point 3. have been allocated can be found in Annex B. Further details can then be viewed on CITnet JIRA by ticket number ("issue key"). The MS Excel with which the list was created was handed over to DG CLIMA together with the final report.

6 References

Hausberger S., Rexeis M., Kies A., Schulte L-E., Steven H., Verbeek R. “Reduction and Testing of Greenhouse Gas Emissions from Heavy Duty Vehicles - LOT 2, Development and testing of a certification procedure for CO2 emissions and fuel consumption of HDV.” Graz, 2012.

Kim N., Rousseau A. P. “Comparison between rule-based and instantaneous optimization for a single-mode power-split HEV.” *Proceedings SAE 2011 World Congress & Exhibition*, 2011.

Luz R., Rexeis M., Hausberger S., Schulte L., Hammer J., Steven H., Verbeek R. “Development and validation of a methodology for monitoring and certification of greenhouse gas emissions from heavy duty vehicles through vehicle simulation, Final report; Service contract CLIMA.C.2/SER/2012/0004; Report No. I 07/14/Rex EM-I 2012/08 699 f.” 2014.

Norris J., Hill N., Kirsch F., Nurse D., Revereault P., Preston M. “Quantifying energy consumption of HDV auxiliary components and their contribution to CO2emissions of buses and coaches. Heavy Duty Vehicles Framework Contract-Service Request 3. Final Report for DG Climate Action Ref: CLIMA.C.2/FRA/2013/0007.” 2016.

Onori S., Serrao L., Rizzoni G. *Hybrid Electric Vehicles: Energy Management Strategies.* London: Springer, 2016.

Rexeis M., Röck M., Quaritsch M., Hausberger S., Silberholz G. “Further development of VECTO”. Final report for Specific contract No 340201/2018/776882/SER/CLIMA.C.4. By order of EUROPEAN COMMISSION DG CLIMA Report No. I 16/19/Rex EM-I 17/24 5670 from 29.11.2019.” 2019.

Rezaei A., Burl J. B., Zhou B. “Estimation of the ECMS equivalent factor bounds for hybrid electric vehicles.” *IEEE Trans. Control Syst. Technol., vol. 26, no. 6*, 2018: pp. 2198-2205.

Silberholz G., Hausberger S. “Feasibility assessment regarding the development of VECTO for hybrid heavy-duty vehicles. Final report by order of the European Commission DG CLIMA for service contract CLIMA.C.4/ETU/2016/0005LV.” 2017.

Six C., Silberholz G., Fredriksson J., Geringer B., Hausberger S. *Development of an exhaust emission and CO2 measurement test procedure for heavy-duty hybrids (HDH), Final Report for UNECE-GRPE HDH Working Group.* Vienna, Austria: IFA Vienna University of Technology, 2014.

Annex A: List of meetings with project relevance

All meetings with project relevance for which documents have been prepared or notes are available are listed below. In the course of the feedback process on the functioning of the VECTO xEV software and the setup of the unit tests, additional ad hoc meetings were held or email threads were conducted that are not listed here.

Table 16: List of meetings with project relevance

Date	Location	Meeting / Topic	Participants
03.12.2018	Audio web	Inception meeting	DG GROW, DG CLIMA, DG JRC, TUG,
23.01.2019	Audio web	Pre-meeting to stakeholder meeting on 30th of January	ACEA, CLEPA, CLCCR, TUG,
30.01.2019	Brussels	Kick-off meeting with stakeholders on HEVs in VECTO	DG GROW, DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, TUG
09.04.2019	Graz	Workshop on modelling of bus auxiliaries	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, TUG
10.04.2019	Graz	Workshop on Hybrids in VECTO	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, TUG, TNO
23.05.2019	Audio web	DHT Architecture	ZF, TUG
18.06.2019	Ispra	Long-term strategy and future perspectives of VECTO	DG JRC, DG CLIMA, ACEA, CLEPA, CLCCR, IRU, T&E, ICCT, IEA, TNM, TUG
03.07.2019	Audio web	VECTO HEV alignment of approaches	ACEA, TUG
04.09.2019	Brussels	HDV CO2 Editing board	Members of the HDV CO_2 Editing board
19.11.2019	Audio web	VECTO HEV component testing procedures	ACEA, TUG
02.12.2019	Brussels	HDV CO2 Editing board	Members of the HDV CO_2 Editing board
04.12.2019	Graz	Workshop on VECTO Advanced Auxiliary Model (AAUX) for Buses	ACEA, CLCCR, TUG
03.03.2020	Brussels	Stakeholder meeting VECTO HEV	DG GROW, DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, TUG
15.06.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, VOITH, TUG
02.07.2020	Audio web	HDV CO2 Editing board	Members of the HDV CO_2 Editing board
07.07.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, VOITH. TUG
09.07.2020	Audio web	Task Force Annex IX	ACEA; DG JRC, CLEPA, CLCCR, TUG
14.07.2020	Audio web	Task Force Annex Xb meets and Task Force Annex VI	ACEA, CLCCR, TUG
18.07.2020	Audio web	Annex Xb	CLEPA, TUG

Date	Location	Meeting / Topic	Participants
18.08.2020	Audio web	Task Force Annex Xb meets and Task Force Annex VI	ACEA, CLCCR, TUG
08.09.2020	Audio web	Project planning	DG CLIMA, DG JRC, TUG
08.09.2020	Audio web	Feedback to xEV VECTO	Scania, TUG
16.09.2020	Audio web	VECTO xEV Workshop #1	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
23.09.2020	Audio web	Scania GEM in VECTO	Scania, TUG
23.09.2020	Audio web	Project internal (Integrated components)	DG GROW, DG CLIMA, TUG
29.09.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, TUG
01.10.2020	Audio web	Battery durability	DG GROW, DG CLIMA, DG JRC, TUG
02.10.2020	Audio web	VECTO xEV Workshop #2	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
14.10.2020	Audio web	HDV CO2 Editing board	Members of the HDV CO_2 Editing board
16.10.2020	Audio web	Annex Xb	CLEPA, TUG
21.10.2020	Audio web	Task Force Annex IX	ACEA, DG CLIMA; TUG
23.10.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; TUG
03.11.2020	Audio web	VECTO xEV Workshop #3	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
04.11.2020	Audio web	Micro and mild HEV	Daimler, TUG
09.11.2020	Audio web	Micro and mild HEV	MAN, TUG
11.11.2020	Audio web	Micro and mild HEV	ACEA, TUG
17.11.2020	Audio web	Annex Xb	CLEPA, TUG
20.11.2020	Audio web	Project planning	DG CLIMA, DG JRC, TUG
20.11.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
24.11.2020	Audio web	VECTO xEV Workshop #4	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
09.12.2020	Audio web	HDV CO2 Editing board	Members of the HDV CO_2 Editing board
14.12.2020	Audio web	Project planning	DG CLIMA, TUG
14.12.2020	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
15.12.2020	Audio web	Task Force Annex IX	ACEA, DG CLIMA; DG JRC, TUG
18.01.2021	Audio web	Task Force Annex IX	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
19.01.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG

Date	Location	Meeting / Topic	Participants
03.02.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
16.02.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
25.02.2021	Audio web	Project planning	DG CLIMA, DG JRC, TUG
09.03.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
26.03.2021	Audio web	Project planning	DG CLIMA, DG JRC, TUG
01.04.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
08.04.2021	Audio web	Task Force Annex III – open xEV topics	ACEA, CLEPA, DG JRC, TUG
09.04.2021	Audio web	Scania GEM Hybrid	Scania, TUG
16.04.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
16.04.2021	Audio web	Scania GEM Hybrid	DG GROW, DG CLIMA; DG JRC, TUG
23.04.2021	Audio web	Scania GEM Hybrid	Scania, TUG
28.04.2021	Audio web	Task Force Annex Xb	ACEA, CLEPA, DG CLIMA; DG JRC, TUG
20.05.2021	Audio web	VECTO xEV Workshop #5	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
07.06.2021	Audio web	Task Force Annex IX – final adjustments bus auxiliaries	ACEA, TUG
09.06.2021	Audio web	Project planning	DG CLIMA, DG JRC, TUG
23.06.2021	Audio web	Project planning	DG CLIMA, DG JRC, TUG
12.07.2021	Audio web	VECTO xEV Workshop #6	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
14.07.2021	Audio web	Feedback VECTO xEV	Scania, TUG
06.10.2021	Audio web	VECTO xEV Workshop #7	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
12.11.2021	Audio web	Discussion approach for OVC vehicles	DG CLIMA, DG JRC, TUG
16.11.2021	Audio web	VECTO xEV Workshop #8	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
19.11.2021	Audio web	Bus HVAC for xEV	ACEA, TUG
11.01.2022	Audio web	VECTO xEV Workshop #9	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
15.02.2022	Audio web	Project planning	DG CLIMA, DG JRC, TUG
16.02.2022	Audio web	VECTO xEV Workshop #10	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG

Date	Location	Meeting / Topic	Participants
09.03.2022	Audio web	Alignment on various xEV and VECTO development related topics	DG CLIMA, DG JRC, TUG
14.03.2022	Audio web	Validation VECTO xEV	MAN, TUG
06.04.2022	Audio web	VECTO xEV Workshop #11	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
18.05.2022	Audio web	VECTO xEV Workshop #12	DG CLIMA, DG JRC, ACEA, CLEPA, CLCCR, others, TUG
29.06.2022	Audio web	Project planning and technical topics	DG CLIMA, DG JRC, TUG

Annex B: List of tickets associated with point 3. of Task 4

Table 17: List of tickets associated with point 3. of Task 4

issue key	component	issue type	title	time spent (hours)
VECTO-930	not specified	Bug	VTP Mode error	1.00
VECTO-931	VECTO Simulation Tool (Certification)	Bug	AT error in VECTO version 3.3.2.1519	2.00
VECTO-932	VECTO Simulation Tool (Certification)	Bug	Consistency in NA values in the vsum file	0.75
VECTO-934	VECTO Simulation Tool (Certification)	Bug	VECTO replace TC measured value by std value	0.50
VECTO-935	not specified	Issue	Abort Simulation in Coach Cycle	1.00
VECTO-936	not specified	Bug	WMA08SZZ7KP128559	0.50
VECTO-937	Notification according to Art. 10(2)	Use Case	Gear: 2 | DistanceRun got an unexpected response: ResponseOverload	0.25
VECTO-938	Notification according to Art. 10(2)	Use Case	Gear: 2 | DistanceRun got an unexpected response: ResponseOverload	0.25
VECTO-939	Notification according to Art. 10(2)	Use Case	Gear: 2 | DistanceRun got an unexpected response: ResponseOverload	0.25
VECTO-940	Notification according to Art. 10(2)	Use Case	WMA10XZZ8KM829766	0.25
VECTO-941	Notification according to Art. 10(2)	Use Case	WMA10XZZ3KM829772	0.25
VECTO-943	Notification according to Art. 10(2)	Use Case	WMA10SZZ6KP129164	0.25
VECTO-944	not specified	Support	Auxiliaries power on VECTO 3.3.2.1548 ENGINEERING Mode	0.50
VECTO-945	Notification according to Art. 10(2)	Use Case	WMA06XZZ5KM830822	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-946	VECTO Simulation Tool (Certification)	Improvement	Refactoring XML reading	64.00
VECTO-947	VECTO Simulation Tool (Certification)	Support	Support Request via E-Mail	0.25
VECTO-948	VECTO Simulation Tool (Certification)	Support	Support Request via E-Mail	0.50
VECTO-949	Notification according to Art. 10(2)	Use Case	Gear: 2 | DrivingAction Accelerate after Overload ResponseUnderload	0.25
VECTO-950	VECTO Simulation Tool (Certification)	Bug	Error when loading Engine Full-load curve	1.00
VECTO-951	VECTO Simulation Tool (Certification)	Support	ADAS settimgs and results viewing	0.25
VECTO-953	Notification according to Art. 10(2)	Use Case	Gear: 2 | TargetVelocity (0.0000 [m/s]) and VehicleVelocity (1.5506 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-954	VECTO Simulation Tool (Certification)	Technical Sub-task	Failed to find operating point for braking power	30.00
VECTO-955	Notification according to Art. 10(2)	Use Case	XLRAEM4100G269507: TargetVelocity (0.000 [m/s]) and VehicleVelocity (0.8617 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-956	Notification according to Art. 10(2)	Use Case	XLRAEL3700L487185: Gear: 2 | Object reference not set to an instance of an object	0.25
VECTO-957	Notification according to Art. 10(2)	Use Case	XLRAEL3700L487473: TargetVelocity (0.000 [m/s]) and VehicleVelocity (0.9493 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-958	Notification according to Art. 10(2)	Use Case	XLRAEL3700L487482: TargetVelocity (0.000 [m/s]) and VehicleVelocity (0.9493 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-959	Notification according to Art. 10(2)	Use Case	XLRAEM4100G269535: TargetVelocity (0.000 [m/s]) and VehicleVelocity (0.8617 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-960	Notification according to Art. 10(2)	Use Case	XLRAEM4100G269567: TargetVelocity (0.000 [m/s]) and VehicleVelocity (0.8617 [m/s]) must be zero when vehicle is halting!	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-961	Notification according to Art. 10(2)	Use Case	WMA06SZZ4KP130436	0.25
VECTO-962	Notification according to Art. 10(2)	Use Case	Gear: 2 | TargetVelocity (0.0000 [m/s]) and VehicleVelocity (0.8024 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-963	Notification according to Art. 10(2)	Use Case	XLRAEL3700L487537: Gear: 1 | Object reference not set to an instance of an object.	0.25
VECTO-964	Notification according to Art. 10(2)	Use Case	XLRAEL3700L487644: Gear: 1 | Object reference not set to an instance of an object.	0.25
VECTO-965	VECTO Simulation Tool (Certification)	Improvement	Add input fields for ADAS into VECTO GUI	4.00
VECTO-966	VECTO Simulation Tool (Certification)	Improvement	Allow selecting Tank System for NG engines in GUI	2.00
VECTO-967	VECTO Simulation Tool (Certification)	Bug	Engine-Only mode: Engine Torque reported in .vmod does not match the provided cycle	1.00
VECTO-968	Notification according to Art. 10(2)	Use Case	WMA06XZZ5KM833381	0.25
VECTO-969	Notification according to Art. 10(2)	Use Case	WMA10XZZ9KM833714	0.25
VECTO-970	Notification according to Art. 10(2)	Use Case	Gear: 2 | TargetVelocity (0.0000 [m/s]) and VehicleVelocity (1.4050 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-971	Notification according to Art. 10(2)	Use Case	Gear: 2 | TargetVelocity (0.0000 [m/s]) and VehicleVelocity (1.4050 [m/s]) must be zero when vehicle is halting!	0.25
VECTO-972	Notification according to Art. 10(2)	Use Case	WMA03SZZ2KM834449	0.25
VECTO-974	VECTO Further Development	Technical Sub-task	Implementing engine stop/start at vehicle stop	32.00
VECTO-976	Notification according to Art. 10(2)	Use Case	WMA08SZZ9KP131379	0.25
VECTO-979	VECTO Simulation Tool (Certification)	Technical Sub-task	VECTO Simulation abort with 8-speed MT transmission	3.00

issue key	component	issue type	title	time spent (hours)
VECTO-980	not specified	Bug	Error during simulation run	3.00
VECTO-981	Notification according to Art. 10(2)	Use Case	XLRAEH4300G276989 Gear: 12 | DistanceRun got an unexpected response	0.25
VECTO-982	Notification according to Art. 10(2)	Use Case	Targetvelocity and vehiclevelocity must be zero when vehicle is halting	0.25
VECTO-983	Notification according to Art. 10(2)	Use Case	Targetvelocity and vehiclevelocity must be zero when vehicle is halting	0.25
VECTO-984	Notification according to Art. 10(2)	Use Case	Targetvelocity and vehiclevelocity must be zero when vehicle is halting	0.25
VECTO-985	Notification according to Art. 10(2)	Use Case	WMA10XZZ0KM830989	0.25
VECTO-986	Notification according to Art. 10(2)	Use Case	YV2RT60D9KA849969	0.25
VECTO-987	Notification according to Art. 10(2)	Use Case	YV2RT60D2KB913876	0.25
VECTO-989	Notification according to Art. 10(2)	Use Case	VF620M963KB000324	0.25
VECTO-990	Notification according to Art. 10(2)	Use Case	XLRAEL1700L487912: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-991	Notification according to Art. 10(2)	Use Case	XLRAEM3700G278230: Gear 4 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-992	Notification according to Art. 10(2)	Use Case	VF640J865KB010412	0.25
VECTO-993	Notification according to Art. 10(2)	Use Case	VF640J861KB010388	0.25
VECTO-994	Notification according to Art. 10(2)	Use Case	VF640J863KB010389	0.25
VECTO-995	Notification according to Art. 10(2)	Use Case	VF620M96XKB000322	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-996	Notification according to Art. 10(2)	Use Case	VF640J563KB012972	0.25
VECTO-997	Notification according to Art. 10(2)	Use Case	VF640J567KB012991	0.25
VECTO-998	Notification according to Art. 10(2)	Use Case	VF640J864KB010370	0.25
VECTO-999	Notification according to Art. 10(2)	Use Case	VF640J86XKB010356	0.25
VECTO-1000	VECTO Simulation Tool (Certification)	Technical Sub-task	Error Loss-Map extrapolation in Declaration Mode	4.00
VECTO-1001	Notification according to Art. 10(2)	Use Case	WMA10XZZ7KP132488	0.25
VECTO-1002	Notification according to Art. 10(2)	Use Case	WMA10XZZ9KM833518	0.25
VECTO-1003	VECTO Simulation Tool (Certification)	Technical Sub-task	Vecto Error: Loss-Map extrapolation in declaration mode required	4.00
VECTO-1004	not specified	Support	Hot cold WLTC correction calculation	0.25
VECTO-1005	not specified	Support	High differences with AT Gearbox	1.25
VECTO-1006	VECTO Simulation Tool (Certification)	Technical Sub-task	Failed to find torque converter operating point on UD cycle	2.00
VECTO-1007	Notification according to Art. 10(2)	Use Case	AT error in VECTO version 3.3.3.1609	0.25
VECTO-1009	Notification according to Art. 10(2)	Use Case	AT error in VECTO version 3.3.3.1609	0.25
VECTO-1010	VECTO Simulation Tool (Certification)	Technical Sub-task	Unexpected Response: ResponseOverload in UD cycle	2.00
VECTO-1011	Notification according to Art. 10(2)	Use Case	WMA06SZZ2KP133058	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1012	Notification according to Art. 10(2)	Use Case	VF630N168KD002631	0.50
VECTO-1014	not specified	Bug	ERROR: Could not find the declaration segment for vehicle	0.25
VECTO-1015	VECTO Hashing Tool	Bug	XML Schema not correctly identified	2.00
VECTO-1016	Notification according to Art. 10(2)	Use Case	VF640J867KB010413	0.25
VECTO-1017	not specified	Support	How to use a Vehicle configuration with a different mission profile	0.25
VECTO-1018	Notification according to Art. 10(2)	Use Case	WMA10XZZ1KM837515	0.25
VECTO-1019	VECTO Simulation Tool (Certification)	Bug	Error opening job in case a file is missing	0.25
VECTO-1020	VECTO Simulation Tool (Certification)	Bug	HashingTool Crashes	1.50
VECTO-1021	VECTO Simulation Tool (Certification)	Bug	Invalid hash of job data	1.00
VECTO-1022	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489407: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1023	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489474: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1024	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489475: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1025	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489484: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1026	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489540: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1027	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489298: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1028	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489279: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1029	not specified	Support	New issues on VECTO 3.3.3.1649?	4.50
VECTO-1030	VECTO Simulation Tool (Certification)	Bug	Exceeded max iterations when searching for operating point! Failed to find operating point!	1.00
VECTO-1032	VECTO Simulation Tool (Certification)	Bug	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1033	Notification according to Art. 10(2)	Use Case	XLRAEL2500L489593: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1035	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489654: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1036	Notification according to Art. 10(2)	Use Case	XLRAEL3700L489509: Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1038	Notification according to Art. 10(2)	Use Case	XLRAEL3700L489508 Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1039	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489722 Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1040	VECTO Simulation Tool (Certification)	Technical Sub-task	Gear 6 LossMap data was extrapolated in Declaration Mode	1.00
VECTO-1041	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489791 Gear 5 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1042	VECTO Simulation Tool (Certification)	New Feature	Add option to write results into a certain directory	1.50
VECTO-1043	Notification according to Art. 10(2)	Use Case	XLRAEM3700G282927 Gear 4 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1044	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489878 Gear 5 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1045	Notification according to Art. 10(2)	Use Case	XLRAEL2700L489881 Gear 5 LossMap data was extrapolated in Declaration Mode	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1046	Notification according to Art. 10(2)	Use Case	DrivingActionAccelerate: Failed to find operating point after Overload	0.25
VECTO-1049	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489994: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1050	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490021: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1051	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490030: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1052	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490034: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1053	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490035: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1054	Notification according to Art. 10(2)	Use Case	WMAN18ZZ1LY402251	0.25
VECTO-1055	Notification according to Art. 10(2)	Use Case	XLRAEL1700L489791: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1056	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490054: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1058	Notification according to Art. 10(2)	Use Case	XLRAEL1500L489859: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1059	Notification according to Art. 10(2)	Use Case	XLRAEL3700L489909: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1060	Notification according to Art. 10(2)	Use Case	XLRAEL2500L489972: Gear: 4 | Failed to find operating point!	0.25
VECTO-1061	Notification according to Art. 10(2)	Use Case	XLRAEL3700L489910: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1062	Notification according to Art. 10(2)	Use Case	WMAN18ZZ5KY399708	0.50

issue key	component	issue type	title	time spent (hours)
VECTO-1063	Notification according to Art. 10(2)	Use Case	WMAN18ZZ6KY399863	0.50
VECTO-1066	VECTO Simulation Tool (Certification)	Support	Support request via e-mail with confidential data	1.00
VECTO-1067	not specified	Bug	Vair and Beta correction for Aerodynamics	2.00
VECTO-1068	Notification according to Art. 10(2)	Use Case	Bug with VECTO 3.3.2.1548 and AT gearbox	0.25
VECTO-1069	Notification according to Art. 10(2)	Use Case	Issue with VECTO 3.3.2.1548 and AT gearbox	0.25
VECTO-1070	Notification according to Art. 10(2)	Use Case	Issue with VECTO 3.3.2.1548 and AT gearbox	0.25
VECTO-1071	Notification according to Art. 10(2)	Use Case	WMAN18ZZ6KY399863	0.25
VECTO-1072	VECTO Hashing Tool	Support	Impossible to use VECTO tool	0.25
VECTO-1074	not specified	Bug	Vecto Calculation Aborts with Interpolation Error	1.00
VECTO-1075	not specified	Support	Request on VECTO Driver Overspeed and Ecororoll	3.00
VECTO-1076	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490229: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1077	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490228: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1078	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490227: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1079	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490226: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1080	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490225: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1081	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490203: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1083	Notification according to Art. 10(2)	Use Case	Issue with VECTO 3.3.2.1548 and AT gearbox	0.25
VECTO-1084	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490402: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1085	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490468: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1086	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490444: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1087	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490428: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1090	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490507: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1091	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490593: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1092	Notification according to Art. 10(2)	Use Case	XLRAEL2500L489973 Gear: 4 | Failed to find operating point	0.25
VECTO-1093	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490648 Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1094	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490647 Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1095	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490616 Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1096	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490646 Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1097	not specified	Support	Error during Air Drag Calculation	0.25
VECTO-1098	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490681: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1099	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490746: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1100	VECTO Simulation Tool (Certification)	Support	XML vs json	0.25
VECTO-1101	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490525: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1102	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490836: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1103	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490843: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1104	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490844: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1105	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490845:Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1106	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490847: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1107	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490593: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1108	Notification according to Art. 10(2)	Use Case	XLRAEL2500L490839: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1110	Notification according to Art. 10(2)	Use Case	WMAN18ZZ6LY402293	0.25
VECTO-1111	VECTO Simulation Tool (Certification)	Sub-task	Simulation Abort in Municipal Reference Load	2.00
VECTO-1112	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490981: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1113	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490962: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1114	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490961: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1115	Notification according to Art. 10(2)	Use Case	HIGH PRIORITY: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1116	Notification according to Art. 10(2)	Use Case	HIGH PRIORITY: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1117	Notification according to Art. 10(2)	Use Case	HIGH PRIORITY: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1118	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1119	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1120	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1121	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1122	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1123	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1124	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1125	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1126	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1127	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1128	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1129	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490893: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1130	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490889: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1131	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490888: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1132	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490869: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1133	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490868: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1134	Notification according to Art. 10(2)	Use Case	XLRAEL1500L490867: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1135	Notification according to Art. 10(2)	Use Case	XLRAEL1700L490896: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1136	Notification according to Art. 10(2)	Use Case	XLRAEL2500L490570: Gear: 6 | Failed to find operating point!	0.25
VECTO-1137	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490647: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1138	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490616: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1139	Notification according to Art. 10(2)	Use Case	XLRAEL2700L490746: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1140	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490646: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1141	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490648: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1142	Notification according to Art. 10(2)	Use Case	XLRAEL3700L490681: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1143	VECTO Further Development	New Feature	Declaration mode for medium lorries	45.00

issue key	component	issue type	title	time spent (hours)
VECTO-1144	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1145	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1146	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1148	VECTO AirDrag	Support	Cross wind influence for Air Drag does not match the calculation	0.42
VECTO-1149	VECTO AirDrag	New Feature	Extension of Declaration Mode to new vehicle categories	16.00
VECTO-1150	Notification according to Art. 10(2)	Use Case	WMAN13ZZ7LY404038	0.25
VECTO-1151	Notification according to Art. 10(2)	Use Case	WMA06SZZ1LP136387	0.25
VECTO-1152	Notification according to Art. 10(2)	Use Case	XLRAEL3700L491403: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1153	Notification according to Art. 10(2)	Use Case	XLRAEL3700L491402: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1154	Notification according to Art. 10(2)	Use Case	XLRAEL3700L491401: Gear 6 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1155	Notification according to Art. 10(2)	Use Case	VECTO error HDV class 2	0.25
VECTO-1156	Notification according to Art. 10(2)	Use Case	VECTO error HDV class 3	0.25
VECTO-1157	Notification according to Art. 10(2)	Use Case	WMA03SZZ6LM843883	0.25
VECTO-1158	Notification according to Art. 10(2)	Use Case	VECTO 3.3.3.1639 issue - VIN ZCFA81TJ102698977	2.58
VECTO-1160	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1161	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1162	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1163	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1165	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1166	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1167	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1168	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1169	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1170	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1171	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1172	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1173	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1174	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25
VECTO-1175	Notification according to Art. 10(2)	Use Case	Gear: 4 | Failed to find operating point!	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1177	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491900: Gear: 4 | Failed to find operating point!	0.25
VECTO-1178	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491899: Gear: 4 | Failed to find operating point!	0.25
VECTO-1179	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491897: Gear: 4 | Failed to find operating point!	0.25
VECTO-1180	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491896: Gear: 4 | Failed to find operating point!	0.25
VECTO-1181	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491895: Gear: 4 | Failed to find operating point!	0.25
VECTO-1182	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491894: Gear: 4 | Failed to find operating point!	0.25
VECTO-1183	Notification according to Art. 10(2)	Use Case	XLRAEL2500L491893: Gear: 4 | Failed to find operating point!	0.25
VECTO-1184	Notification according to Art. 10(2)	Use Case	Unknown error with VECTO 3.3.4.1716	1.00
VECTO-1185	Notification according to Art. 10(2)	Use Case	XLRAEL2700L491697: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1186	Notification according to Art. 10(2)	Use Case	XLRAEL2700L491698: Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1187	Notification according to Art. 10(2)	Use Case	Gear: 5 | Gear 5 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1188	Notification according to Art. 10(2)	Use Case	Gear: 5 | Gear 5 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1189	VECTO Simulation Tool (Certification)	Technical Sub-task	Error in delaunay triangulation invariant violated	2.00
VECTO-1191	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1192	not specified	Bug	System:Out of Memory Exception	0.50

issue key	component	issue type	title	time spent (hours)
VECTO-1193	Notification according to Art. 10(2)	Use Case	Error in VECTO extrapolation	0.25
VECTO-1195	VECTO Engine	New Feature	Dual fuel + WHR implementation	62.00
VECTO-1196	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1197	VECTO Further Development	Bug	Invalid input for fuel type for dual fuel simulations	0.50
VECTO-1198	Notification according to Art. 10(2)	Use Case	DistanceRun got an unexpected response	1.50
VECTO-1199	VECTO Further Development	Support	Questions about VECTO with ADAS in-the-loop	0.25
VECTO-1200	VECTO Simulation Tool (Certification)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1201	VECTO Simulation Tool (Certification)	Issue	Customer information file	1.25
VECTO-1202	Notification according to Art. 10(2)	Use Case	WMAN18ZZ1LY407112	0.50
VECTO-1203	not specified	Support	VECTO GS not working with time based cycles	0.25
VECTO-1204	Notification according to Art. 10(2)	Use Case	Gear 5 LossMap data was extrapolated in Declaration Mode: range for loss map is not sufficient	0.25
VECTO-1205	not specified	Bug	Problem in VECTO-ADAS with more .vdri chosen	0.42
VECTO-1206	VECTO Simulation Tool (Certification)	Support	Calculation of shift losses for AT gearboxes	1.50
VECTO-1208	not specified	Support	Problems with rear axle files	1.00
VECTO-1209	VECTO Simulation Tool (Certification)	Technical Sub-task	Unexpected Response Response Overload	1.50
VECTO-1211	VECTO Simulation Tool (Certification)	Technical Sub-task	Simulation Abort Urban Delivery Ref Load	1.50
VECTO-1212	VECTO Simulation Tool (Certification)	Support	Simulation Aborts	0.50

issue key	component	issue type	title	time spent (hours)
VECTO-1214	VECTO Simulation Tool (Certification)	Technical Sub-task	Validation of input data fails when gearbox speed limits are applied	0.50
VECTO-1215	not specified	Support	ADAS Parameter questions	0.25
VECTO-1216	not specified	Support	Simulated fuel consumption gets higher at higher gearbox efficiencies	1.00
VECTO-1217	VECTO Simulation Tool (Certification)	Bug	Torque and speed limits error	0.25
VECTO-1218	Notification according to Art. 10(2)	Use Case	Issue with Urban Delivery cycle at reference load stopping	0.25
VECTO-1220	VECTO Simulation Tool (Certification)	Technical Sub-task	Simulation Abort Urban Delivery RefLoad	2.00
VECTO-1224	not specified	Bug	Failed Interpolation in Fuel Consumption Map	0.25
VECTO-1225	not specified	Improvement	Vocational customer.xml	1.00
VECTO-1226	VECTO Engine	Bug	Automatic check of FCMC points	4.00
VECTO-1227	not specified	Support	Default torque losses of an electrical retarder	0.25
VECTO-1228	Notification according to Art. 10(2)	Use Case	WMAN14ZZ7LY410573	0.25
VECTO-1229	not specified	Bug	Torque converter map not complete in exported xml	0.50
VECTO-1230	VECTO Simulation Tool (Certification)	Support	Differences between input data (fuel map) and map interpolated from VECTO results	1.00
VECTO-1232	not specified	Support	Gearshift strategy "Not specified - Use default" in VECTO 0.5.0.1841-DEV	0.25
VECTO-1233	not specified	Bug	Torque and speed limits error	0.33
VECTO-1235	not specified	Support	Test made by IVECO on groups 1 and 5 on ADAS InTheLoop	2.50
VECTO-1236	not specified	Support	PT1 Time Constant	0.50
VECTO-1237	VECTO Simulation Tool (Certification)	Support	ATVoith Shiftstrategy	0.25
VECTO-1239	VECTO Simulation Tool (Certification)	Improvement	Adaptation of Mission Profile Weighting Factors	1.00

issue key	component	issue type	title	time spent (hours)
VECTO-1242	VECTO PrimaryBus	Support	Error with VECTO 0.6.0.1884 for Medium Lorries and fan technology	0.33
VECTO-1243	VECTO Simulation Tool (Certification)	Bug	Bug in VTP mode for heavy lorries	1.00
VECTO-1244	VECTO PrimaryBus	Support	Error with generating XML export in VECTO 0.6.0.1884	0.50
VECTO-1245	VECTO PrimaryBus	Bug	Errors from Engineering Mode in VECTO 0.6.0.1884	1.00
VECTO-1246	not specified	Support	Weighting factors for the WHTC road category correction factors	0.75
VECTO-1247	VECTO PrimaryBus	Support	Error in Declaration mode in VECTO 0.6.0.1884	1.00
VECTO-1249	VECTO Simulation Tool (Certification)	Bug	Error when simulating with RetarderType "Primary Retarder" together with AT	7.75
VECTO-1251	VECTO Simulation Tool (Certification)	Bug	Error when adding a gear to an existing gearbox file	0.50
VECTO-1252	VECTO PrimaryBus	Technical Sub-task	Aux FAN: handling of electrical Fan	1.00
VECTO-1253	VECTO PrimaryBus	Technical Sub-task	Aux STP: handling of electric steering pump	1.00
VECTO-1254	VECTO Hashing Tool	Bug	Hashing method does not ignore certain XML attributes	1.00
VECTO-1258	Infrastructure	Support	Update download links in VECTO releases to "citnet.tech."	1.00
VECTO-1259	VECTO Simulation Tool (Certification)	Bug	Mission profile weightinf factors for vehicles of group 16 are not correct	1.00
VECTO-1260	VECTO CompletedBus	New Feature	Factor method for heavy buses	2.25
VECTO-1261	VECTO PrimaryBus	New Feature	Additional vehicle technologies for the Bus Auxiliary Model	32.00
VECTO-1262	VECTO Medium Lorries	New Feature	VTP Medium lorries	7.00
VECTO-1263	VECTO Further Development	New Feature	VTP Dual-fuel	17.00
VECTO-1264	VECTO PrimaryBus	New Feature	VTP heavy buses	31.00

issue key	component	issue type	title	time spent (hours)
VECTO-1265	VECTO PrimaryBus	New Feature	new acceleration curve for buses	1.00
VECTO-1266	VECTO Simulation Tool (Certification)	Bug	Gear 4 Loss-Map was extrapolated	4.00
VECTO-1267	VECTO Further Development	Support	Support Questions received via e-mail	0.50
VECTO-1271	not specified	Change Request	Changes VECTO for Buses discussed in ExpertWorkshop	40.00
VECTO-1274	VECTO Further Development	Bug	VECTO3 from version 0.6.1.1975 doesn't work on my laptop	0.25
VECTO-1276	VECTO CompletedBus	Bug	0.6.1.1975 Unable to run with HVAC SystemConfiguration=4 and PassengerAC=none	0.50
VECTO-1277	VECTO CompletedBus	Bug	0.6.1.1975 Unable to run with HVAC SystemConfiguration=10	0.50
VECTO-1280	VECTO Simulation Tool (Certification)	Technical Sub-task	Simulation abort UD RefLoad	8.00
VECTO-1282	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1283	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1284	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1285	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1286	Notification according to Art. 10(2)	Use Case	Gear 6 LossMap data was extrapolated in Declaration Mode	0.25
VECTO-1287	not specified	Bug	Issues with VECTO version 0.6.1.1975	0.50
VECTO-1288	VECTO Simulation Tool (Certification)	Technical Sub-task	Simulation Abort UD RL	8.00
VECTO-1289	Notification according to Art. 10(2)	Use Case	Gear 6 loss map data was extrapolated in Declaration mode	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1290	Notification according to Art. 10(2)	Use Case	Gear 6 loss map data was extrapolated in Declaration Mode	0.25
VECTO-1292	not specified	Improvement	Add explnation on Engine Idle Speed in .vveh	0.50
VECTO-1293	not specified	Bug	Problems to access the user manual	0.50
VECTO-1295	not specified	Bug	Correction for work required to restart the engine is not fully correct	1.00
VECTO-1296	VECTO CompletedBus	Bug	Duplicates in generic FC-Map (completed bus)	1.50
VECTO-1297	VECTO Simulation Tool (Certification)	Support	Support request on specific CO2 emissions	2.00
VECTO-1300	Notification according to Art. 10(2)	Use Case	Gear 6 loss map extrapolation - XLRAEL2500L498520	0.25
VECTO-1301	Notification according to Art. 10(2)	Use Case	Gear 6 loss map extrapolation - XLRAEL2500L498432	0.25
VECTO-1303	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499014	0.25
VECTO-1304	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498918	0.25
VECTO-1305	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498879	0.25
VECTO-1306	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498878	0.25
VECTO-1307	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498877	0.25
VECTO-1308	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498846	0.25
VECTO-1309	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498845	0.25
VECTO-1310	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498809	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1311	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498808	0.25
VECTO-1312	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498807	0.25
VECTO-1313	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498805	0.25
VECTO-1314	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L498804	0.25
VECTO-1316	VECTO CompletedBus	Change Request	Buses: Allow door drive technology 'mixed'	1.00
VECTO-1318	VECTO PrimaryBus	Improvement	Update of classification scheme and payloads for completed buses	8.00
VECTO-1319	Notification according to Art. 10(2)	Use Case	WMA92SZZ7MM864589 Error 2 (Construction ReferenceLoad)	0.25
VECTO-1320	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499267	0.25
VECTO-1321	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499309	0.25
VECTO-1322	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499352	0.25
VECTO-1323	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499353	0.25
VECTO-1324	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499403	0.25
VECTO-1325	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499404	0.25
VECTO-1326	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499405	0.25
VECTO-1327	VECTO Simulation Tool (Certification)	Technical Sub-task	Simulation abort Construction RefLoad: unexpected response ResponseOverload	1.00

issue key	component	issue type	title	time spent (hours)
VECTO-1328	VECTO Simulation Tool (Certification)	Support	Support questions ISUZU	1.50
VECTO-1329	Notification according to Art. 10(2)	Use Case	Gear 6 loss map - XLRAEL2500L499482	0.25
VECTO-1330	Notification according to Art. 10(2)	Use Case	WMA92SZZ6MM864678 Error 2 (Construction ReferenceLoad)	0.25
VECTO-1331	not specified	Bug	VTP Mode does not function for vehicles of group 3	2.00
VECTO-1332	Notification according to Art. 10(2)	Use Case	gear 6 Loss map L499473	0.25
VECTO-1333	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map L499521	0.25
VECTO-1334	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map L499522	0.25
VECTO-1335	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499523	0.25
VECTO-1336	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499524	0.25
VECTO-1337	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499525	0.25
VECTO-1338	Notification according to Art. 10(2)	Use Case	Gear 6 Lossmap - L499559	0.25
VECTO-1339	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499560	0.25
VECTO-1340	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499561	0.25
VECTO-1341	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499562	0.25
VECTO-1342	Notification according to Art. 10(2)	Use Case	gear 6 Loss map - L499563	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1343	VECTO Further Development	Bug	Engine only mode dual fuel <tank system specified>	1.00
VECTO-1344	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499825	0.25
VECTO-1345	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499824	0.25
VECTO-1346	Notification according to Art. 10(2)	Use Case	gear 6 loss map - L499855	0.25
VECTO-1347	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499972	0.25
VECTO-1348	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499971	0.25
VECTO-1349	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L499973	0.25
VECTO-1350	Notification according to Art. 10(2)	Use Case	Gear 6 Loss map - L500025	0.25
VECTO-1351	not specified	Issue	Generic primary vehicle data format: transmission	0.50
VECTO-1353	VECTO Further Development	Bug	WHR power fuel map reduced by factor 5	0.50
VECTO-1354	VECTO Simulation Tool (Certification)	Support	Support request MAN	1.00
VECTO-1355	VECTO Simulation Tool (Certification)	Bug	VTP Simulation Abort	1.00
VECTO-1356	VECTO Simulation Tool (Certification)	Bug	PTO Losses not considered in VTP simulation	0.50
VECTO-1358	Notification according to Art. 10(2)	Use Case	gear 6 map loss - L500455	0.25
VECTO-1359	Notification according to Art. 10(2)	Use Case	gear 6 map loss - L500456	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1360	VECTO Simulation Tool (Certification)	Improvement	make unit tests execute in parallel	0.50
VECTO-1361	VECTO Simulation Tool (Certification)	Bug	Torque Converter in use for the First and Second Gear VTP file does not allow for this	3.00
VECTO-1369	VECTO Simulation Tool (Certification)	Support	VECTO VTP crashes	1.00
VECTO-1371	not specified	Improvement	loading of multiple job files at a time	0.25
VECTO-1374	VECTO Simulation Tool (Certification)	Bug	VECTO VTP error	1.00
VECTO-1382	not specified	Support	RESS capacity	0.50
VECTO-1392	VECTO Simulation Tool (Certification)	Bug	Fuel consumption unit in test.VTP_Report.xml and in MANUFACTURER.xml is not the same	1.50
VECTO-1395	VECTO Medium Lorries	Bug	Error with VECTO 0.6.2.2076	0.75
VECTO-1396	VECTO Further Development	Support	NaN [ ] is not allowed for SI-values in Vecto.	4.50
VECTO-1397	VECTO Hashing Tool	New Feature	EEA Hashing Tool	80.00
VECTO-1401	not specified	Support	error in retarder VECTO-3.3.8.2052	0.25
VECTO-1402	Notification according to Art. 10(2)	Use Case	error in retarder map	0.25
VECTO-1403	VECTO Simulation Tool (Certification)	Support	Vectocmd in 0.7.3.2164	0.50
VECTO-1404	VECTO Simulation Tool (Certification)	Improvement	Correct URL for CSS in MRF and CIF	0.50
VECTO-1406	VECTO Simulation Tool (Certification)	Support	Questions on VECTO Operation	3.00
VECTO-1407	not specified	Issue	error message is way ambiguous	0.50
VECTO-1408	not specified	Issue	Validation of Run-Data failed (axle)	0.75
VECTO-1411	VECTO Simulation Tool (Certification)	Improvement	Switching to new .NET version	45.00

issue key	component	issue type	title	time spent (hours)
VECTO-1418	VECTO CompletedBus	Support	Issues raised by CNH via e-mail	2.00
VECTO-1420	VECTO Simulation Tool (Certification)	Technical Sub-task	Failed to find operating point on search braking power with TC gear	2.00
VECTO-1429	VECTO Simulation Tool (Certification)	Bug	Error due to MaxNetPower1 when running ZeroEmissionVehicle with new XML schema	1.00
VECTO-1434	VECTO CompletedBus	Support	Factor method is not utilizing the PIF generated from the primary file run	1.25
VECTO-1435	VECTO Simulation Tool (Certification)	Bug	VECTO changes Vocational input	0.25
VECTO-1439	VECTO Simulation Tool (Certification)	Bug	Error running job	1.00
VECTO-1471	not specified	Bug	Vehicles from Group 16 are not driving the correct Routes (RD and CO)	0.50
VECTO-1474	VECTO Simulation Tool (Certification)	Improvement	merge ADAS in-the-loop simulation	64.00
VECTO-1475	VECTO Engine	Improvement	XML file generation	43.00
VECTO-1481	not specified	Support	New warning message regarding transmission: what does it mean?	0.50
VECTO-1488	not specified	Bug	VTP Simulation abort when shifting from Gear 1 to 2 with AT and TC_active = 1	1.00
VECTO-1498	VECTO Medium Lorries	Improvement	Crosswind correction in engineering mode	2.00
VECTO-1521	VECTO Simulation Tool (Certification)	Improvement	Updating tyre dimensions	2.00
VECTO-1522	VECTO PrimaryBus	Improvement	VECTO warning if there are more steered axles than steering pump technologies	3.00
VECTO-1523	VECTO Simulation Tool (Certification)	Issue	2017/2400 Draft 20211202 HDV CO2 act for TCMV dates	0.17
VECTO-1524	VECTO AirDrag	Improvement	Update VECTO Air Drag for 2nd amendment	23.50
VECTO-1526	not specified	Support	Multiple Type-Approvals for the same vehicle	0.25

issue key	component	issue type	title	time spent (hours)
VECTO-1527	Notification according to Art. 10(2)	Use Case	error in simulation VTP	0.67
VECTO-1549	not specified	Technical Sub-task	Error in gearshift behavior for AT transmissions when braking	3.00
VECTO-1550	not specified	Bug	Error in hashing tool	2.50
VECTO-1551	not specified	Bug	AT-P Transmission Bus Application: Error during braking phase	1.75
VECTO-1560	not specified	Improvement	update toolchain for generating usermanual	6.00
VECTO-1561	VECTO Simulation Tool (Certification)	Bug	Simulation abort with AT transmission	3.00
VECTO-1568	VECTO Simulation Tool (Certification)	Bug	Vecto Tool - Development version - Long haul 157	0.25
VECTO-1570	Notification according to Art. 10(2)	Use Case	error in urban delivery	0.75
VECTO-1574	not specified	Support	Questions on XML schemas	0.83
VECTO-1589	not specified	Support	ADAS signals	1.00
VECTO-1593	not specified	Support	Verify exempted Result Data	0.50
VECTO-1596	VECTO Engine	Improvement	Special method for limitation of WHTC correction factors for Dual Fuel engines	31.00
VECTO-1601	VECTO Simulation Tool (Certification)	Support	CO2 results with VECTO-3.3.11.2675 official release	2.00
VECTO-1608	VECTO Simulation Tool (Certification)	Improvement	Adaptation of Reports (MRF/CIF) for transition in official VECTO Release	10.10
VECTO-1612	AAUX	Improvement	Rework of the methodical incorrect post-processing approach of the AAUX model	250.65

Annex C: Relevant application cases for consideration of ESS and auxiliary power demand during ICE-off phases

Table 18: Application case 1 (according to Table 12 in 2.6.3)

Driving behavior	iceOn	P_aux_mech	P_busAux_ES_gen	P_busAux_ES_consumer_sum	P_busAux_ES_mech	P_aux_ESS_mech_ICE_off	P_aux_ESS_mech_ICE_on	NI_busAux_PS_gen	NI_busAux_PS_cons	P_busAux_PS_gen
Driving	**true**	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEfficiency	P_ES	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	**false**	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Halted	**true**	P_aux_mech_base + P_PS(n_idle) + P_ES / AlternatorEfficiency	P_ES	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	**false**	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base + (P_ES - P_ES_ICEOff_st) / AlternatorEfficiency	0	NI_PS	0
Braking	**true**	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEfficiency	P_ES	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)

Table 19: Application case 2 (according to Table 12 in 2.6.3)

Driving behavior	iceOn	P0 battery SoC	P_aux_mech	P_busAux_ES_gen	- P_bat_P0	P_busAux_ES_consumer_sum	P_busAux_ES_mech	P_aux_ESS_mech_ICE_off	P_aux_ESS_mech_ICE_on	NI_busAux_PS_gen	NI_busAux_PS_cons	P_busAux_PS_gen
Driving	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	**true**	**0**	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEfficiency	P_ES	0.00	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	**false**	**0<x<1**	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Driving	**false**	**0**	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Halted	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_idle)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Halted	**true**	**0**	P_aux_mech_base + P_PS(n_idle) + P_ES / AlternatorEfficiency	P_ES	0.00	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Halted	**false**	**0<x<1**	0	0	P_ES_ICEOff_st	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base + (P_ES - P_ES_ICEOff_st) / AlternatorEfficiency	0	NI_PS	0
Halted	**false**	**0**	0	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base + (P_ES - P_ES_ICEOff_st) / AlternatorEfficiency	0	NI_PS	0
Braking	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	MaxAlternatorPower - P_ES	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	**true**	**1**	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEfficiency	P_ES	0.00	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)

Table 20: Application case 3 (according to Table 12 in 2.6.3)

Driving behavior	iceOn	REES SoC	P_aux_mech	P_busAux_ES_gen	P_busAux_ES_consumer_sum	P_busAux_ES_mech	P_aux_ESS_mech_ICE_off	P_aux_ESS_mech_ICE_on	P_DCDC_out	P_DCDC_missing	NI_busAux_PS_gen	NI_busAux_PS_cons	P_busAux_PS_gen
Driving	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_ice)	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	**true**	**REESS_MinSoC**	P_aux_mech_base + P_PS(n_ice)	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_ice)
Driving	**false**	**0<x<1**	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	P_ES_ICEOff_dr	0	0	NI_PS	0
Driving	**false**	**REESS_MinSoC**	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base_dr	0	P_ES_ICEOff_dr	0	NI_PS	0
Halted	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_idle)	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	**true**	**REESS_MinSoC**	P_aux_mech_base + P_PS(n_idle)	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_idle)
Halted	**false**	**0<x<1**	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	P_ES_ICEOff_st	0	0	NI_PS	0
Halted	**false**	**REESS_MinSoC**	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	0	P_ES_ICEOff_st	0	NI_PS	0
Braking	**true**	**0<x<1**	P_aux_mech_base + P_PS(n_ice)	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	**true**	**REESS_MinSoC**	P_aux_mech_base + P_PS(n_ice)	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_ice)
Braking	**false**	**0<x<1**	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	P_ES_ICEOff_dr	0	0	NI_PS	0
Braking	**false**	**REESS_MinSoC**	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	P_ES_ICEOff_dr	0	NI_PS	0

Table 21: Application case 4 (according to Table 12 in 2.6.3)

Driving behavior	IceOn	P0 battery SoC	P1 recup Pwr %	P_aux_mech	P_busAux_ES_gen	- P_bat_P0	P_busAux_ES_consumer_sum	P_busAux_ES_mech	P_aux_ESS_mech_ICE_off	P_aux_ESS_mech_ICE_on	NI_busAux_PS_gen	NI_busAux_PS_cons	P_busAux_PS_gen
Driving	true	0<x<1	-	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	true	0	-	P_aux_mech_base + P_PS(n_ice)+P_ES / AlternatorEff	P_ES	0	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	false	0<x<1	-	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Driving	false	0	-	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Halted	true	0<x<1	-	P_aux_mech_base + P_PS(n_idle)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	true	0	-	P_aux_mech_base + P_PS(n_idle) + P_ES / AlternatorEff	P_ES	0	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	false	0<x<1	-	0	0	P_ES_ICEOff_st	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base + (P_ES - P_ES_ICEOff_st) / AlternatorEfficiency	0	NI_PS	0
Halted	false	0	-	0	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base + (P_ES - P_ES_ICEOff_st) / AlternatorEfficiency	0	NI_PS	0
Braking	true	0<x<1	<100	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	1	<100	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	<100	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEff	P_ES	0	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	false	0<x<1	<100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Braking	false	1	<100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Braking	false	0	<100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Braking	true	0.5	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES-MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	1	100	P_aux_mech_base + P_PS(n_ice) + P_ES / AlternatorEfficiency	P_ES	0	P_ES	P_ES / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES-MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	false	0.5	100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Braking	false	1	100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0
Braking	false	0	100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base + (P_ES - P_ES_ICEOff_dr) / AlternatorEfficiency	0	NI_PS	0

Table 22: Application case 5 (according to Table 12 in 2.6.3)

Driving behavior	IceOn	P0 battery SoC	REESS SoC	P1 recup Pwr %	P_aux_mech	P_busAux_ES_gen	- P_bat_P0	P_busAux_ES_consumer_sum	P_busAux_ES_mech	P_aux_ESS_mech_ICE_off	P_aux_ESS_mech_ICE_on	P_DCDC_out	P_DCDC_missing	NI_busAux_PS_gen	NI_busAux_PS_cons	P_busAux_PS_gen
Driving	true	0<x<1	0<x<1	-	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	true	0	0<x<1	-	P_aux_mech_base + P_PS(n_ice)	0	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	true	0<x<1	REESS_MinSoC	-	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Driving	true	0	REESS_MinSoC	-	P_aux_mech_base + P_PS(n_ice)	0	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_ice)
Driving	false	0<x<1	0<x<1	-	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Driving	false	0	0<x<1	-	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	P_ES_ICEOff_dr	0	0	NI_PS	0
Driving	false	0<x<1	REESS_MinSoC	-	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Driving	false	0	REESS_MinSoC	-	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	P_ES_ICEOff_dr	0	NI_PS	0
Halted	true	0<x<1	0<x<1	-	P_aux_mech_base + P_PS(n_idle)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	true	0	0<x<1	-	P_aux_mech_base + P_PS(n_idle)	0	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	true	0<x<1	REESS_MinSoC	-	P_aux_mech_base + P_PS(n_idle)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_idle)
Halted	true	0	REESS_MinSoC	-	P_aux_mech_base + P_PS(n_idle)	0	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_idle)
Halted	false	0<x<1	0<x<1	-	0	0	P_ES_ICEOff_st	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	0	0	0	NI_PS	0
Halted	false	0	0<x<1	-	0	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	P_ES_ICEOff_st	0	0	NI_PS	0
Halted	false	0<x<1	REESS_MinSoC	-	0	0	P_ES_ICEOff_st	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	0	0	0	NI_PS	0
Halted	false	0	REESS_MinSoC	-	0	0	0	P_ES_ICEOff_st	0	P_aux_mech_ICEoff_st	P_aux_mech_base	0	P_ES_ICEOff_st	0	NI_PS	0
Braking	true	0<x<1	0<x<1	<100	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	0<x<1	<100	P_aux_mech_base + P_PS(n_ice)	0	0	P_ES	0	0	0	P_ES	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0<x<1	REESS_MinSoC	<100	P_aux_mech_base + P_PS(n_ice)	0	P_ES	P_ES	0	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	REESS_MinSoC	<100	P_aux_mech_base + P_PS(n_ice)	0	0	P_ES	0	0	0	0	P_ES	NI_PS	NI_PS	P_PS(n_ice)
Braking	false	0<x<1	0<x<1	<100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Braking	false	0	0<x<1	<100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	P_ES_ICEOff_dr	0	0	NI_PS	0
Braking	false	0<x<1	REESS_MinSoC	<100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Braking	false	0	REESS_MinSoC	<100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	P_ES_ICEOff_dr	0	NI_PS	0
Braking	true	0<x<1	0<x<1	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES - MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	0<x<1	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES - MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0<x<1	REESS_MinSoC	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES - MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	true	0	REESS_MinSoC	100	P_aux_mech_base + P_PS(n_ice) + MaxAlternatorPower / AlternatorEfficiency	MaxAlternatorPower	P_ES - MaxAlternatorPower	P_ES	MaxAlternatorPower / AlternatorEfficiency	0	0	0	0	NI_PS	NI_PS	P_PS(n_ice)
Braking	false	0<x<1	0<x<1	100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Braking	false	0	0<x<1	100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	P_ES_ICEOff_dr	0	0	NI_PS	0
Braking	false	0<x<1	REESS_MinSoC	100	0	0	P_ES_ICEOff_dr	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	0	0	NI_PS	0
Braking	false	0	REESS_MinSoC	100	0	0	0	P_ES_ICEOff_dr	0	P_aux_mech_ICEoff_dr	P_aux_mech_base	0	P_ES_ICEOff_dr	0	NI_PS	0