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# Impact of variable driving conditions and additional consumers on the driving range and energy consumption of light commercial electric vehicles

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**Summary**

Due to the climate change transport technologies progress in a more environmentally friendly direction, which leads to a transition from conventional fossil fuel technologies to climate-neutral ones and therefore creates new challenges to handle in order to substitute the previous drivetrain systems with new concepts. These can cause e.g. difficulties or limitations regarding energy storage and driving range. This study investigates the energy demands of commercial vehicles to create a guideline for a drivetrain concept. In order to represent as many different application profiles as possible, it considers additional weights, secondary consumers and typical route types of commercial vehicles.

*Keywords: Simulation, BEV (Battery Electric Vehicle), Consumers, Energy Consumption, Range*

## 1 Introduction

The number of the electric vehicle (EV) registrations and their share in total in the fleets of vehicles are increasing constantly. In Germany, the percentage of EV registrations, which counts battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell vehicles (FCV), has already reached over 30 % for October 2021 while the trend and the acceptance of such vehicles are also positive [1]. Especially in commercial vehicle fleets the transformation to alternative drivetrain types is more likely to be observed due to financial advantages and reputational profits compared to conventional drivetrain types. In Germany, buying BEVs, PHEVs and FCVs is governmentally aided with a bonus of up to 9000 €. Furthermore, BEVs and FCVs are exempted from vehicle taxes for up to 10 years with a registration before 2026 [2]. The transformation has influenced e.g. the postal delivery company DHL, which is aiming a total number of 37,000 BEV's by the end of 2025 [3]. Due to the fact that their postal delivery vehicles have daily routes of 10 km to 50 km with an average distance of 23.58 km per day [4], vehicles with electric drivetrains seem to be suitable for a commercial application.

Nevertheless, the electrification of a vehicle fleet brings several difficulties regarding the electric driving range, the vehicle handling or the fleet management. Due to different requirements, depending on the industry segment, companies should consider which EVs are suitable for their main application and comply with the criteria. These criteria include the minimum electric driving range in dependency of the needed secondary consumers, e.g. climatisation systems, which usually use the same energy source as the traction system. Therefore, an additional demand for energy is an important aspect to consider for the transition to EVs. Another criterion is the maximum payload of the vehicle, which coheres with the electric driving range.

Based on the above-mentioned criteria, this study analyses the suitability of EVs and the required energy amount in commercial fleet vehicles considering variable parameters and loads, which affect the electric driving range. The analysis of this study examines exclusively light commercial vehicles such as delivery vehicles used for the distribution of private parcels and sensitive goods like food or medicine, which require a well-regulated climatisation. The selected approach to examine the impact of the variable parameters is to simulate a drivetrain model considering a variety of test cases in the simulation software GT-Suite from Gamma Technologies.

The aim of the study is to create modularly combineable variable parameters to enable the representation of a wide field of commercial uses. This allows the calculation of the energy demands for specific applications.

# 2 Methodology

In order to investigate the impact of variable loads and routes on the consumption characteristics on vehicles with an electric drivetrain, certain variation possibilities define the simulation frame. The strategy is to run simulations of the drivetrain model with each possible variation of every parameter to determine the changes in the energy consumption with only the effect of the particular factor. This study only considers individual parameters that are predictable characteristics related to the applications of commercial vehicles.

## 2.1 Modelling of the Test Vehicle

A fully electric BMW i3 without range extender is available in the institute of automotive technology of the University of Applied Sciences Ulm and hence serves as a test carrier. The main characteristics such as vehicle mass, engine power and battery capacity are comparable to a light postal delivery car and represent a basis vehicle model that can be extended with additional consumers and masses. Table 1 shows the relevant vehicle data.

Table 1: Vehicle Data of the BMW i3 [5]

| **BMW i3 Technical Data** | | |
|---|---|---|
| Vehicle mass | | 1195 kg |
| Powertrain | | Synchronous permanent magnet electric motor<br>Single speed transmission, Rear wheel drive |
| Battery | | Lithium-Ion battery |
| Engine power | Nominal | 75 kW |
| | Maximum | 125 kW |
| Maximum torque | | 250 Nm |
| Nominal voltage | | 360 V |
| High voltage battery energy (1p96s) | gross | 22.0 kWh |
| | net | 18.8 kWh |
| Energy consumption (NEDC*) | | 12.8 kWh/100 km |
| Electric range (NEDC) | | 190 km |
| Maximum regenerated power | | 50 kW |

*New European Driving Cycle

An electric drivetrain model in the simulation software GT-Suite from Gamma Technologies has already been validated and allows the effect analysis of variable loads. The 1D-simulation model contains a high voltage battery, a battery management system containing a power electronics unit and the electric motor powering a single gear transmission, which includes the differential gear. Those components represent the minimum variety to shape an electric drivetrain, that is arbitrarily parametrisable and extendable.

Each component of the drivetrain contains specific data like the torque and efficiency map or geometrical data of the vehicle. Figure 1 shows the topology of the simulation model.

The model considers the driving resistances such as air resistance, road grade and tyre friction dependent on the speed of the vehicle. The combination of the parametrised components and the tractive force resulting from the driving resistances enables the calculation of the correct driving values and energy consumption including the recuperated energy.

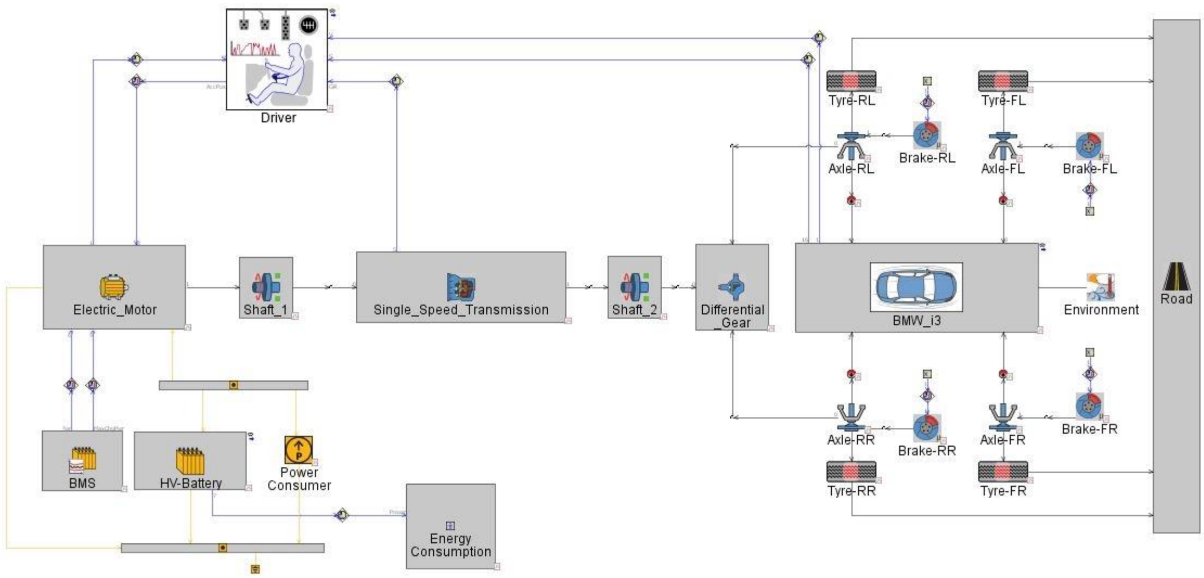


Figure 1: Topology of the Simulation Model

## 2.2 Variation of Parameters

The simulation considers the variable loads such as additional masses and secondary consumers in order to map specific load collectives. Figure 2 shows parameters like additional consumers, variable masses and different route types which serve for creating a full factorial experimental design that displays all the configurations for the study.

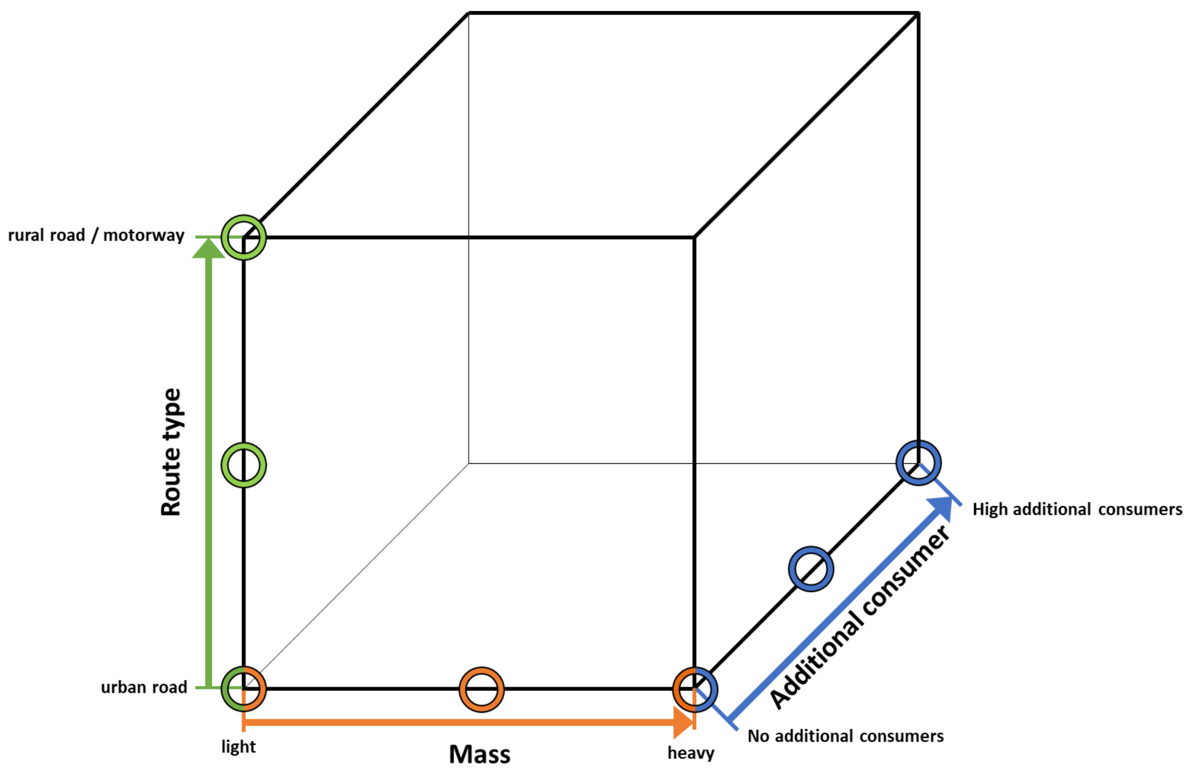


Figure 2: Possible Variations of Driving Loads

Subsequently the individual parameters are defined:

### 2.2.1 Mass

Different applications of commercial vehicles change their weight during a drive, e.g. postal delivery vehicles which pick up parcels at parcel shops (increasing) or distribute them to private homes (decreasing). These changes can remarkably affect the total weight of the vehicle. The chosen masses in the study derive from the prevalent electric delivery vehicles of the company DHL in Germany. Table 2 shows the variation of the mass levels. The first and lightest level is the curb weight of the standard BMW i3 as a reference point. Starting at this level the mass goes up to 4050 kg, which is the gross vehicle weight of the StreetScooter Work XL. These mass levels serve as a division of the possible mass span. In the simulation it is possible to add a passenger and cargo mass for the required additional mass.

Table 2: Mass Levels [6,7,8]

| **Masses** | | | | |
|---|---|---|---|---|
| Model | BMW i3 | DHL StreetScooter Work | DHL StreetScooter Work L | DHL StreetScooter Work XL |
| Curb weight | 1195 kg | 1460 kg | 1770 kg | 2900 kg |
| Gross vehicle weight | 1620 kg | 2180 kg | 2800 kg | 4050 kg |
| Chosen mass for simulation | 1195 kg | 2000 kg | 2800 kg | 4050 kg |

### 2.2.2 Additional Consumers

Additional devices like climatisation systems or electrically riseable loading platforms can consume a significant amount of energy during the operation. Different than the other parameters, the additional consumers are also demanding power in the standstill times and hence are affected by the total time of a run. The most permanently energy demanding consumers are the refrigeration units of cooling trucks, which can require up to 8 kW [9] of power. Starting level is a state without additional consumers. Table 3 shows the levels of additional consumers.

Table 3: Additonal Consumer Levels

| **Power levels** | | | | |
|---|---|---|---|---|
| Consumers | none | cabin climatisation | (windshield) heating + all comfort consumers | storage climatisation + comfort consumers |
| Power | 0 kW | 2 kW | 5 kW | 10 kW |

The simulation model includes an additional power source with a negative value serving as a sink. This component allows to vary the power request for every run.

### 2.2.3 Route Type

To run simulations with the drivetrain model, appropriate generic driving routes are adapted to the given applications. The usage of generic routes allows the variation of typical driving and route parameters to approximate the driving behaviour of commercial vehicles. These parameters contain e.g. the standstill time at traffic lights or the speeds in each segment. Thus, it is possible to generate different types of routes with specific characteristics. Table 4 shows four typical variations of routes with their data. These explicit routes are generated from real route segments with route type specific parameters like speed level, standstill times and acceleration values.

Table 4: Route Data

| | **Urban Postal** | **Urban** | **Rural** | **Highway** |
|---|---|---|---|---|
| Total distance | 27.1 km | 27.5 km | 33.1 km | 28.1 km |
| Average speed | 18.6 km/h | 28.2 km/h | 82.1 km/h | 112.4 km/h |
| Maximum speed | 56.9 km/h | 56.5 km/h | 99.9 km/h | 131.2 km/h |
| Total travelling time | 5260 s | 3514 s | 1450 s | 901 s |
| Number of standstills | 20 | 13 | - | - |
| Total time of standstills | 1768 s | 192 s | - | - |
| Percentage of standstill time | 33.6 % | 5.5 % | - | - |

Figure 3 shows the speed profile of the Urban Postal route, which has a low average speed with frequent and long standstill times, in which the potential additional consumers are still running and therefore consuming energy. The standstill times represent the typical delivery process. This way, the standstill times can have a severe impact on the energy consumption.

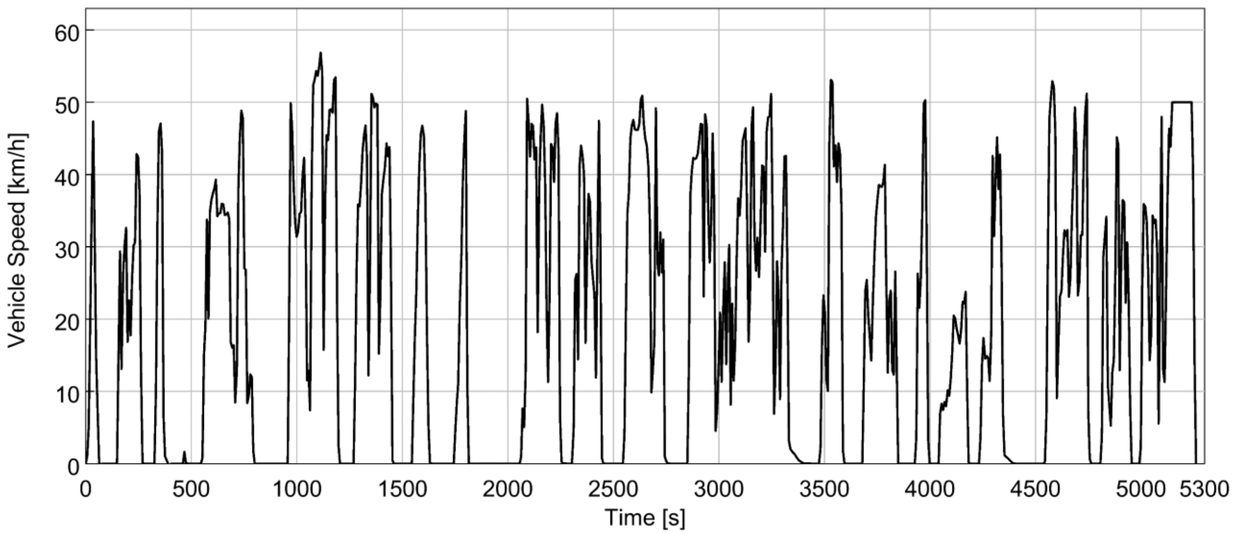


Figure 3: Urban Postal Speed Profile

Figure 4 shows the speed profile of the Urban route, which is also characterised by low speeds and many stops, but unlike the Postal route with short standstill times due to conventional stops in urban traffic.

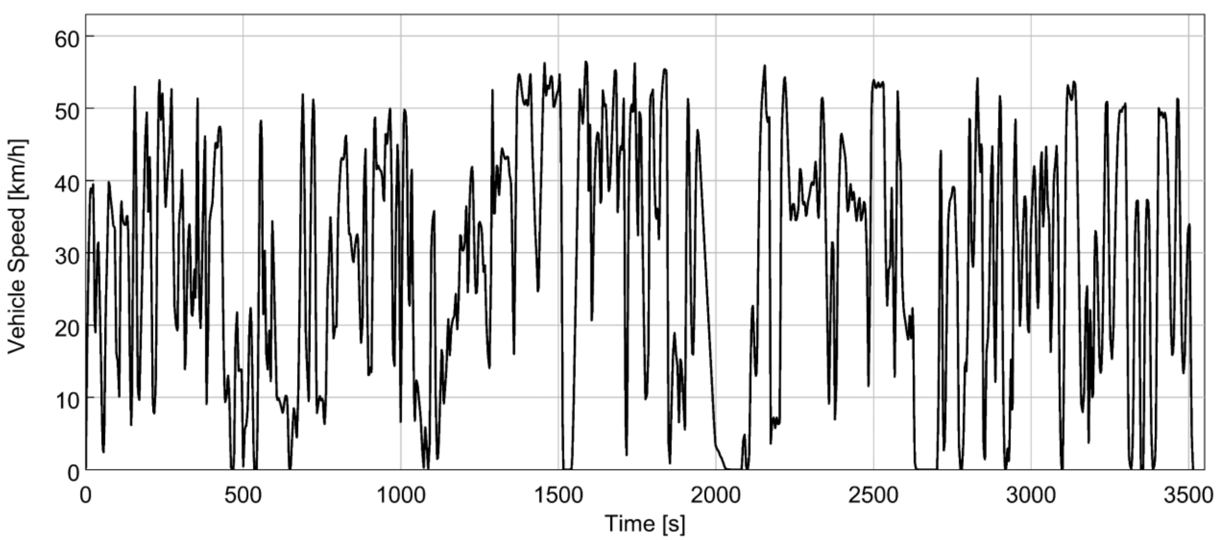


Figure 4: Urban Speed Profile

In Figure 5 both the Rural and Highway routes are displayed, which do not contain standstill times like the Urban routes. They are characterised by high average speeds and only minor braking times.

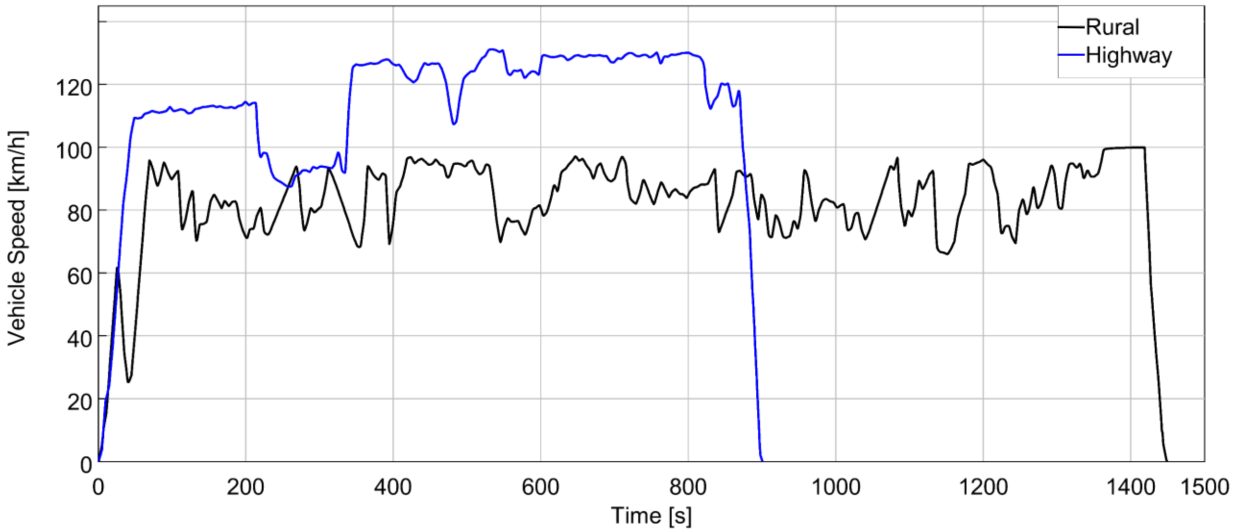


Figure 5: Rural and Highway Speed Profile

### 2.3 Composition of the Test Cases

The combination of three parameters with each four variations results according to the calculation $4^3$ in 64 different test cases. Thus the simulation examines the impact of the different parameters isolated and individually in order to fulfill the realisation of a full factorial approach with independent parameters. This enables the evaluation of each parameter without the impact of the others.

For the analysis of the study the energy consumptions will be compared standardised to 100 km (kWh/100 km) to enable an independence from the different total distances of the routes and a universal reference value.

Table 5 shows the numbered possible test case variations for each route type in order to allow the differentiation and comparison of the test cases in each route type equally.

Table 5: Test Case Definitions

| **Test Case** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| Mass | 1195 kg | 2000 kg | 2800 kg | 4050 kg | 1195 kg | 2000 kg | 2800 kg | 4050 kg |
| Consumers | 0 kW | 0 kW | 0 kW | 0 kW | 2 kW | 2 kW | 2 kW | 2 kW |

| **Test Case** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
|---|---|---|---|---|---|---|---|---|
| Mass | 1195 kg | 2000 kg | 2800 kg | 4050 kg | 1195 kg | 2000 kg | 2800 kg | 4050 kg |
| Consumers | 5 kW | 5 kW | 5 kW | 5 kW | 10 kW | 10 kW | 10 kW | 10 kW |

# 3 Results

Figure 6 shows the energy consumption results of all test cases standardised for 100 km marked with the different route types and ordered by the test case number.

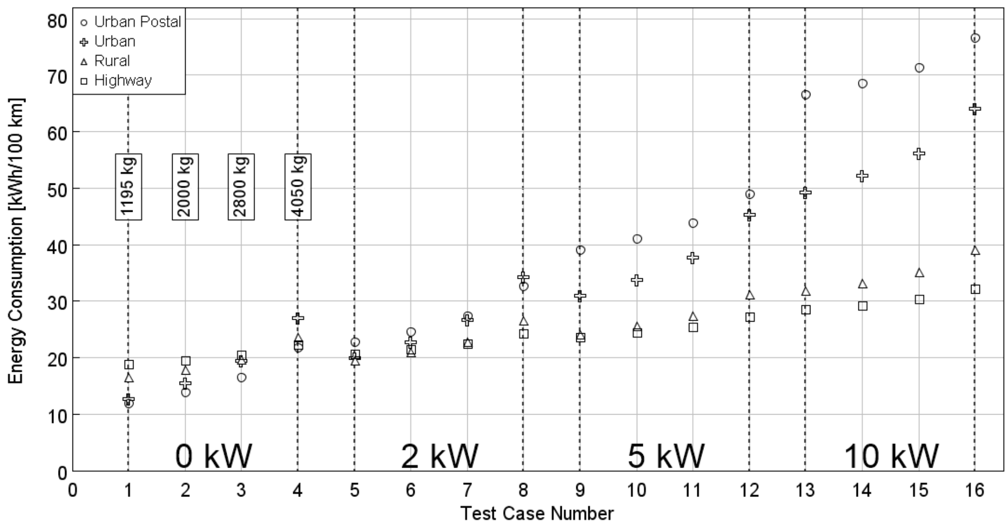


Figure 6: Energy Consumptions by Routes

Each of the four groups of consecutive points marked with the vertical lines represents simulation runs with the same amount of additional consumer power and increasing weight as labeled.

**Urban Postal**: The energy consumption for 100 km has a minimum value of 11.9 kWh and a maximum value of 76.7 kWh. In this route the largest energy consumption differences are caused by the additional consumers, which can increase the consumption by 55.0 kWh/100 km from 0 kW to 10 kW at the same weight of 4050 kg (Test Case 4 vs. 16) from the lowest to highest level, whereas the additional weight adds at most 10.2 kWh/100 km from 1195 kg to 4050 kg with an additional consumer power of 10 kW (Test Case 13 vs. 16). The additional consumption for the weight increase from 1195 kg to 4050 kg in case 1 vs. 4 is less with 9.8 kWh/100 km due to the battery voltage dependency in Test Case 13 vs. 16 related to the additional consumers. The impact difference is a result of the many and long standstill times and shows, that the additional consumers are the most impactful parameter of this route type, whilst the mass is less relevant.

**Urban**: The energy consumption for 100 km has a minimum value of 12.6 kWh and a maximum value of 63.9 kWh. Due to the more frequent acceleration and braking sections than in the Urban Postal route there is a higher dependency on the weight with an addition of at most 14.7 kWh/100 km from 1195 kg to 4050 kg with an additional consumer power of 10 kW (Test Case 13 vs. 16). Contrary the consumption increase from the additional consumers is less affecting than in the Urban Postal route with at most 37.0 kWh/100 km from 0 kW to 10 kW at 4050 kg (Test Case 4 vs. 16) due to the fewer and shorter standstill times for the route.

**Rural**: The energy consumption for 100 km has a minimum value of 16.5 kWh and a maximum value of 39.1 kWh. The Rural route is less dependent on the additional weight and consumers than the Urban type routes because of the less frequent acceleration and braking sections and the overall shorter driving time. The weight addition causes an energy demand increase of at most 7.2 kWh/100 km from 1195 kg to 4050 kg with an additional consumer power of 10 kW (Test Case 13 vs. 16) and the additional consumers at most 15.5 kWh/100 km from 0 kW to 10 kW at 4050 kg (Test Case 4 vs. 16).

**Highway**: The energy consumption for 100 km has a minimum value of 18.8 kWh and a maximum value of 32.2 kWh. The base energy consumption is higher than in the Rural route due to the higher average speed in this route, but the span is smaller due to the fewer acceleration and braking sections and the overall shorter driving time. The effect of the added weight is an energy consumption increase of at most 3.7 kWh/100 km from 1195 kg to 4050 kg with an additional consumer power of 10 kW (Test Case 13 vs. 16) and the increase from the additional consumers is at most 9.8 kWh/100 km from 0 kW to 10 kW at 4050 kg (Test Case 4 vs. 16).

The comparison of the consumptions shows, that the additional consumers are mostly affected by the total time of a route and hence impact the consumption of Urban type routes the most, whereas the Rural and Highway routes change their consumptions less because of the additional consumers. The mass changes show similar characteristics, but with a smaller impact on the consumption.

Table 6 shows the base energy consumptions and the consumption increases because of the additional weights and consumers for each route type. It shows clearly the slope in the consumption increase from the Urban Postal to the Highway route.

Table 6: Additional Energy Consumption

| | **Base Consumption* in kWh/100 km** | **Consumption Increase** | | |
|---|---|---|---|---|
| | | **with 4050 kg and 0 kW** | **with 1195 kg and 10 kW** | **with 4050 kg and 10 kW** |
| Urban Postal | 11.9 | + 83.2 % | + 459.7 % | + 544.5 % |
| Urban | 12.6 | + 113.5 % | + 290.5 % | + 407.1 % |
| Rural | 16.5 | + 43.0 % | + 93.3 % | + 137.0 % |
| Highway | 18.8 | + 19.1 % | + 51.6 % | + 71.3 % |

*without additional weight or consumers

The diagram on the left hand side of Figure 7 shows the electric driving ranges for all route types focusing on the 0 kW (Test Case 1 to 4) and 10 kW (Test Case 13 to 16) additional consumer groups. For a reference value the given NEDC driving range [5] of the basis vehicle model is displayed as a horizontal line. Whilst the driving range within the 0 kW group decreases significantly from ca. 160 km to ca. 84 km for the Urban Postal route with increasing weight, the range of the 10 kW group only decreases from ca. 28 km to ca. 24 km for the Urban Postal route, which marks the minimum driving range out of 64 test cases. The diagram on the right hand side shows the total absolute amount of energy consumed in each test case in the Urban Postal route. It shows that the test cases 15 and 16 demand more energy than the battery provides and hence can only be driven without a charging stop, because the vehicle recuperates energy during the run.

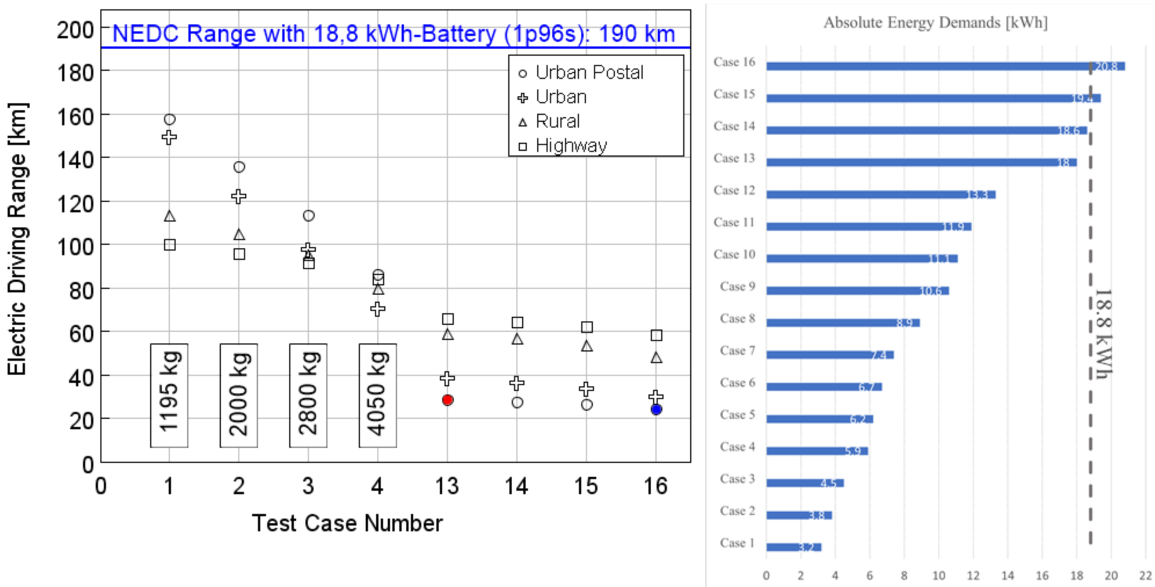


Figure 7: Electric Driving Ranges for 0 kW and 10 kW additional Consumers and absolute Energy Demands

Figure 8 displays the battery power of the coloured dots in Figure 7 over the time for a section of the Urban Postal route. It shows the difference between test cases with the lowest and the highest mass, in which additional consumers of 10 kW are active. The power demand of the additional consumers is represented by the dotted green line and visualises the share of the consumers in the total power demand. It is visible, that the Test Case 16 with the higher weight has higher power values both in the positive direction for accelerations and negative direction for recuperation. Furthermore the share of the additional consumers in the total power demand is much lower in Test Case 16 compared to Test Case 13. So in contrast to the energy demand the power demand is much more affected by the additional weight.

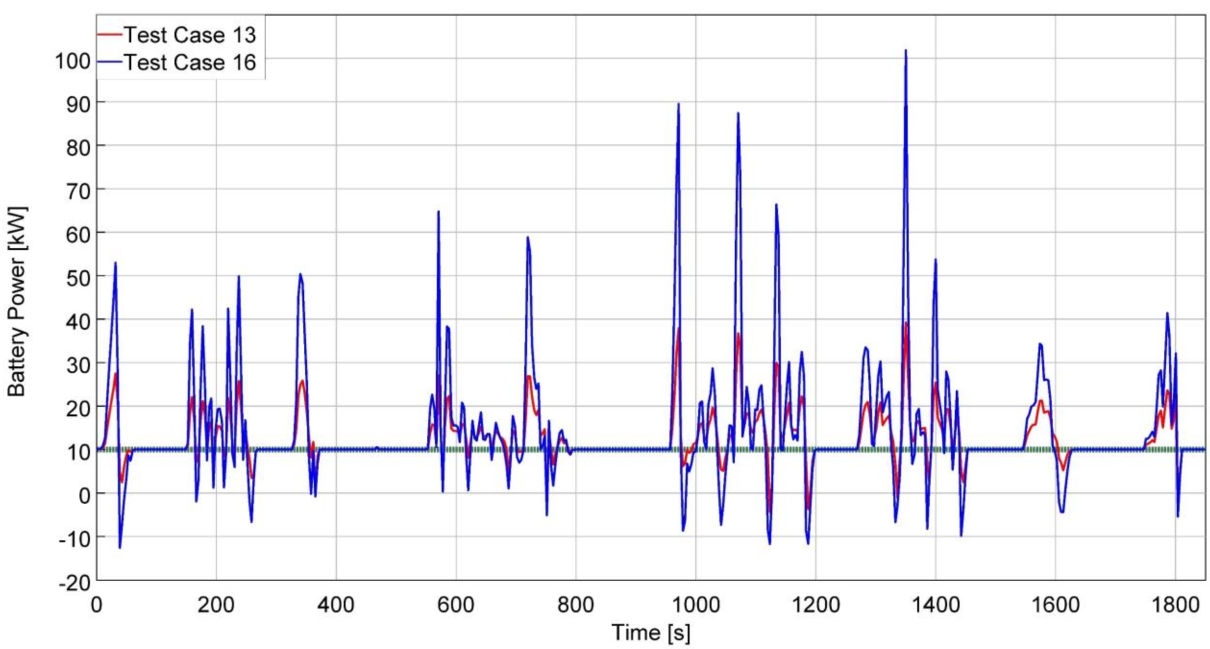


Figure 8: Comparison of the Battery Power over Time for the Urban Postal Route at minimum and maximum Mass with 10 kW additional Consumers

# 4 Discussion

This study leads to the conclusion that the examined parameters can have a severe impact on the energy consumption and hence on the driving range, which can affect the availability and working hours of commercially used vehicles. The heaviest impact comes as expected from the additional consumers, especially in the Urban and Urban Postal routes and can multiply the energy consumption by a factor of 5.6, whereas the additional weight can lead to an energy consumption multiplication by 2.1 at most. Over all test cases the impact of the route type is also remarkable, increasing with the additional consumer power level.

An aspect that did not turn out as expected is, that the additional consumption can not be standardised inbetween the simulated mass and additional consumer levels due to their non-linearity.

Another inaccuracy in the study is the simulation of all test cases with the drivetrain of the BMW i3, which would not be selected in a heavy duty application and hence leads to differing drivetrain losses. In the same way the air resistance of a larger vehicle would lead to increased consumptions. These parameters are not considered in this study in order to maintain the comparability of the selected parameters.

In summary the chosen variable steps can help finding a suitable dimensioned energy source for a certain application adapted to the determined energy demand caused by the variation of vehicle mass, additional consumers and individiual route types.

# 5 Conclusion and Future Work

The aim of the study was the analysis of the energy consumptions concerning different parameters such as additional consumers, route types and mass loads. The results show that the energy consumptions are with increasing addidtional consumers more and more severly affected by the route type. E.g. the Urban Postal route in the 10 kW additional consumer cases has an energy demand more than the double of the energy demands on the Highway route, whereas the consumptions with no additional consumers take place in a narrow range. Moreover the increase of the consumption within a route type is highly dependent on the route type itself. Whilst the Highway route consumption in the test case 16 is 1.7 times high as in case 1, for the Urban Postal route the comparison of the same cases has a factor of 6.4. These correlations show the significance of routes with long and frequent standstill times. In general the impact of high power additional consumers is severe, whilst the impact of high mass loads is – especially on Highway routes – less significant, because the vehicle does not fulfill high and frequent accelerations.

Equivalently the driving range for the considered battery with 18.8 kWh (Table 1) of energy is the highest without any consumers and mass loads on the Urban Postal route. Simultaneously the Urban Postal route also includes the test case 16 with the lowest range at 24.5 km, in which the 18.8 kWh battery can only provide the needed energy with the help of energy recuperation. For these types of routes a battery with more cells and another layout e.g. 96s2p would eventually be required.

Considering the power demand for the battery the test cases with the highest mass are the most significant ones. As in Figure 8 displayed the acceleration sections of the cases with the highest mass require the most power, because the power needed for the driving is up to ten times as high as the power of the additional consumers.

For more accurate results in following studies further model characteristics like air resistance or larger drivetrains with higher power losses in the mechanical or electrical components can be considered and varied. Thus a wider field of applications could be represented and the energy demand splitted into their elements. Furthermore different temperature levels could be set in order to examine the differences between areas or seasons. These adjustments of parameters require a new validation of the simulation model.

# 6 Acknowledgment

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