Seasonal Energy Efficiency: A Case Study of an Urban Distribution Battery Electric Truck Operating in Brazil

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Abstract

Electric heavy-duty trucks fully powered by batteries are already a reality in European, North American, and Chinese cities, thanks to strict CO₂ emission regulations. These regulations promote zero greenhouse gas emissions in the road transport sector through technologies such as battery-powered electric trucks (BETs). The increasing prevalence of BETs necessitates an assessment of their energy efficiency in different weather and driving conditions, since they directly impact operational costs and, thus, influence the acceptance of BETs by companies and fleet owners. In this sense, evaluating seasonal energy efficiency may drive improvements in technology performance, vehicle specifications, and driving conditions to reduce energy consumption and losses. To understand and quantify the factors affecting energy consumption and driving range in real-world driving conditions, various studies on energy efficiency have been conducted worldwide; nevertheless, South American metropolitan areas lack such attention. Therefore, this paper presents the main findings of an experimental study of BETs in terms of energy consumption, driving range, and energy recharging due to operational and climatic factors.

1. INTRODUCTION

For automobiles, energy is used for different purposes, being energy efficiency a quite relevant property that is widely employed by the automotive industry to calculate, simulate, and measure the energy that is effectively used and resulted losses. Most of the energy is utilized to propel the automobiles, characterized as propulsion energy, thus supplied to the drivetrain. Another important portion of the energy is supplied to auxiliary systems. Some of the auxiliary systems are the cooling system to refrigerate the drivetrain, air conditioning and cab interior instruments (WANG, BESSELINK and NIJMEIJER, 2015).

When energy efficiency is applied to assess electrified vehicles, specifically for heavy-duty trucks, it is focused on the energy supplied by the grid, actual energy consumed by the drivetrain, energy consumed for auxiliary systems, regenerated energy as well as losses related to internal resistance, heat, electrical conversion, and mechanical friction (SYNAK, KUCERA and SKRUCANY, 2020). For heavy-duty trucks, this property directly impacts the operational costs leading to the feasibility or not of this new technology on pursuing the net-zero emission goals. Moreover, the energy efficiency is very sensitive to operational factors, such as payload, driving behaviour, recharging strategy, rolling resistance, and weather conditions (BASSO et al., 2019; DONKERS, YANG and VIKTOROVIC, 2020). Therefore, understanding and dealing with the effects of these operational factors on the energy efficiency is crucial for Original Equipment Manufacturers (OEM) and the logistic sector.

In this sense, energy efficiency models have been created to estimate the driving range and calculate the energy consumption (EC) of electrical vehicles in Europe, North America, and Asia (GRUNDITZ & THIRINGER, 2016). Nonetheless, there is a lack of studies seeking to analyse seasonal energy efficiency of BETs operating in South America metropolitan areas, where the operation and weather conditions
usually differ from the regions previously cited. Additionally, heavy-duty trucks have not been focused by these researches, which have addressed mostly passenger cars and small commercial vehicles (XU et al., 2023).

On the other hand, the shift towards electrification of transportation accomplished by medium and heavy-duty trucks is a pivotal step to tackle resource shortage and environmental degradation. BETs emerged as a promising solution to mitigate or even eliminate direct and indirect greenhouse gases emissions and to reduce the reliance on conventional propulsion systems for the commercial transportation sector (WEISS, CLOOS and HELMERS, 2020). In this context, it is necessary to further understand the factors affecting energy efficiency in BETs, particularly in urban areas of Brazil, because of the great potential of this strategy in the Brazilian market (TANCO, CAT and GARAT, 2019). The outcomes of such studies could enable us to identify the technologies that provide better efficiency and to drive government decisions on incentives or taxes reduction (GRANGEIA et al., 2023), particularly for a country whose energy matrix is mostly generated from renewable sources, such as hydropower, solar and wind (EPE, 2022).

Considering the arguments exposed in the latter paragraphs, this paper presents the main findings of an experimental study proposed to evaluate the energy efficiency of an electric heavy-duty truck running on a specific route in São Paulo metropolitan area. The arrangement of this experimental test made it possible to evaluate the seasonal energy variation under different weather conditions, allowing us to observe the condition that results in higher energy consumption, and to identify how some operational factors contributes to energy consumption. Saying that, the remaining of this paper is structured as follows: Section 2 provides an overview of energy efficiency; Section 3 delineates the materials and methods employed for the experimental test; Section 4 outlines main outcomes of the experimental study; finally, in Section 5, the concluding remarks are provided.

2. BACKGROUND ON ENERGY EFFICIENCY

The energy used on BETs covers a couple of important functions, being a primary function to power the electric machine (EM) to propel the vehicle, in the so-called discharging mode (WANG, BESSELINK and NIJMEIJER, 2015). The energy comes from the electrical grid and, through the recharging unit, supplies the electric vehicle energy battery storage system. Shortly after, the energy flows towards drivetrain, where the energy is converted from DC (Direct Current) to AC (Alternate Current) on an inverter, then, the inverter controls the electric machine, modulating the frequency to raise or drop the synchronous speed (GRUNDITZ & THIRINGER, 2016; LIU, PLACKE and CHAU, 2022). At the transition between the electric machine and automated gearbox, the electric energy shifts to mechanical energy and it is reduced by a gearbox and rear axle central gear to increase torque and, finally, reach wheel hubs (WANG, BESSELINK and NIJMEIJER, 2015).

In the opposite direction, energy is recovered when the truck requires speed reduction by applying braking or during coasting while going downhill. A considerable portion of the energy comes from
regeneration produced by kinetic and potential energies (EVTIMOV, IVANOV and SAPUNDJIEV, 2017). For instance, when the EM rotates inversely to generate braking force, the most efficient regeneration performance is observed. Both service braking, which is the conventional brake actuated by the pedal, and downhill coasting are not so effective for regeneration purpose. In this context, it is necessary an efficient strategy to transfer to the electric machine the responsibility for the biggest amount of braking force needed, which can be achieved by specific algorithms (WANG, BESSELINK and NIJMEIJER, 2015).

In addition, energy is used to supply auxiliary systems, which include systems powered by 12 V or 24 V and even higher voltage. The auxiliary systems play a key role on total EC and this energy is utilized for comfort purpose, e.g., media, cab climate control, portable refrigerator, coffee maker, and audio; and for safety purpose, e.g., lights, cameras, horn, and windscreen cleaner (ABBES et al., 2022; EVTIMOV, IVANOV and SAPUNDJIEV, 2017; KAVALCHUK et al., 2015). Specific for medium and heavy-duty trucks, other systems that can be tied up to auxiliary systems are the following: air compressed system, that supplies air for suspension and braking functions; cooling and heating systems, that control the internal temperature of propulsion batteries and power converters; and electrical power take-offs, that control bodywork actuation functions (EVTIMOV, IVANOV and SAPUNDJIEV, 2017).

Throughout the energy flux, the energy efficiency can be jeopardized by losses occurring at various stages of BETs use, including during battery recharging, energy conversion and driving. Battery losses are mostly due to internal resistance, which transforms some of the stored chemical energy into internal heat instead of externally supplied power. With increased recharging or output power, a larger share of the energy turns into internal heat losses, lowering the energy efficiency. Increasing the ratio between electrode area and volume can lower the specific resistance and raise the maximum power output, nonetheless, for the same energy capacity, this leads to a more costly battery (EL-BAYEH et al., 2021; DOLLINGER & FISCHERAUER, 2021; AYEVIDE et al., 2022).

Effective energy management systems are essential to reduce these losses and to ensure optimal vehicle performance (YILDIRIM and KURT, 2021). Propulsion battery assembly usually consists of three main levels of components: cells, packages, and modules; while the Electronic Control Unit (ECU) is responsible for their management, thus comprising the Battery Management System (BMS). BMS ensures the reliable and safe operation of electric vehicles. During recharging and discharging, it facilitates the batteries to exert their optimal performance and prolong their service life. Thus, battery management system performs a series of functions, including battery state estimation, cell balancing, package recharging discharging control, thermal management, fault prognosis and health diagnosis, and correspondence. Sometimes, additional ECUs are part of the propulsion battery management system to assist BMS functions, being designated as slave ECUs (LIU, PLACKE and CHAU, 2022). Figure 1 exhibits an energy flux diagram containing the energy path through main components of an electric vehicle.

Other major aspects that influence energy efficiency are driving style, weather variables, infrastructural elements, and traffic intensity. The findings described in Donkers, Yang and Viktorovic (2020) corroborated previous researches about energy efficiency on electric vehicles, using modeling and on-
road driving tests. The study found that driving style has a significant influence, such as high speed, aggressive accelerations and decelerations, and speed oscillations result in a significant increase in energy. Low temperatures play an important influence on the consumed energy because of the use of the heating system. During severe winter, air drag and rolling resistance increased the energy consumption. Driving on urban areas showed that the rolling resistance and acceleration forces are dominant and traffic intensity is responsible for increasing energy consumption, and air drag is a dominant aspect on highways due to fluid traffic. Infrastructural elements usually encountered in urban areas substantially increase the energy consumption, such as sharp curves, slopes, intersections, and speed bumpers (EVTIMOV, IVANOV and SAPUNDJIEV, 2017). Therefore, there are many aspects that influence energy efficiency, which can be described as a measure of how effectively a system converts input energy into useful output energy or work, expressed as a percentage. The energy efficiency can be calculated using three different modes, i.e., propulsion, regenerative and cycling or net modes (GRUNDITZ and THIRINGER, 2016).

3. MATERIALS AND METHODS

3.1. Technical specification of the BET

The battery electric heavy-duty truck chosen for the experimental study features the following technical specifications: (cabin type) extended; (axle distance) 5750 mm; (tires) section width of 275 mm, aspect ratio of 80, rim diameter of 22.5 mm; (bodywork) sider box; (legal gross vehicle weight) 23000 kg; (propulsion unit) electric machine; (propulsion unit type) three-phase star coupling permanent magnet synchronous motor; (propulsion unit power and torque) 230 kW and 2100 Nm; (gearbox type) two speeds; (central gear ratio) 5.25; (energy capacity) 297 kWh at a state of charge of 73%.

3.2. Design of the experimental study

The experimental study proposed in this paper to evaluate the energy efficiency of a battery electric heavy-duty truck was conducted with an urban distribution vehicle operating under real-world conditions, including both summer and winter seasons. Through this arrangement, the study would be capable of revealing the potential variation in energy consumption patterns related to ambient temperature and to the primary contributors to energy consumption growth.

The BET was assigned to a predefined route in the São Paulo metropolitan area, where it carried packages and automotive parts between a factory and a nearby warehouse center, covering a round-trip distance of 13 km. Figure 2 shows in red the route location considered for the purpose of the experimental study, in São Bernardo do Campo city. The BET operated continuously, through two daily shifts lasting eight hours each, covering both day and night periods. Each shift was managed by different experienced drivers. All available vehicle functionalities were used by the drivers without any external intervention or guided influence from the personnel collecting data.

3.3. Data structure
The data was organized to provide insights into several key factors: actual energy consumption, impact of operational factors and weather conditions, regenerated energy, energy consumed by the drivetrain along with losses in electric machine, energy recharging losses, energy consumption by auxiliary systems, cycled energy of the propulsion batteries, and energy efficiency in both propulsion and braking modes. The next subsections give a brief overview of each of the factors just mentioned.

3.3.1. Energy consumption

The energy consumption of an electric vehicle is influenced by many internal and external factors. The comprehensive scope of these factors often defies precise control due to elements such as design limitations or the unpredictability of natural occurrences. Notably, the internal factors include electrical losses, mechanical losses, internal temperature, and internal resistance, whereas external factors involve weather, traffic, driving style, aerodynamic drag, road infrastructure, rolling resistance, and vibration. The energy consumption can be obtained by adding the total energy discharged by the propulsion battery system and the energy regeneration, which is considered a negative energy that is withdrawal from the energy consumption.

3.3.2. Energy regeneration

Energy regeneration is an energy that results from kinetic and potential energies produced generally by braking or gravity forces. The best braking performance is achieved when it is applied the auxiliary brake, which is the electric machine inversely rotating, towards the opposite power direction. The BET chosen for this experimental study features an auxiliary brake lever with five positions. The major advantage is that electric machine directly generates electric energy. The pedal brake, also known as service brake, when going downhill in coasting promotes some regeneration, without a satisfactory performance though. Because of that, braking blending functionality must be designed in a way to improve fit usage and braking performance.

3.3.3. Auxiliary systems energy consumption

Regarding the energy consumption of auxiliary systems, it is split into three main consumers: 24 V consumers comprising, e.g., infotainment, internal and external illumination, horn, refrigerator; compressed air supply system for suspension and brake; the others, including heating, ventilating, and air conditioning (HVAC) and cooling and heating systems for the propulsion battery systems.

3.3.4. Drivetrain energy consumption

The components that make up the drivetrain of an electric vehicle serve both electrical and mechanical functions. Alongside energy consumption, there are losses scattered throughout the energy supply process. A significant portion of the energy is used by the electrical components, and a notable share is dedicated to powering the brakes. Additionally, the energy needed to overcome factors like friction from the road, air resistance, and uphill slopes is conventionally known as road load.

3.3.5. Energy recharging losses
Energy recharging losses occur during the process of recharging an electric vehicle due to a combination of factors related to the conversion, transmission, and storage of electrical energy. Primarily, these losses are caused by the inherent inefficiencies in the energy conversion process. When an electric vehicle is plugged for recharging, the electrical energy from the power source, such as a charging station or an electrical outlet, needs to be converted into a form that can be stored in the vehicle's battery. This conversion process involves several steps, including rectifying AC to DC power, regulating voltage levels, and managing the flow of energy. Certain amount of loss is due to factors, for instance, resistance in the components and heat dissipation.

3.3.6. Cycled energy

Cycled energy calculates the number of discharges/recharges on the propulsion battery system resulting in the degraded battery health. The outcome from cycled energy can be described as the remained state of health. Conventionally, fully automotive propulsion battery systems have a lifetime limit equal to 80%. Below this value, the battery system become unsuitable for use in an electric vehicle, though it can continue to be used a second-life application, such as domestic or industrial energy storage tasks (BAEK et al., 2020).

3.3.7. Energy efficiency

Energy efficiency is the ratio between the useful output and input of an energy conversion process. The energy efficiency is determined through three modes: firstly, the energy flow from the propulsion batteries to the electric machine, denoted as Propulsion Mode Efficiency; secondly, the regenerative mode, which accounts for the energy returned from the electric machine to the propulsion batteries, referred to as Regenerative Mode Efficiency; and finally, the combined effect known as Cycled Energy, which is a product of both propulsion and regenerative modes.

3.4. Data acquisition and visualization

After each work shift, the drivers were asked to fill a form that included questions on ambient temperature, transported payload, and recharged energy and time. Additionally, a data logger was connected to the truck's CAN (Controller Area Network) to remotely store and process data. The logger splits all data into parts with a fixed time length dependent on the number of parameters to be logged. The stored data was then extracted, sorted out, and processed using a Matlab (ver. R2021b) by MathWorks. The processed data was exported to an Excel spreadsheet for graphical analysis.

4. EXPERIMENTAL RESULTS

The running test with the BET described in section 3.1 was done from December 2022 to July 2023 within the São Paulo metropolitan area, thus covering summer, autumn, and winter seasons. The parameters relevant to the study were collected through the logger connected to the truck's CAN network and then classified into three groups related to the temperature range: very warm (i.e., temperature from 28°C to 32°C), warm (i.e., temperature from 21°C to 27°C), and moderate-cold (i.e., temperature from
16°C to 20°C). In addition, the consumption values from the analyzed systems were standardized to the unit kWh/km.

### 4.1 Energy consumption

Energy consumption is composed, in part, by the total discharged energy and, in the other part, by the regenerated energy. The graph shown in Fig. 3 illustrates the battery energy discharging and the energy consumption for the three classes defined for ambient temperature. From the graph one can observe that both energy discharging and consumption gradually reduce as temperature drops.

By comparing the obtained battery discharging and energy consumption values shown in the graph, it becomes evident that the energy consumption reduces as the ambient temperature drops. As for the operational parameters of the battery electric heavy-duty truck, they exhibited a slight variation when considering the predefined ambient temperature ranges. The operational data obtained from the experimental test is summarized in Table 1.

<table>
<thead>
<tr>
<th>Temperature Condition</th>
<th>Battery Discharging [kWh/km]</th>
<th>Energy Consumption [kWh/km]</th>
<th>Average Vehicle Weight [kg]</th>
<th>Average Speed [km/h]</th>
<th>Stop Frequency [# / 100 km]</th>
<th>Ambient Temperature [ºC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very warm</td>
<td>1.49</td>
<td>1.06</td>
<td>16.33</td>
<td>16.26</td>
<td>243.43</td>
<td>27.60</td>
</tr>
<tr>
<td>Warm</td>
<td>1.42</td>
<td>1.01</td>
<td>16.82</td>
<td>15.42</td>
<td>238.48</td>
<td>23.20</td>
</tr>
<tr>
<td>Moderate-cold</td>
<td>1.37</td>
<td>0.98</td>
<td>16.21</td>
<td>15.55</td>
<td>236.96</td>
<td>17.50</td>
</tr>
<tr>
<td>Average</td>
<td>1.43</td>
<td>1.02</td>
<td>16.45</td>
<td>15.74</td>
<td>239.62</td>
<td>22.80</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.06</td>
<td>0.04</td>
<td>321.80</td>
<td>0.45</td>
<td>3.39</td>
<td>5.08</td>
</tr>
</tbody>
</table>

### 4.2 Energy regeneration

From the experimentally-obtained data, regeneration slightly reduces as ambient temperature drops. This behavior can be observed in the graph shown in Fig. 4. The experimental results, however, are insufficient to infer that the temperature variation has a decisive influence on the energy regeneration.

### 4.3 Energy consumption of auxiliary systems

The auxiliary systems consumed less energy in the moderate-cold temperature category, as shown in Fig. 5. The higher energy consumption could be verified in the warm temperature range, reaching 14.25% of the total energy discharging. Regarding the energy consumption of the consumers, Fig. 6 highlights
that 24 V consumers increased 29.24% from very warm to moderate-cold temperature ranges. Air supply has low consumption contribution, and the average from the three main consumers is 0.98%. For the other systems that mainly comprise cooling and heating system of the propulsion batteries and cab HVAC decreased 29.40% from very warm to moderate-cold temperature range. The reason for this pattern could be the fact that a milder temperature results in a reduction in energy consumption. Under this temperature range, energy consumption significantly drops due to a less intensive utilization of the cab HVAC, as well as the propulsion battery cooling and heating system.

### 4.4 Drivetrain energy consumption

Figure 7 shows that the energy supplied to the electric machine and mechanical parts gradually decreases with temperature dropping. The response for this behavior can be explained by the rain season most common in summer and, consequently, very warm weather conditions. Wet asphalt surface reduces tires grip leading to more work to be carried out to break the BET. The auxiliary brake on very warm weather conditions reached 40.69% of the total energy supplied to the drivetrain, while, in contrast, on moderate-cold weather conditions it was 38.65%, a decrease of 2.04%.

Both gearbox and rear axle mechanical losses increased 0.43% from very warm to moderate-cold weather conditions, being 9.95% on very warm and growing to 10.38% on moderate-cold. This loss increase can be in part due to internal worn and lubricant oil degradation. The road load that is the work to overcome air drag, rolling resistance and slope raised 1.60% on moderate-cold in comparison with very warm weather condition. It reached 49.68% of the energy supplied to drivetrain on very warm and for moderate-cold, the energy supplied reached 50.96%.

### 4.5 Energy recharging losses

The difference between the nominal energy supplied by the recharging unit and the effective charged energy was evaluated. Three types of recharging units were employed during the test: 30 kW, 40 kW, and a fast-charging unit of 150 kW, but with useful energy supply capacity of 130 kW, because of a limitation on the BET. Figure 8 shows the energy recharging losses observed for the three weather conditions; in average, the loss of energy was of 1.83%.

### 4.6 Cycled energy

It was not possible to measure the actual cycled energy loss capacity; for this reason, an estimative was determined. Per quarter, the BET was consuming an average of cycled energy of 4500 MWh, leading to 0.71% of estimated energy loss capacity. After a year in operation this would imply an estimated accumulated energy loss capacity of 2.85%. As previously mentioned, for automotive purpose, a vehicle's propulsion battery life time is currently used until this reaches from 70–80% depending on OEM, in other words, eight to ten years in operation until requiring to be replaced. According to this analysis, the measured BET’s propulsion battery system is performing in accordance the technical specification. In
Fig. 9, the trend line shows that in eight years of operation, considering the consumed cycled energy, 22.72% storage energy capacity would be lost.

4.7 Energy efficiency

Table 2 shows the energy efficiency for the three modes, propulsion, regeneration and cycling and it is possible to observe that on very warm weather conditions the efficiency drops. The best energy efficiency was reached on moderate-cold weather conditions. This can be attributed to milder temperatures, resulting in reduced energy consumption, leading to lower discharging energy, reduced energy usage for braking, and decreased consumption of auxiliary systems. Another important point found is that the regenerative mode is less efficient than propulsion mode. According to Grunditz & Thiringer (2016), the same efficiency trend was found comparing these two modes.

<table>
<thead>
<tr>
<th>Temperature Condition</th>
<th>Propulsion Mode</th>
<th>Regenerative Mode</th>
<th>Cycling Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very warm</td>
<td>93.75%</td>
<td>90.55%</td>
<td>84.90%</td>
</tr>
<tr>
<td>Warm</td>
<td>94.40%</td>
<td>90.84%</td>
<td>85.75%</td>
</tr>
<tr>
<td>Moderate-cold</td>
<td>94.61%</td>
<td>90.96%</td>
<td>86.06%</td>
</tr>
</tbody>
</table>

5. CONCLUDING REMARKS AND OUTLOOK

The objective of this research was to address a gap in the existing literature by examining seasonal energy efficiency, demonstrating variations in energy consumption and efficiency under actual operational conditions on specific routes within the São Paulo metropolitan area. Through this study, it was observed that very warm weather conditions led to higher energy discharges and consumption. In contrast, under moderate-cold conditions, EC was 7.31% lower compared to very warm conditions. The region where the battery electric truck operated is known for its relatively stable temperature range, however, this characteristic did not result in linear energy consumption.

The regeneration data revealed a decline during moderate-cold conditions, primarily attributed to reduced energy consumption. Additionally, the energy consumption of auxiliary systems showed a decrease from very warm to moderate-cold conditions, with air conditioning playing a significant role in this trend, as it operates less frequently in colder temperatures. Similarly, the energy directed towards the drivetrain also showed a decrease in moderate-cold conditions, with a notable 6.06% reduction compared to very warm conditions. Losses, on average, accounted for 10.21% of the total energy supplied to the drivetrain. Moreover, the projected cycling lifetime of the propulsion battery system was in accordance with the OEM specifications, showing an energy storage capacity loss of 22.72% after an eight-year period. The OEM specification stipulates a use lifetime limitation for automotive purpose of 70–80% of energy storage capacity within eight to ten years.
The efficiency calculations across the three operating modes presented a satisfactory outcome, being in average 94.25% for propulsion, 90.78% for regenerative and 85.57% for cycling. The results show that a BET can achieve approximately 50% greater efficiency compared to an ordinary diesel combustion engine vehicle, which typically achieves an efficiency of 35% (GUSTAFSSON and JOHANSSON, 2015). Thus, the BET performed satisfactory in the subjected operation, demonstrating a good performance to weather conditions found in the test region. Notably, in very warm weather conditions, there was an increase in EC directly attributed to air conditioning usage. As for EC, effective internal cab thermal insulation can mitigate the necessity for additional air conditioning power, thereby directly contributing to the reduction of EC. Also, the heavy rainfall during summer season in São Paulo metropolitan area influences EC. Consequently, the condition of the tires plays an important role and its maintenance is essential to provide the suitable rolling resistance, avoiding unnecessary EC. In summary, the BET proved to be well-suited to the operation and the prevailing conditions.

Regarding upcoming studies, the impact of off-road cases on energy efficiency could be explored, particularly in challenging operational scenarios such as construction, forestall, and agricultural sites. Understanding how different factors impact on EC in these situations could lead to more effective energy management strategies and specification suitability. In addition, the integration of other correlated technologies, such as solar panel systems on trucks combined with semi-trailers and trailers, could be the focus of further researches. These investigations could lead to advancements in energy-efficient transportation and contribute to environmental sustainability.

References


Figures
Figure 1

Energy flux diagram illustrating the energy path through the main components of an electric vehicle.
Figure 2
Operating region of the BET in the São Paulo metropolitan area for the purpose of the experimental study.

![Energy Discharging and Energy Consumption](image)

- Battery discharge [kWh/km]
- Energy consumption [kWh/km]

Figure 3
Experimental test outcomes for energy discharging and consumption considering the three predefined temperature ranges.

![Energy Regeneration](image)

- 30%
- 28.85%
- 28.79%
- 28.09%

- Very warm
- Warm
- Moderate-cold
Figure 4

Experimental results for energy regeneration considering the predefined temperature ranges.

![Energy Consumption of Auxiliary Systems]

Figure 5

Experimental outcomes for auxiliary systems energy consumption for the predefined temperature ranges.
Figure 6

Auxiliary systems consumers for the predefined temperature ranges.
Figure 7

Drivetrain consumers for the predefined temperature ranges.
Energy Recharging Losses

Figure 8

Energy recharging losses for the predefined temperature ranges.

Figure 9

Trend line of storage energy capacity loss