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Experimental Test Campaign on a Battery Electric Vehicle: On-Road Test Results (Part 2)

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ABSTRACT

The experimental measurement of the energy consumption and efficiency of Battery Electric Vehicles (BEVs) are key topics to determine their usability and performance in real-world conditions. This paper aims to present the results of a test campaign carried out on a BEV, representative of the most common technology available today on the market. The vehicle is a 5-seat car, equipped with an 80 kW synchronous electric motor powered by a 24 kWh Li-Ion battery. The description and discussion of the experimental results is split into 2 parts: Part 1 focuses on laboratory tests, whereas Part 2 focuses on the on-road tests.

As far as on-road tests are concerned, the vehicle has been tested over three different on-road routes, ranging from 60 to 90 km each, with a driving time ranging from approximately one and half to two and half hours. The routes have been designed to include different pathways (i.e. city driving, rural roads and highway), different vehicle speeds and road slopes that could be encountered in real-world driving. The influence of the driving modes of the vehicle (i.e. normal versus economic driving mode (ECO) drive) on the energy consumption and range has been also addressed. The results show that the energy consumption of the vehicle ranges from 111 to 148 Wh/km (i.e. equivalent gasoline consumption from 1.2 to 1.7 l/100km) in normal driving mode, depending on the route. The ECO driving mode shows lower energy consumption compared to the normal driving mode, with higher energy recuperation from regenerative braking. The driving range calculated with an abbreviated test approach goes from 139 to 185 km in normal driving mode, and up to 188 km for the ECO mode.

The paper provides the reader with a detailed description of the measurement equipment and setup adopted during the tests, setting the background for future technical analyses and experimental campaigns.

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INTRODUCTION

Determining the energy consumption and efficiency of Battery Electric Vehicles (BEVs) under different driving conditions is a key topic to understand the potential benefits of this technology in replacing conventional fuel vehicles. Although the conventional fuel vehicles have substantially increased their efficiency over the last decade [1], in order to reduce the dependency on oil and as well as pollutants and Greenhouse Gases (GHGs) emissions [2, 3], new low-carbon vehicles technologies (i.e. Hybrid Electric Vehicles, (HEVs), and BEVs) are constantly expanding their market shares.

HEVs technology basically aims to complement the combustion engine technology by means of energy recuperation and boosting and/or an alternative propulsion system based on an electric motor. In particular, the energy recuperation system recovers part of the kinetic energy which the vehicle dissipates during braking and deceleration driving phases. This energy is typically stored in a battery and then used to boost the vehicle during the accelerations and/or provide a short full-electric driving range to the vehicle. HEVs are typically equipped with a small sized battery and a small-to-medium sized electric motor, designed to support and/or replace combustion engine torque, especially at low rotational speeds, where the combustion engine is characterized by low fuel efficiency. Such technology can be arranged in many different configurations (i.e. micro, mild and full hybrid) according to the battery capacity and costs, the drivetrain architecture (i.e. serial/parallel/through-the-road hybrids) and the relative power of the electric motor with respect to the total power installed (i.e. Degree of Hybridization, DoH). Although HEVs technology enables to increase the overall efficiency of the vehicle, constituting a valuable technological step forward with respect to conventional fuel vehicles, this increase is not always linked to a decrease of gaseous emissions, as shown by the authors [4].

On the other hand BEVs constitute a paradigm shift compared to conventional fuel vehicles, although their popularity is still limited by their high purchase cost (mainly due to the cost of the battery) and the doubts of the consumers on their effective driving range and usability. Beyond these limitations, previous studies from the authors suggest that the relatively short range of the current generation of BEVs is not a strict limitation, and approximately one-fourth of the urban cars could be shifted from conventional fuel vehicles to BEVs [5] without any negative impact due to the shorter range. This share increases to approximately half of the fleet by accepting a very limited modal-shift [6]. These studies are based on a large-scale activity datasets acquired on conventional fuel vehicles from private citizens, and highlight that the actual potential of BEVs might go far beyond the common expectations. However they rely on the fine-tuning of the numerical models and, therefore, on an accurate experimental estimate of BEVs' energy consumption in real driving conditions.

The objective of this study is to provide the scientific community with the results of a test campaign carried out on a BEV. This vehicle is representative of the most common BEVs technology available on the market today. The tests have been carried out in the laboratories of the Joint Research Centre of the European Commission (JRC), in collaboration with the Italian National Agency for new Technologies, Energy and Sustainable Economic Development (ENEA). The test campaign is carried out in the frame of the pre-normative research activities of the JRC in support of the development of the type approval regulation, and consists of two parts: Laboratory Tests (i.e. Part 1) and On-road Tests (i.e. Part 2).

The laboratory tests are targeted to determine the energy consumption, energy efficiency and driving range over different driving cycles (i.e. NEDC [7, 8, 9, 10], WLTC, WMTC [11] and MAC [12]) and ambient conditions. Ambient temperatures of +25 °C and −7 °C are considered, as prescribed by the current type approval test procedures for passenger cars, and the tests are carried out with and without the Heating, Ventilation and Air-Conditioning (HVAC) system in operation (in cooling and heating mode), [13].

The on-road tests have the objective of determining the same parameters (i.e. energy consumption and range) over three different real-driving routes, ranging from 60 to 90 km each, with a driving time ranging approximately from one and half to two and half hours. The routes have been designed to include different pathways (i.e. city driving, rural driving and highway), and are partially based on the criteria established for the on-road emissions tests for conventional fuel vehicles with Portable Emissions Measurement System (PEMS), [14]. These include the full range of driving speeds which might be encountered in real-world driving, the effect of road slope and altitude variation, as well as the effect of the different driving modes (i.e. normal drive and ECO drive). The shares of the driving time during which the acceleration pedal position is above or equal to 40%, and of the share of driving distance during which the vehicle speed is above or equal 50 km/h, have been used to monitor the driving style aggressiveness, as per [15] and [16], setting the basis for future studies to define eco-driving rules and eco-indices, or correlating HEVs gaseous emissions to the driving style, [17, 18].

In order to measure the energy consumption, the vehicle has been instrumented with a data logger capable to monitor in real-time the energy flows from and to the different vehicle's sub-systems. A detailed description of this measurement system and its configuration layout is also provided.

These two parts of the test campaign allow a direct comparison of the results, in order to obtain a comprehensive overview of the energy consumption and driving range in type approval and real-driving test conditions for the tested vehicle. This will contribute to the correlation between type approval duty cycles and real-world driving cycles as well as to the evaluation of the impact of auxiliary systems on the driving energy consumption not prescribed by the current regulation.

EXPERIMENTAL SET-UP

Test Vehicle and Measurement Points

The BEV adopted for this study is a 5-seat car, with an empty weight of 1520 kg and powered with a 80 kW / 280 N·m synchronous electric motor in front-wheel driving configuration. The vehicle is equipped with a 96-cells Lithium-Ion battery, accounting for a 24 kWh nominal capacity and approximately 360 V nominal voltage. The vehicle's main characteristics are summarized in Table 1, while its schematic representation is provided in Figure 1. With reference to this figure the vehicle's main sub-systems are:

- Charger unit and AC/DC converter: it converts the 3.3/6.6 kW Alternating Current (AC) from the grid to Direct Current (DC) for the high-voltage battery. The current from the DC charging flows directly into the high-voltage battery;
- High-voltage battery: it is the main energy storage device of the vehicle;
- Inverter unit: it converts DC from the high-voltage battery to 3-phases AC for the Electric Motor (i.e. EM);
- DC/DC converter: it converts the DC from the high-voltage battery to low-voltage DC for the auxiliary systems (i.e. air-conditioning and cabin ventilation system, lights, wipers, etc.);
- Heater: a 5 kW DC resistance to heat-up the cabin, directly connected to the high-voltage battery.

Table 1. Test vehicle characteristics.

Architecture	BEV
Propulsion	Synchronous electric motor
Max. Power [kW]	80
Max. Torque [N·m]	280
Mass [kg]	1520
Battery	24 kWh – 96 Li-Ion cells 360 V (nominal voltage)

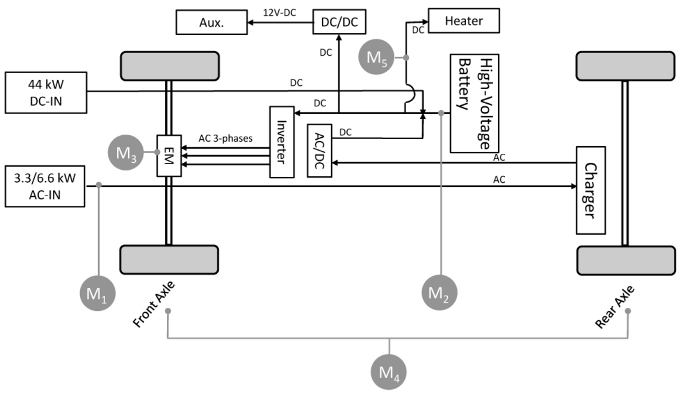

Figure 1. BEV schematic representation and measurement points (see Table 2).

Please note that the cooling system of the cabin is loaded on the low-voltage auxiliaries (i.e. downstream with respect to the DC/DC), whereas the heating system is directly loaded on the high-voltage battery.

All the sub-systems are inter-connected by several power lines. The schematic representation of Figure 1 reports the main power-line, each depicted with an arrow; single arrows refer to the mono-phase AC power lines (AC label), the low-voltage DC power lines (DC-12V label), and the high-voltage DC power lines (DC label). The three parallel arrows refer instead to the 3-phases AC power line (AC 3-phases label). The vehicle is also equipped with a 44 kW DC fast charging line. Gray circles in Figure 1 represent the measurement points on the vehicle used to monitor the energy flows, and used for the analyses reported in this article. A detailed description of these measurement points is provided in Table 2.

Table 2. Measurement points summary (see Figure 1).

Measurement point label	Description
M_1	Energy from the grid to the high-voltage battery [Wh]; (acquired directly on the recharging station)
M_2	Current [A] and Voltage [V], from the high-voltage battery feeding the inverter, the low-voltage auxiliary systems and the heating system → energy outflow from the battery to all subsystems [Wh]; (acquired both by CANbus and current clamp. Note that it can be also calculated by SOC scaling)
M_3	Rotational speed [rpm] and torque [N·m] of the electric motor → mechanical energy of the electric motor [Wh]; (acquired by CANbus)
M_4	Energy at the wheel [Wh]; (calculated by (1)).
M_5	Current [A] and Voltage [V], from the high-voltage battery to the heater → energy from the battery to the cabin heating system [Wh]; (acquired by current clamp)

The measurement at the stage M_1 is acquired directly on the 3.3/6.6 kW AC recharging station, by monitoring the electric energy required to recharge the battery. The measurement at the stages M_2 is acquired in double mode, i.e. via the vehicle CANbus and via a current clamp directly mounted on the battery output power-line. Additionally the energy outflow from the battery (i.e. M_2) can be also calculated by considering the SOC variation, scaled on the nominal capacity of the battery. The measurement at the stage M_3 is acquired only via CANbus, whereas the measurement at the stage M_5 is acquired only via current clamp. The energy at the wheel (i.e. stage M_4) is calculated by (1), according to the parameters reported in Table 3.

Table 3. Parameters to calculate the energy consumption at the wheel (i.e. measurement point M_4), according to (1).

Parameters	Description	Value
m_v	Vehicle mass: - Laboratory tests: = curb weight + driver (75 kg). - On-road tests: = curb weight + driver (75 kg) + one passenger (70 kg) + equipment (5 kg).	1595 [kg] 1670 [kg]
g	Gravity acceleration.	9.81 [m/sec^2]
μ	Road friction coefficient.	0.0127 (non-dim.)
ρ	Air density.	1.18 [kg/m^3]
c_x	Vehicle drag coefficient.	0.28 (non-dim.)
A	Vehicle front surface area.	2.27 [m^2]
α	Road slope angle.	Variable, [rad]
v_{wind}	Wind speed velocity	[m/sec]
sign	Sign function, it determines the sign of the algebraic sum $(v + v_{wind})$	(non-dim).

$$E_{wheel} = \int_{t_{in}}^{t_{fin}} \left[m_V a(t) + m_V \cdot g \cdot \sin(\alpha(t)) + \mu \cdot m_V \cdot g \cdot \cos(\alpha(t)) + sign(v(t) + v_{wind}(t)) \frac{\rho}{2} c_x A (v(t) + v_{wind}(t))^2 \right] \cdot v(t) dt \tag{1}$$

These parameters have been kept constant, regardless the change of the environmental conditions, such as ambient temperature, humidity and atmospheric pressure (e.g. variations due to the altitude during the on-road tests).

Please note that application of the formula (1) is particularly difficult for on-road tests, because of the inaccuracies in the real time measurement of the road slope angle α, the wind speed and the wind direction during the test. In particular the road slope angle has been derived from the altitude maps of the on-road routes, given the vehicle instantaneous position by GPS records, according to [19]. These values have been also integrated with GPS altitude measurements appropriately smoothed and processed, and a sensitivity technique analysis has been carried out to assess the effect of this smoothing on the derived road slope angle. The wind speed and direction during the on-road driving have been instead measured by an ultrasonic sensor (see *Measurement Equipment* section) and the recorded values have been submitted to a smoothing process too. Also the of the road friction coefficient was particularly difficult to quantify for the on-road tests, due to the changes in the road surface (i.e. inhomogeneous asphalt) and tire dynamic. Equations from the literature related to the wheel dynamic have been applied to perform a sensitivity study of these effects; however this represents only a simplified attempt to address these issues and dedicated future study are needed to improve the results to derive on-road efficiency.

The tested vehicle is three years old (i.e. registered in 2011 and tested in 2014), with a total mileage of approximately 5,000 kilometres. Therefore it is likely that its battery performance is slightly degraded by aging compared to a brand new vehicle. For example we noticed during our tests that the State-of-Charge (SOC) indicator at a CANbus level did not allow recharging above a variable threshold between 86% and 90% (upper bound) and discharging below 3% (lower bound). This has been also confirmed by battery energy-in measurements in M_2 (i.e. via vehicle CANbus) during overnight full recharge tests, which allowed an average value of recharge energy equal to 20.5 kWh (i.e. 85% of the nominal energy capacity). For this reason we have decided to use this value to scale the driving range test results, later referred as battery usable SOC.

Measurement Equipment

The measurement equipment installed on the vehicle consists of a data logger based on a modular chassis with 8 configurable slots (Figure 2, from label 4 to 11). Its operative temperature ranges from −40 to +70 °C, it is dust-proof and shock resistant, designed to be powered with 9-30 volts DC (i.e. Power-in label 1 in Figure 2) to be mounted on-board of the tested vehicle. It embeds a dual-core CPU plus a configurable FPGA chip. The data can be either stored on the embedded 1 GB non-volatile flash memory (expandable via USB-port) or downloaded via the Ethernet port (i.e. Output-port, label 2 in Figure 2). This port can be also used to configure the modules for live telemetry.

The structure of the data logger is:

- GPS, label 3 in Figure 2: serial port for GPS-receiver, it works with NMEA standard sentences, providing the system with: dynamic update of absolute UTM timestamp, absolute geographical position, vehicle speed related to ground, vehicle course related to North, signal quality and number of satellites.
- Power (V-in), labels 4 and 6 in Figure 2: two groups of 3 channels each with voltage input for single or three-phases power measurements. Voltage input up to 300 V rms, 24 bits, differential, simultaneous sampling, integrated anti-alias filters, 50 k-samples/second per channel, (i.e. bandwidth at 24.6 kHz).
- Power (I-in), labels 5 and 7 in Figure 2: two groups of 4 channels each with current input for single or three-phases power measurements. Current input up to 1600 A rms (with 1600:5 transformer), 24 bits, differential, simultaneous sampling, integrated anti-alias filters, 50 k-samples/second per channel, (i.e. bandwidth at 24.6 kHz).
- Analog-in, label 8 in Figure 2: 16 channels for analogic inputs at the voltage of ±10 V, 16 bits, differential, 250 k-samples/second multiplexed.
- Thermocouples, label 9 in Figure 2: 16 channels, 24 bits, integrated with a Cold Junction Compensation (CJC), supporting thermocouples of types J, K, T, E, N, B, R, S.
- Frequency-in, label 10 in Figure 2: 8 channels for frequency-dependent digital acquisition plus 32 channels for logical states. Switching speed at 7 μ-seconds, inputs voltage up to 24 V.
- CANbus-in label 11 in Figure 2: 2 independent CAN High Speed ports at 11 bits and 29 bits messages IDs, baud rate up to 1 Mbps, interfaced with the Electronic Control Unit (ECU) for both standard (i.e. DBC, OBD, FMS) and non-standard (i.e. editable) protocols.

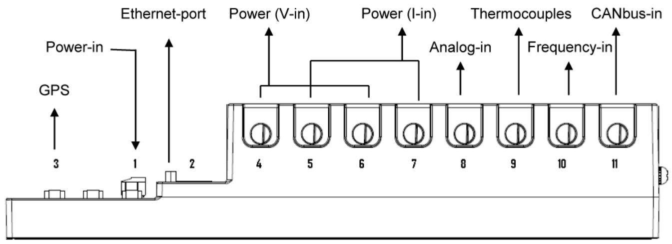

Figure 2. Schematic representation of the measurement system.

The data logger modules are based on standard components from [20] and assembled with a customized software interface from [21]. This interface is capable to perform live-data visualization, data synchronisation and remote storage as well as control the configuration of the system. The system has been configured for the present test campaign according to the measurement points described in Table 2.

The modules 4 to 7have been used for the inverter acquisition, (i.e. 3-phases voltages and currents acquired by means of current transformer); the module 6 for the recording of the AC recharging pilot signal [22,23]; the module 8 has been used for DC acquisition, (i.e. from and to the high-voltage battery and heater system acquired by means of current clamps based on Hall effect) plus ambient data acquisition from a sensors array mounted on the vehicle's roof. This array implements ambient temperature, pressure and relative humidity sensors, plus wind speed and wind direction ultrasonic sensors. Module 9 has been used for cabin thermal acquisition, according to the specifications described in the European MAC draft test procedure [12], while module 11 has been used for CANbus acquisition, integrated with a GPS antenna mounted on port 3. Please note that 3-phases voltages and currents measured at the inverter have not been used for deriving the results presented in this work.

On-Road Routes

Three on-road driving routes have been used in this study. They have been designed to include different pathways (i.e. city driving, extra-urban driving and highway), the full range of vehicle speeds which might be encountered in real-world driving, and different road conditions (i.e. uphill, downhill, flat terrain). The selected routes are partially based on the criteria established for on-road emissions tests for conventional fuel vehicles with Portable Emissions Measurement System (PEMS) [14].

The routes have been labeled Route 1, Route 2 and Route 3 and their details are reported in Appendix, in Figure 5-(a), (b) and (c) respectively. All routes begin and end at the **V**ehicle **E**mission **LA**boratories (**VELA**) of the Joint Research Centre of the European CoMission in Ispra (Italy), at the GPS latitude of 45.809870 deg north and GPS longitude of 8.628956 deg east from Greenwich (i.e. checkered flag in the GPS-traces figures). Each route has been repeated three times: twice in the normal driving mode and once in the ECO driving mode.

Route 1 is representative of an uphill and downhill extra-urban driving, characterized by a significant altitude variation (i.e. from approximately 220 to approximately 1150 meters above the sea level), and low driving speed (i.e. approximately 50 km/h). The route has been split into two phases: phase 1 (30.32 km, lasting for approximately 50 minutes) representative of the uphill part, and phase 2 (31.46 km, lasting for approximately 50 minutes) representative of the downhill part. These two phases are very different, and they have been designed to identify the different working modes of the electric motor, i.e. driving mode uphill and regenerative mode downhill.

Route 2 is representative of a mixed extra-urban and city driving. It has been split in two phases too, i.e. phase 1 (31.15 km, lasting for approximately 40 minutes) and phase 2 (32.91 km, lasting for approximately 60 minutes). Phase 1 is characterized by extra-urban driving (i.e. non congested roads with a driving speed between 50 and 70 km/h), whereas phase 2 is characterized by a short high-speed extra-urban road (i.e. driving speed peaked at 90 km/h), followed by approximately 15 minutes of city driving (i.e. driving speed below 50 km/h) and 40 minutes of extra-urban driving (i.e. driving speed between 50 and 70 km/h). Altitude varies between 220 meters (starting point) and 450 meters (city driving) above the sea level.

Route 3 is instead representative of mixed conditions: extra-urban driving, city driving and highway, split into 4 phases. The route has been designed to have approximately 1/3 of urban, 1/3 of extra-urban and 1/3 of highway path. Phase 1 (21.71 km, lasting for approximately 30 minutes) is characterized by extra-urban driving (i.e. non congested roads with a driving speed between 50 and 70 km/h). Phase 2 is characterized by three repetitions of an 8.40 km urban driving cycle, accounting for 25.2 km and approximately 80 minutes. This part takes place over congested city roads, with several traffic lights and a driving speed below 50 km/h. Phase 3 is characterized by a highway path, lasting for 34.21 km and 20 minutes, with a driving speed between 80 and 130 km/h, while phase 4 is again an extra-urban driving as per phase 1 (7.89 km lasting for approximately 15 minutes). As per route 2, the altitude varies between 220 meters (starting point) and 400 meters (city driving) above the sea level.

RESULTS

Energy Consumption Results

Table 4, Table 5 and Table 6 presents the results of the road tests, for Route 1, Route 2 and Route 3 respectively. Three tests have been performed for each route: two repetitions in normal driving mode (i.e. Normal 1st and 2nd, first two lines in each cell) and one repetition in ECO driving mode (ECO, third line in each cell, italic). According to the technical specification of the tested vehicle, the ECO mode imposes a partial cut-off of the power of the electric motor, in order to save energy.

All the on-road tests have been performed with the HVAC system switched-off, whereas the auxiliary systems imposed by law to drive on public roads (i.e. front lights and turn signals) have been used during the driving.

The tables report for each test a summary of the ambient conditions (i.e. ambient temperature and weather at the route starting point), while the time-dependent atmospheric pressure, ambient temperature and humidity and the battery 96-cells temperature range (acquired by the vehicle CANbus) are reported in appendix, from Figure 6, 7, Figure 8. It can be noticed that the battery cells temperature during these tests never goes higher than +36 °C. However, it depends on ambient temperature and driving load (e.g. it increases during the uphill part of Route 1 and highway part of Route 3).

The tables also summarize the length in km of the driving route and the main characteristic of its phases speed profile (i.e. uphill, downhill, urban, extra-urban, highway driving), as given above, together with the overall altitude variation, to evaluate its effect on the energy consumption.

For each route the table reports the energy consumption results calculated at the battery level (i.e. without considering the efficiency loss of the recharge) by the current and voltage at the battery outlet from the CANbus (i.e. M_2 according to Table 2), as per the laboratory tests. These values are given in Wh/km per route phase, as defined above, and combined for the entire route, per each test condition, i.e., normal driving 1st and 2nd, and ECO mode.

The distance specific energy consumption values have been converted to equivalent liters of gasoline per 100 km (i.e. liters/100km, see values in parenthesis), by applying the conversion suggested by the Environmental Protection Agency (EPA, [24]) as per (2). The energy content of the gasoline fuel has been assumed equal to 8.90 kWh/liter (i.e. 115 kbtu/gallon).

$$Consumption \ \frac{l}{100km} = Consumption \ \frac{Wh}{km} \cdot \frac{0.1123}{10} \tag{2}$$

The results show that the distance specific energy consumption significantly depends on the characteristics of the driving route (i.e. driving speed and slope profile). The values range from 111-130 Wh/km for Route 1 and 2 (combined results in normal driving mode), characterized by uphill/downhill phases and extra-urban driving, up to 148 Wh/km for Route 3, characterized by highway driving.

Table 4. Energy consumption results for Route 1.

Route 1	**Phase 1** Normal 1st Normal 2nd *Eco*	**Phase 2** Normal 1st Normal 2nd *Eco*	**Combined** Normal 1st Normal 2nd *Eco*
HVAC	OFF		
Weather Conditions	+25 ºC – Cloudy +27 ºC – Cloudy/Sunny *+30 ºC – Cloudy*		
Altitude variation	~ 930 m (i.e. from 220 to 1150 m).		
Driving Length [km]	~ 30.32 (uphill)	~ 31.46 (downhill)	~ 62
Energy Consumption [Wh/km] ([l/100 km])	262.0 (2.94) 252.6 (2.82) *253.4(2.85)*	2.6 (0.03) 2.2(0.02) *11.5 (0.13)*	129.8 (1.46) 122.7 (1.38) *118.5 (1.33)*
$E_{IN,BATT}$ [kWh]	-0.63 -0.67 *-0.83*	-2.95 -3.17 *-3.44*	-3.59 -3.83 *-4.27*
$E_{OUT,BATT}$ [kWh]	8.57 8.29 *8.51*	3.03 3.10 *3.08*	11.61 11.39 *11.59*
Rec. Ratio (Battery) [%]	7.4 8.1 *9.8*	97.3 102.2 *111.7*	30.9 33.7 *36.8*
Rec. Ratio (EM) [%]	10.6 10.7 *13.2*	135.0 130.9 *149.4*	42.4 43.1 *48.7*
Pedal position ≥ 40% [% of time]	0.6 0.2 *27.0*	0.003 0.0 *5.2*	0.3 0.09 *15.9*
Speed ≥ 50km/h [% of travelled distance]	19.9 27.8 *22.6*	24.6 22.3 *19.5*	22.3 25.0 *21.0*
Max. Speed [km/h]	63.3 62.0 *58.4*	61.6 62.8 *58.8*	63.3 62.8 *58.8*
Average Speed [km/h]	35.4 35.8 *33.4*	35 32.4 *33.4*	35.2 34.0 *33.4*

Table 5. Energy consumption results for Route 2.

Route 2	**Phase 1** Normal 1st Normal 2nd *Eco*	**Phase 2** Normal 1st Normal 2nd *Eco*	**Combined** Normal 1st Normal 2nd *Eco*
HVAC	OFF		
Weather Conditions	+21.5 ºC – Sunny +27.0 ºC – Cloudy *+28.0 ºC – Sunny*		
Altitude variation	~ 230 m (i.e. from 220 to 450 m).		
Driving Length [km]	31.15 extra-urban	32.91 urban and extra-urban	~ 64
Energy Consumption [Wh/km] ([l/100 km])	126.1 (1.42) 120.4 (1.23) *118.9 (1.94)*	101.8 (1.14) 101.3 (1.14) *99.5(1.12)*	113.6 (1.28) 110.6(1.24) *109.0 (1.22)*
$E_{IN,BATT}$ [kWh]	-1.03 -1.05 *-1.14*	-1.44 -1.64 *-1.81*	-2.47 -2.69 *-2.94*
$E_{OUT,BATT}$ [kWh]	4.95 4.79 *4.83*	4.78 4.97 *5.08*	9.73 9.75 *9.91*
Rec. Ratio (Battery) [%]	20.8 21.8 *23.5*	30.1 33.0 *35.6*	25.4 27.5 *29.7*
Rec. Ratio (EM) [%]	27.6 29.6 *31.7*	39.6 44.2 *47.7*	33.5 37.1 *39.9*
Pedal position ≥ 40% [% of time]	0.02 0.03 *17.6*	0.2 0.03 *14.1*	0.1 0.03 *15.6*
Speed ≥ 50km/h [% of travelled distance]	54.4 57.6 *61.9*	30.5 27.3 *39.5*	42.1 40.0 *50.2*
Max. Speed [km/h]	69.1 68.7 *69.8*	92.8 83.1 *84.2*	92.8 83.1 *84.2*
Average Speed [km/h]	43.8 41.5 *45.2*	34.2 32.7 *38.2*	38.4 36.5 *41.3*

Concerning Route 1, there is a large variation of the energy consumption between the phase values. In particular this route presents the highest consumption in phase 1, (uphill part), with more than 250 Wh/km. This value is approximately 100 times higher than the consumption in phase 2 (downhill part), which results to be mostly driven with the energy recuperated during the downhill coasting by the regenerative braking system. No major differences can be noticed between the normal and the ECO driving mode energy consumptions for phase 1, showing how the effect of the slope almost hides the driving mode of the vehicle. The ECO driving mode exhibits a lower combined consumption with respect to the normal driving modes.

Concerning Route 2, the energy consumptions in the two phases are different each other, with higher values for the first phase. Lower energy consumption is measured for the ECO mode.

Concerning Route 3, there are some differences in the energy consumption values between the phases, with the higher energy consumption in phases 1 (i.e. extra-urban driving) and 3 (i.e. highway driving), in both driving modes. Phase 4, driven over extra-urban roads in an area not affected by road congestion, exhibits lower energy consumption. However combined values suggest that Route 3 is more energy consuming than Route 1 and 2, having longer urban and high-speed highway driving. Also in this case the ECO driving mode exhibits a lower combined consumption with respect to the normal driving modes.

Table 6. Energy consumption results for Route 3.

Route 3	**Phase 1** Norm. 1st Norm. 2nd *Eco*	**Phase 2** Norm. 1st Norm. 2nd *Eco*	**Phase 3** Norm. 1st Norm. 2nd *Eco*	**Phase 4** Norm. 1st Norm. 2nd *Eco*	**Combined** Norm. 1st Norm. 2nd *Eco*
HVAC	OFF				
Weather Conditions	+19.0 ºC – Cloudy +23.0 ºC – Sunny *+23.5 ºC – Sunny*				
Altitude variation	~ 180 m (i.e. from 220 to 400 m).				
Driving Length [km]	21.71 extra-urban	8.40 x 3 urban (3 cycles)	34.21 highway	7.89 extra-urban	~ 91
Energy Cons. [Wh/km] ([l/100 km])	161.3 (1.81) 159.1 (1.79) *158.3* *(1.78)*	136.0 1.53) 117.3 (1.32) *116.8* *(1.31)*	158.4 (1.78) 155.4 (1.74) *148.1* *(1.66)*	99.5 (1.12) 85.4 (0.96) *86.9* *(0.98)*	147.5 (1.66) 139.3 (1.56) *138.8* *(1.50)*
$E_{IN,BATT}$ [kWh]	-0.6 -0.7 *-0.7*	-1.6 -1.6 *-1.7*	-0.8 -0.9 *-0.9*	-0.6 -0.6 *-0.9*	-3.6 -3.8 *-4.2*
$E_{OUT,BATT}$ [kWh]	4.1 4.2 *4.1*	5.0 4.6 *4.6*	6.2 6.2 *5.9*	1.4 1.3 *1.3*	16.7 16.1 *16.0*
Rec. Ratio (Battery) [%]	14.7 17.0 *16.5*	31.7 35.1 *36.4*	13.5 14.5 *14.8*	42.5 45.9 *68.0*	21.6 23.3 *26.0*
Rec. Ratio (EM) [%]	20.4 22.3 *20.6*	43.8 46.1 *48.8*	17.9 18.7 *20.1*	54.9 58.0 *63.0*	29.1 30.3 *32.0*
Pedal position ≥ 40% [% of time]	0.1 0.5 *20.0*	0.1 0.03 *7.6*	3.5 5.4 *42.5*	0.6 1.4 *17.2*	0.8 1.3 *13.9*
Speed ≥ 50km/h [% of travelled distance]	51.9 52.5 *54.2*	4.5 1.9 *6.0*	94.9 93.6 *96.3*	47.7 36.8 *53.4*	54.6 52.5 *56.4*
Max. Speed [km/h]	69.7 74.0 *74.8*	56.0 53.8 *59.5*	125.9 125.2 *124.0*	69.8 68.0 *73.6*	125.9 125.2 *124.0*
Average Speed [km/h]	38.9 41.4 *39.3*	19.3 19.9 *20.9*	73.0 73.3 *69.6*	32.3 30.9 *30.1*	34.5 35.4 *35.4*

Looking at the comparison between the normal and the ECO driving modes in more detail, the latter is always less energy consuming. In particular by comparing the energy consumption of the ECO mode with the average values between the two repetitions of the normal mode, we find combined energy consumption lower than 6.6% for Route 1, 2.8% for Route 2 and 3.3% for Route 3. The higher reduction is visible in the phase 1 for Route 2 (extra-urban driving), and phase 3 for Route 3 (highway driving). However, as mentioned above, these results might be affected by specific driving conditions met during the day of the tests, and in particular we can mention that Route-3 ECO test was affected by particular traffic conditions during the urban phase, responsible of test duration 20 minutes longer that the normal mode driving tests.

The cumulative energy consumptions in [kWh] during the routes are reported in appendix, from Figure 6, 7, Figure 8. These plots show the lower energy consumption for the ECO driving mode in respect to the normal modes.

In order to provide more detailed information on the tests, Table 4, 5 and 6 report a number of additional results:

- $E_{IN/OUT,BATT}$ and Rec. Ratio (Battery): battery energy inflow (negative) and outflow (positive), in [kWh] (measured by CANbus current and voltage reading, i.e. measurement point M_2) and their ratio in [%]. They represent the energy that is recuperated at the battery level, and it is lower than the ratio at the engine level because it accounts for the losses between the battery and the electric motor (i.e. power lines and inverter);
- Rec. Ratio (EM): electric motor recuperated energy divided by the electric motor driving energy, in [%]. It represents the energy that is recuperated at the electric motor level;
- Pedal position: it gives the share of driving time in [%] during which the acceleration pedal position is above or equal 40%, according to [15]. Note that 0% represents no acceleration, and 100% full acceleration;
- Speed ≥ 50 km/h: it gives the share of driving distance in [%] during which the vehicle speed is above or equal 50 km/h, according to [16];
- Max. speed and average speed in [km/h], to better characterize the driving route and its overall energy consumption.

The recuperation ratio at the electric motor level (i.e. Rec. Ratio (EM)) results to be between 29% and 43% for the normal driving mode (combined results), with a tendency to increase for the ECO driving mode to 32% and 49%. In particular it varies between 42% and 49% for Route 1, between 34% and 40% for Route 2 and between 29% and 32% for Route 3, exhibiting a dependence on the driving route. Higher values are found for the Route 1 with the higher slope variation in the driving route and in Route 2, mixed extra-urban and urban driving. Route 3 has the lowest recuperation ratio among the three routes considered. By analyzing the phases' values, the energy recuperation for the downhill part of Route 1 is higher than that of the uphill part, while for Route 3 higher values of recuperation are found for the fourth phase (i.e. extra-urban driving) and second phase (i.e. urban driving) rather than the third phase (i.e. highway driving). This suggests that high speed driving is characterized by fewer deceleration and braking phases, allowing for less recuperation.

Similar considerations are also valid at the battery level (i.e. Rec. Ratio (Battery)), although the values are scaled down of about one-third to account for the losses between the battery and the electric motor (i.e. i.e. power lines and inverter). Observing the absolute values of the energy at the battery level (i.e. $E_{IN/OUT,BATT}$) for Route 1, we can notice that $E_{OUT,BATT}$ is almost the same for all driving modes (i.e. from 11.4 to 11.6 kWh), while $E_{IN,BATT}$ increases from approximately 3.7 kWh (average value between the two normal driving repetitions) to 4.3 kWh (ECO driving mode). Similar results can be found also for Route 2 and Route 3, with lower increase of $E_{IN,BATT}$ between the two driving mode for Route 2.

The distance specific energy consumption results are also reported in Figure 3, versus the share of driving time during which the acceleration pedal is above or equal to 40% and in Figure 4 versus the share of driving distance during which the vehicle speed is above or equal 50 km/h. Tables 4, 5 and 6 also report these values for the single phases.

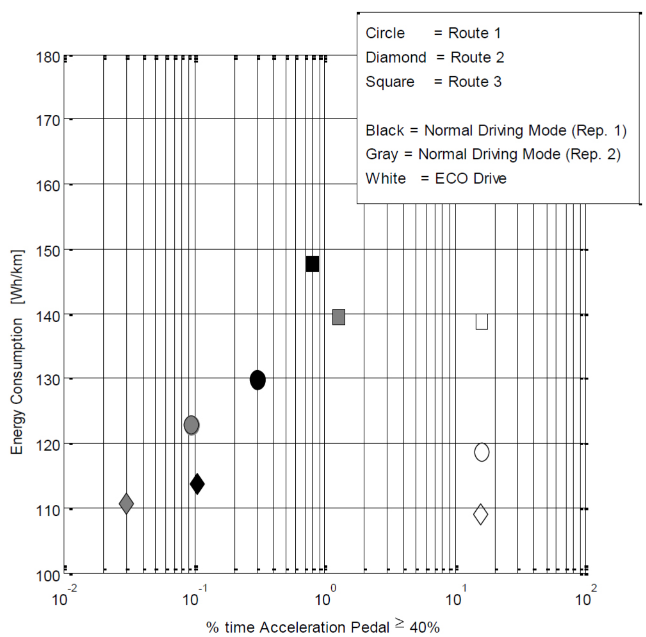

Figure 3. Distance specific energy consumption in Wh/km versus the share of driving time during which the acceleration pedal is above or equal to 40% (for the two repetitions in normal driving mode and ECO mode).

From these figures the energy saving from the ECO driving is immediately visible, together with the higher percentage of time with acceleration pedal position higher than 40% while driving in ECO mode. This means that the driver has to press more the acceleration pedal in ECO mode rather than in normal mode for the same route. By considering that the acceleration pedal position is significantly higher in the ECO mode tests compared to normal driving, it can be assumed that the ECO driving mode works both cutting off the electric motor's response to the pedal as well as enhancing the regenerative braking and preventing heavy braking. These two combined effects lead to a higher recuperation, and hence to a lower overall energy consumption.

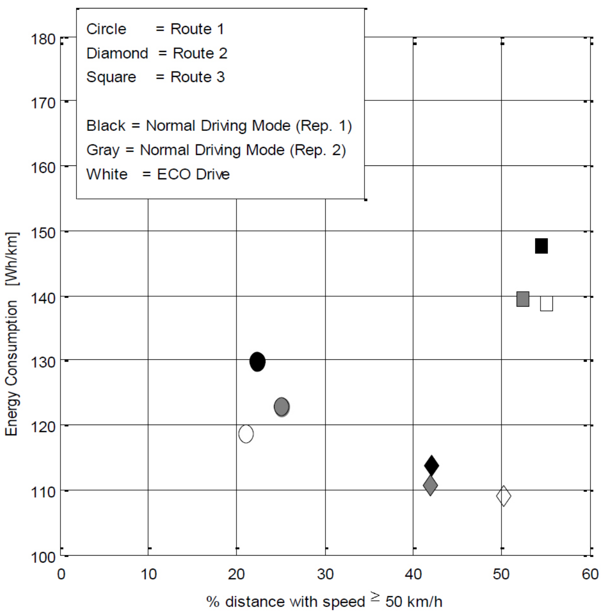

Figure 4. Distance specific energy consumption in Wh/km versus the share of driving distance during which the vehicle speed is above or equal 50 km/h (for the two repetitions in normal driving mode and ECO mode).

This effect is further highlighted in Figure 9 in appendix, where the speed of the vehicle, the acceleration pedal position in [%] and the EM instantaneous power are reported for Route 3 (normal driving mode 1st repetition compared with ECO driving mode). It can be noticed how the position of the acceleration pedal is significantly higher in ECO driving mode than in normal driving mode during comparable phases of the driving route. Similarly this is also valid for Route 1 and Route 2.

A dedicated study on the pedal position (both acceleration and braking pedals) has not been carried out in this experimental campaign. However, some information about the recuperation by coasting and braking can be derived from Figure 9 (and similar for the other routes, not reported here for brevity of the text) and Figure 10 in appendix, where the cloud plots of the EM power versus the acceleration pedal position are reported. Each dot represents an acquisition point; black and blue dots refer to the normal driving mode (i.e. first and second repetition, respectively), whereas gray dots refer to the ECO driving mode. For Route 1 and 2 it can be clearly distinguished the difference of the acceleration pedal response patterns between the two modes. Route 3 exhibits instead a spread pattern in ECO mode, probably due to the higher variation of the vehicle speed profile in this route than in the other two, together with the EM power upper cut-off at 55 kW. The recuperation by coasting depends on the vehicle speed and different threshold acceleration pedal positions exist after which the recuperation phase starts. Considering Route 3, it is observed that a higher recuperation by coasting corresponds to a threshold pedal position of approximately 30-37% for a vehicle speed of about 60 km/h (below this value lower recuperation occurs), whereas it corresponds to a lower pedal position (i.e. approximately 10-15%) at higher driving speed (approximately 100 km/h). Additionally we observed that In ECO mode the recuperation by coasting is higher than the recuperation by braking. However, these correlations appear to depend on the route characteristic such as road slope and further analyses are needed to derive conclusion.

Table 7 reports a sensitivity analysis of the battery energy outflow measurements. As reported above the distance specific energy consumption values reported in Tables 4, 5 and 6 are calculated by the current and voltage at the battery outlet from CANbus. These values might be also calculated by means of CANbus SOC scaling (referring to the nominal battery capacity of 24 kWh) and by means of DC measurement via a current clamp (Hall effect clamps, see *Measurement equipment* section). These approaches constitute separate measurements of the energy inflow and outflow of the battery, providing an indication on the sensitivity of the accuracy of the energy consumption results. Table 7 shows the percentage deviation of the combined consumption by SOC scaling and by clamp measurement with respect to the values reported in Tables 4, 5 and 6 by CANbus measurements. This analysis shows the poor correlation of these measurements, especially for Route 2 and 3, characterized by higher driving speeds (i.e. higher current values), and longer driving time. As far as the SOC scaling is concerned, the deviation can be explained with possible inaccuracies in the SOC calculation algorithm implemented in the vehicle CANbus, whereas as far as the DC clamp measurement is concerned, this deviation can be partially explained by a drift of the instrument (i.e. this drift has been noticed to increase over time, since the clamp zero needs a periodical reset). This drift has been monitored during the test and it is a variable value approximately between 0 and 2 amperes. The SOC scaling measurements are also affected by a different deviation depending on the route. The energy consumptions as derived by the other two approaches are reported in Appendix in Tables 9 and 10.

Table 7. Battery energy outflow measurements: sensitivity analysis

	Route 1		Route 2		Route 3	
	SOC	Clamp	SOC	Clamp	SOC	Clamp
Normal Mode 1st	8.1%	2.1%	28.1%	3.3%	16.5%	-11.2%
Normal Mode 2nd	18.2%	7.0%	22.3%	7.3%	17.7%	13.7%
Eco Mode	11.4%	1.5%	2.3%	1.0%	19.5%	6.3%

Driving Range Results

Among the topics discussed within the scientific community on the BEVs testing, the driving range test plays a fundamental role. As described in Part 1 [13], the current type approval range test consists in driving the type approval cycle in sequence, up to when the vehicle is not capable to follow the duty cycle for 5 seconds. This test is designed to be carried out in the laboratory and typically takes some hours. A proposed way to estimate the driving range consists in the abbreviated test [25, 26]. One possible approach for abbreviated tests consists in applying the formula (3) considering a limited number of driving cycles:

$$Range = \frac{C}{E} D \tag{3}$$

where C is the usable battery capacity, E is the energy consumption during the test measured at the battery level (measured at the battery level, i.e. without considering the grid-to-battery efficiency), and D the distance travelled during the test. This formula allows estimating the range of the vehicle by simply scaling-up the energy demand related to a certain driving distance to the full energy capacity of the battery. It has been applied to the distance specific energy consumption values reported in Tables 4, 5 and 6, and the results are reported in Table 8.

Table 8. Abbreviated driving range test results

ABBREVIATED RANGE TEST	Route 1 [km]	Route 2 [km]	Route 3 [km]
Normal driving mode (1st rep.)	157.9	180.5	139.0
Normal driving mode (2nd rep.)	167.1	185.4	147.2
ECO driving mode	173.0	188.1	147.7

They show that the driving range varies between 139 and 185 km, depending on the route (normal driving mode). Lower range is derived for Route 3 characterized by higher driving speed and consumption. Driving in the ECO mode is possible to achieve a range up to 188 km, underlining that the driving mode selection has a direct influence on the vehicle range. In particular this mode allows higher driving range than the normal one, achieving a range increase of 1.5% and 4% for Route 1 and 2 respectively respect the mean value between the two normal driving results. The slope of the road, i.e. uphill part of Route 1, does not seem to affect the driving range, being balanced by the downhill part.

Comparison of the Laboratory Test Results with On-Road Test Results

The two parts of the present work (i.e. Part-1: Laboratory Tests and Part-2: On-road Tests) have been designed to allow a direct comparison of the results, in order to obtain a comprehensive overview of the energy consumption and driving range in type approval and real-driving test conditions for the tested BEV. This will contribute to the correlation between type approval duty cycles and real-world driving cycles as well as to the evaluation of the impact of auxiliary systems on the driving energy consumption not prescribed by the current regulation.

By comparing the distance specific energy consumption results, we derive that combined laboratory test results (at +25 °C and with the HVAC system switched-off) ranges from approximately 157 to 183 Wh/km, whereas on-road tests (performed at an ambient temperature from +21 °C to +30 °C and with the HVAC system switched-off) ranges from approximately 111 to 148 Wh/km in normal driving mode and from 109 to 139 Wh/km in economic driving mode (i.e. ECO).

By comparing the low-to-medium speed phases of the laboratory test cycles (i.e. phase 1 for the NEDC, and phases 1 and 2 for the WLTC and WMTC) with similar phases from on-road tests (i.e. phases 1 and 2 for Route 2, and phases 1, 2 and 4 for Route 3), we observe that the energy consumption from laboratory tests ranges from 144 to 174 Wh/km, whereas the energy consumption from on-road tests ranges from 85 to 161 Wh/km. Instead high-speed phases (i.e. phases 3 and 4 for WLTC, phase 3 for WMTC and phase 3 for Route 3) show energy consumption from 163 to 202 Wh/km for laboratory tests and from 155 to 158Wh/km for on-road tests.

From the results on the BEV tested we can derive that on-road tests exhibit a larger variation of energy consumption values compared to laboratory tests for low-to-medium speed phases, whereas we find the opposite trend for high-speed phases. Combined data show that laboratory test results are in line with on-road test results, with a slight tendency to provide higher consumption values (especially when compared with ECO driving mode). Therefore it is possible to conclude that the type approval test cycles are representative of the real-driving energy consumption for the tested BEV.

A similar conclusion might be drawn by looking at the one-cycle approach driving range estimate, which provides a value from 73.7 to 130.7 km for laboratory tests (at +25 °C and with the HVAC system switched-off) and from 139 to 185 km for the on-road tests (normal driving mode), showing a shorter range from the type approval tests. ECO driving mode on-road tests exhibit a range slightly higher compared to the normal driving mode, i.e. up to 188 km.

The comparison between the recuperation ratio from laboratory tests and on-road tests, at both battery and EM level, highlights higher values for on-road tests. This can be ascribed to the uncontrolled speed profile and slope variation of the on-road routes, with respect to the type approval test cycles.

Different conclusions might be derived by looking at the laboratory test results with cold ambient temperature or with the HVAC systems switched-on, as well as by looking at the on-road test results from Route 1 (uphill and downhill driving paths). Although these tests are not comparable with each other, they suggest how BEV's energy consumption might be significantly affected by ambient temperatures, auxiliaries' load and altitude's variation, elements not considered in the type approval regulation.

CONCLUSIONS

This paper describes the results of a test campaign carried out on a BEV, equipped with an 80 kW synchronous electric motor powered by a 24 kWh Li-Ion battery package. The test campaign includes both laboratory tests (Part-1) and on-road tests (Part-2) and this paper discuss the results from the Part-2.

As far as the on-road tests are concerned, the vehicle has been tested over three different routes with different speed profiles, i.e., road type proportion (urban, extra-urban, highway) and slopes of the road.

To further investigate the effect of the different driving modes on the consumption the same route has been driven both with normal and ECO mode driving, selectable on the vehicle. The vehicle has been equipped with a programmable portable data logger capable to store and synchronize data from the vehicle's CANbus, GPS acquisitions, voltages and current clamps measurements, thermocouples measurement and ambient data. A detailed description of the measurement points and systems is provided.

The results show that the distance specific energy consumption of the vehicle ranges from 111 to 130 Wh/km for Route 1 and 2, up to 148 Wh/km for Route 3 (i.e. equivalent gasoline consumption from 1.2 to 1.7 l/100km). Route 1 presents higher energy consumption in the first phase, i.e. uphill, in comparison to the second phase, i.e. downhill, mostly driven with the recuperated energy, while Route 3 presents the highest energy consumption during phase 1, i.e. extra-urban driving and 3 (i.e. highway driving). Looking at the ECO driving mode, its energy consumption is generally lower than normal driving mode, of approximately 6.1% for Route 1, 2.8% for Route 2 and 4.3% for Route 3.

The recuperation ratio at the electric motor level sets between 29% and 43% in normal driving mode, with a tendency to increase for the ECO driving conditions, setting between 32% and 49%. The driving range calculated with the abbreviated approach results to be between 139 and 185 km in normal driving mode. ECO driving mode allows to higher driving range, up to 188 km.

The on-road test results have been compared with the laboratory test results, deriving that on-road tests exhibit a larger variation of energy consumption values compared to laboratory tests for low-to-medium speed phases, whereas we find the opposite trend for high-speed phases. Combined data show that laboratory test results are in line with on-road test results, with a slight tendency to provide higher consumption values, and it is possible to conclude that the type approval test cycles are representative of the real-driving energy consumption for the tested BEV.

The paper aims to provide the scientific community with experimental data to support the pre-normative research and type approval test definition for BEVs, as well as to support the calibration of BEVs' simulation models. The work aims to set the background for future technical analyses and testing activities in the fields of electric vehicles.

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DEFINITIONS/ABBREVIATIONS

AC - Alternating Current

BEV - Battery EV

CJT - Cold Junction Compensation

CPU - Central Processing Unit

DC - Direct Current

DoH - Degree of Hybridization

ECO - ECOnomic driving mode

EM - Electric Motor

FPGA - Field Programmable Gate Array

GHG - Greenhouse Gas

LDV - Light Duty Vehicle

HEV - Hybrid EV

MAC - Mobile Air-Conditioning

NEDC - New European Driving Cycle

NMEA - National Marine Electronics Association

PEMS - Portable Emissions Measurement System

SOC - State of Charge

TTW - Tank-To-Wheel

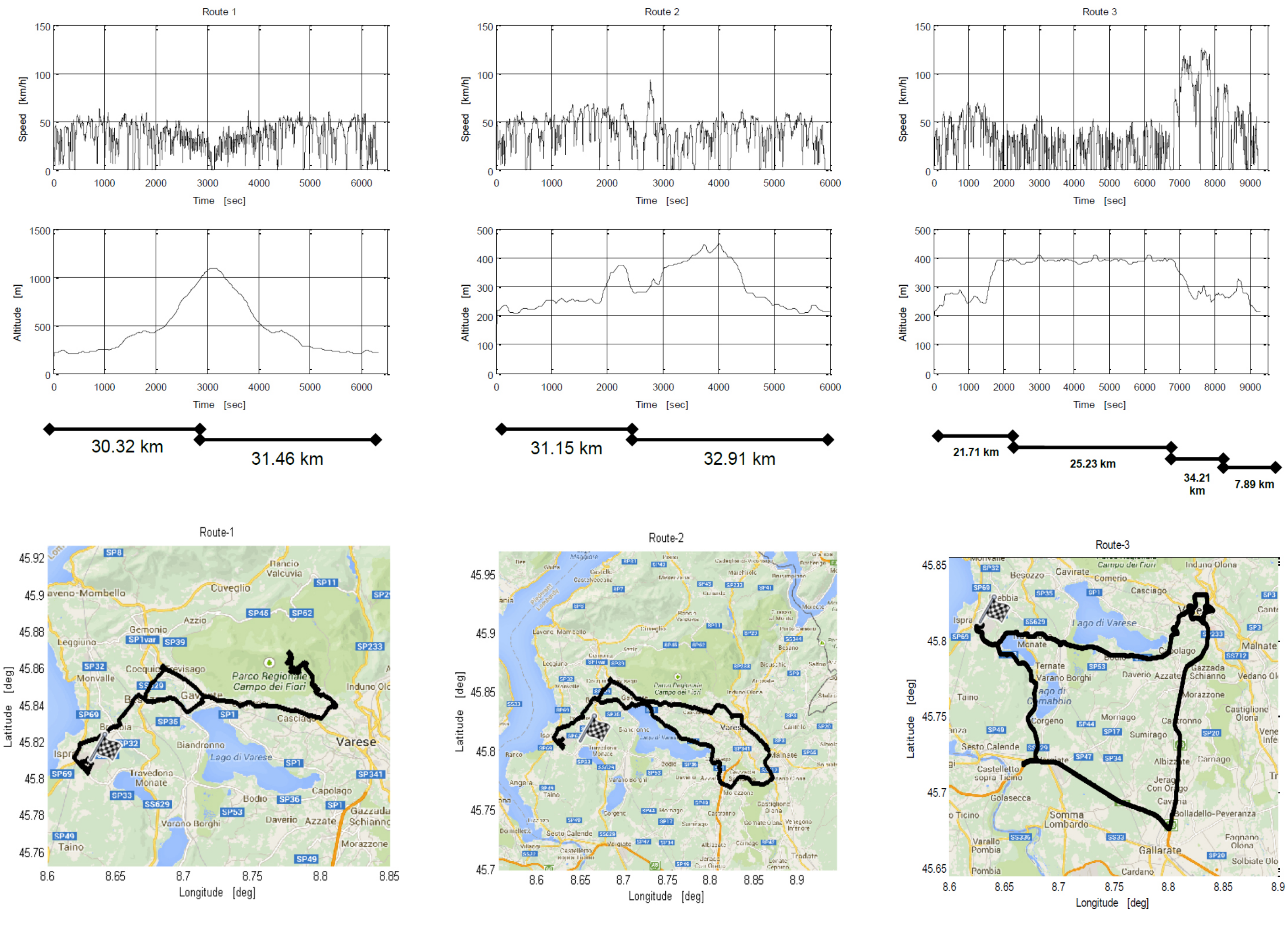
UNECE - United Nation Economic Commission for Europe

UTM - Universal Transverse Mercator

WLTC - World-wide harmonized Light vehicles Test Cycle

WMTC - World-wide Motorcycle emission Test Cycle

APPENDIX



(a) (b) (c)

Figure 5. On-road routes: velocity profile [km/h], altitude profile [m], driving phases and GPS track for Route-1 (a), Route-2 (b) and Route 3 (c).

Route-1

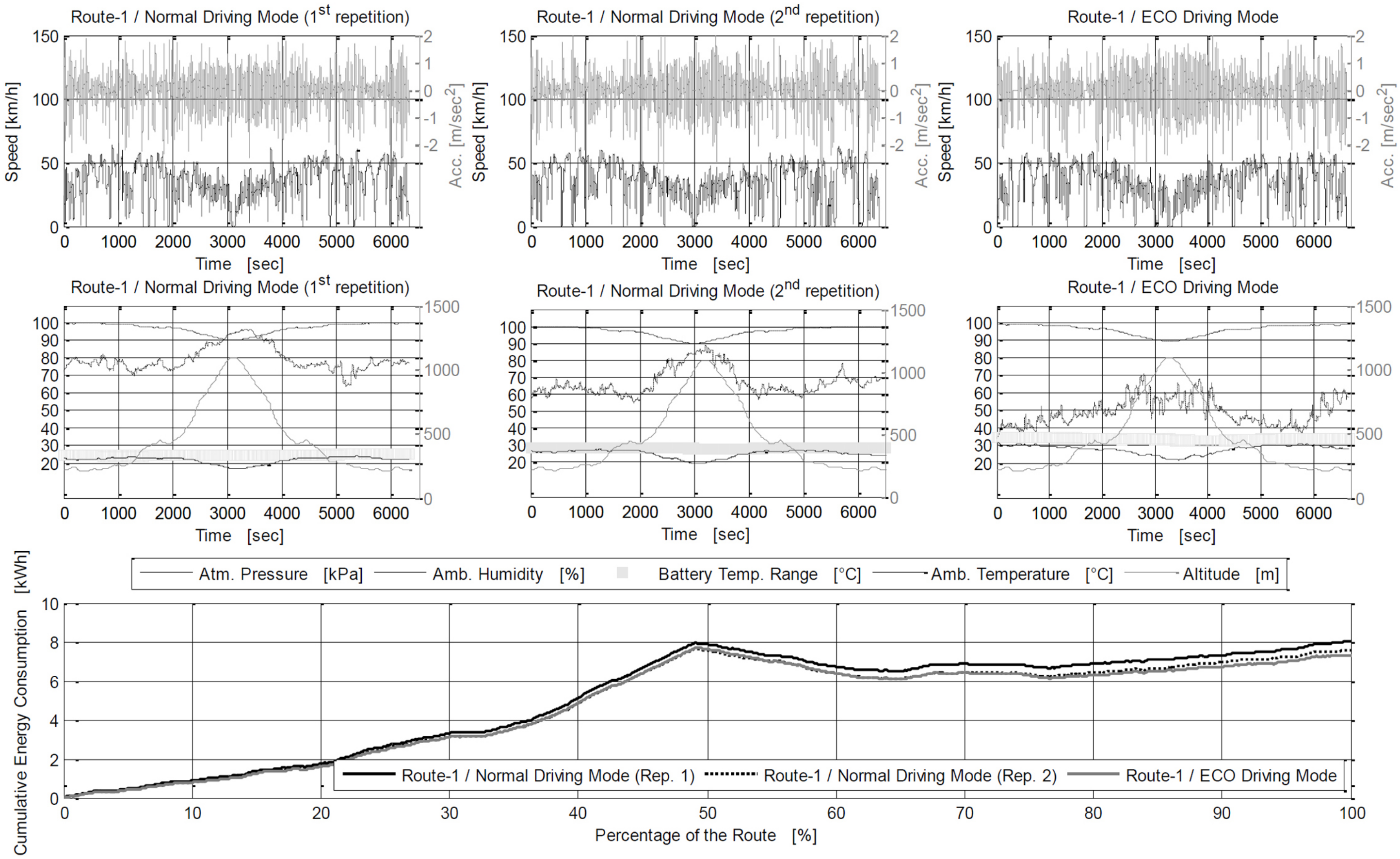


Figure 6. Route-1, summary of results. Speed and acceleration during the test, environmental conditions, range of variation (maximum and minimum) of the temperature of the battery cells and cumulative energy consumption in [kWh] during the tests.

Route-2

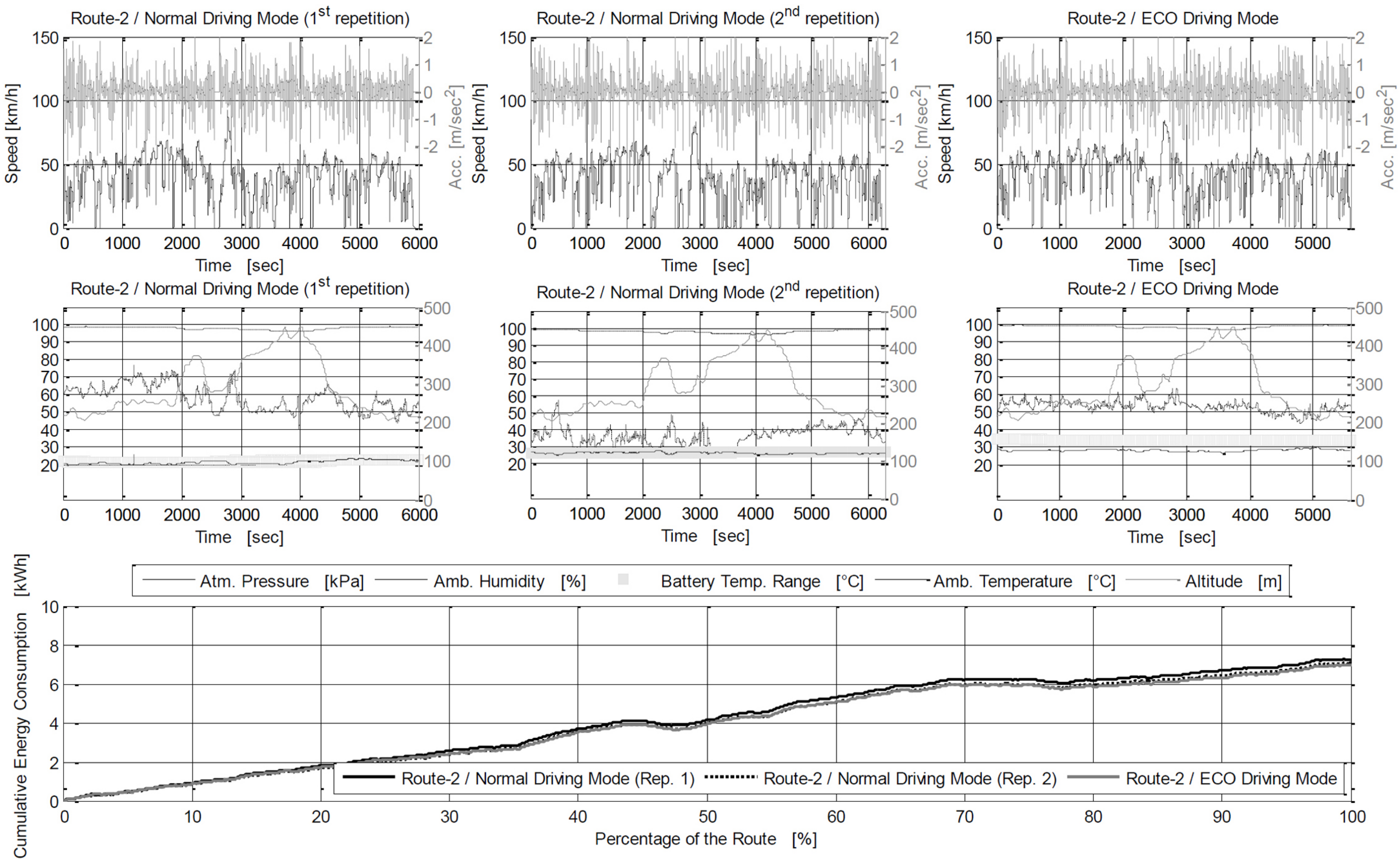


Figure 7. Route-2, summary of results. Speed and acceleration during the test, environmental conditions, range of variation (maximum and minimum) of the temperature of the battery cells and cumulative energy consumption in [kWh] during the tests.

Route-3

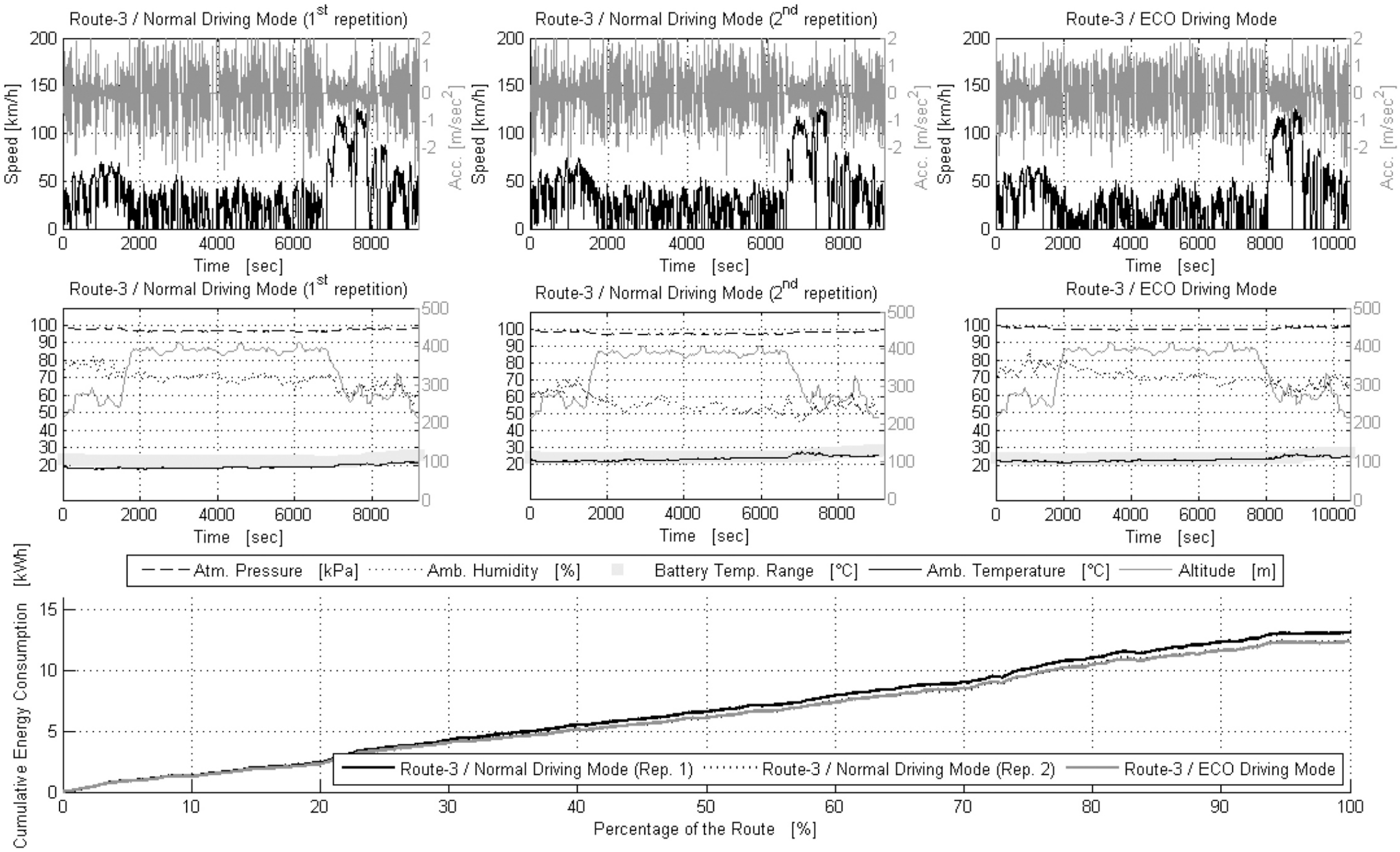


Figure 8. Route-3, summary of results. Speed and acceleration during the test, environmental conditions, range of variation (maximum and minimum) of the temperature of the battery cells and cumulative energy consumption in [kWh] during the tests

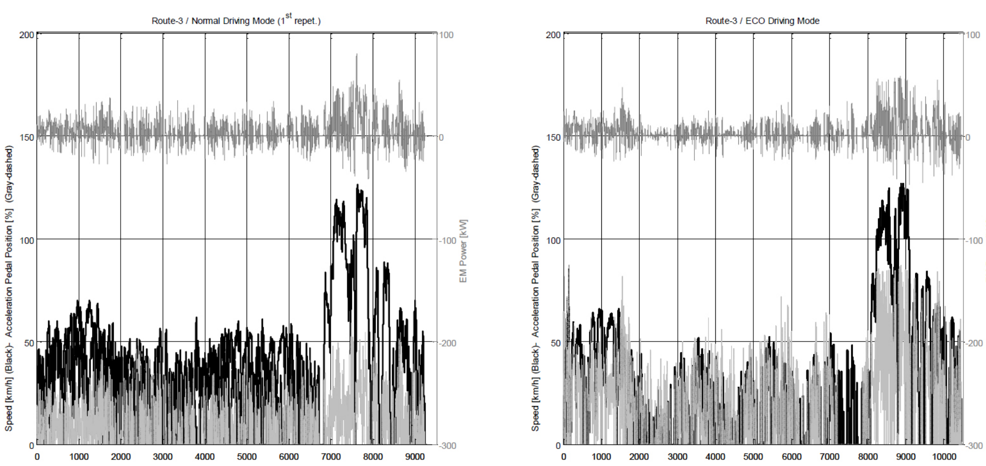


Figure 9. Speed of the vehicle (black), acceleration pedal position (light gray-dashed) and EM instantaneous power (gray). Comparison between the Route 3, normal driving mode (1st repetition) and the ECO mode.

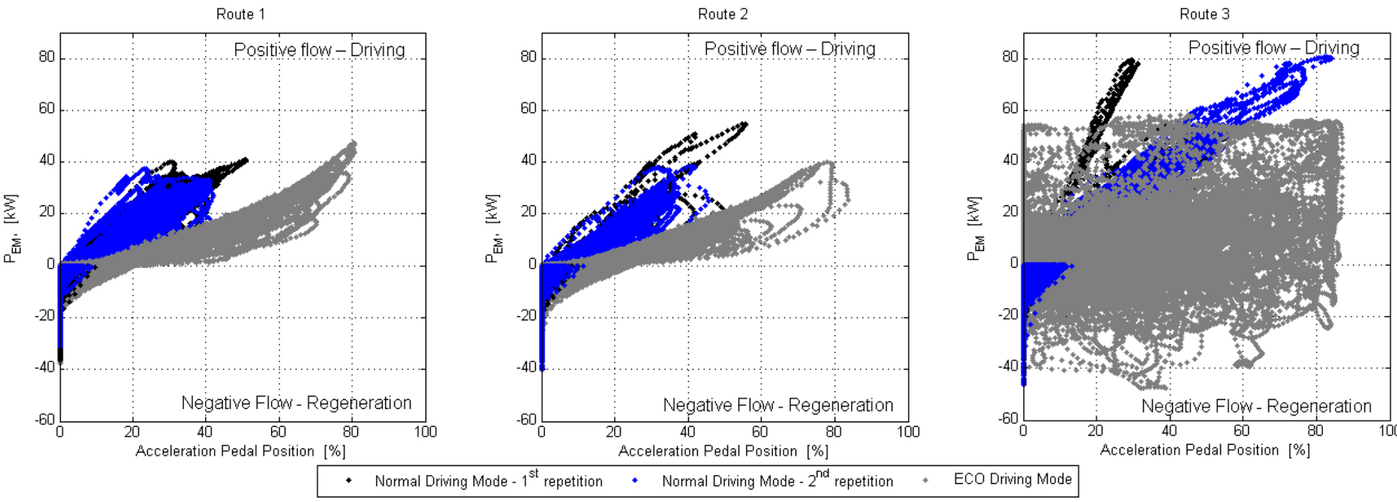


Figure 10. Electric motor power versus acceleration pedal position for the three routes. Normal driving mode (black and blue dots, first and second repetition respectively) and ECO driving mode (gray dots).

Table 9. Energy consumption results using the SOC variation values.

Energy Consumption (SOC variation from CANbus) [Wh/km] ([l/100 km])					
HVAC	OFF				
	Phase 1 Normal 1st Normal 2nd *Eco*	**Phase 2** Normal 1st Normal 2nd *Eco*	**Phase 3** Norm. 1st Norm. 2nd *Eco*	**Phase 4** Norm. 1st Norm. 2nd *Eco*	**Combined** Normal 1st Normal 2nd *Eco*
Route 1	276.8 (3.1) 276.1 (3.1) *273.0 (3.1)*	8.9 (0.1) 18.0 (0.2) *3.7 (0.04)*	-	-	140.4 (1.6) 145.0 (1.6) *132.1 (1.5)*
Route 2	126.6 (1.4) 167.4 (1.9) *91.2 (1.0)*	163.5 (1.8) 104.9 (1.2) *130.6 (1.5)*	-	-	145.6 (1.6) 135.3 (1.5) *111.5 (1.3)*
Route 3	161.1 (1.8) 156.8 (1.8) *158.9 (1.8)*	208.3 (2.3) 197.2 (2.2) *195.3 (2.2)*	167.6 (1.9) 161.4 (1.8) *164.2 (1.8)*	104.0 (1.2) 89.1 (1.0) *98 (1.1)*	171.9 (1.9) 164.0 (1.8) *165.8 (1.9)*

Table 10. Energy consumption results using the battery current clamp values.

Energy Consumption (battery current clamp measurement) [Wh/km] ([l/100 km])					
HVAC	OFF				
	Phase 1 Normal 1st Normal 2nd *Eco*	**Phase 2** Normal 1st Normal 2nd *Eco*	**Phase 3** Norm. 1st Norm. 2nd *Eco*	**Phase 4** Norm. 1st Norm. 2nd *Eco*	**Combined** Normal 1st Normal 2nd *Eco*
Route 1	263.7 (2.96) 259.6 (2.92) 255.4 (2.87)	6.4 (0.07) 6.8 (0.08) 10.0 (0.11)	-	-	132.6 (1.49) 131.3 (1.47) 120.3 (1.35)
Route 2	126.1 (1.42) 124.9 (1.40) 119.5 (1.34)	109.0 (1.22) 112.8 (1.27) 101.2 (1.14)	-	-	117.3 (1.32) 118.7 (1.33) 110.1 (1.24)
Route 3	137.7 (1.55) 167.3 (1.88) 157.7 (1.77)	124.5 (1.40) 150.1 (1.69) 131.7 (1.48)	138.8 (1.56) 167.4 (1.88) 161.5 (1.81)	100.1 (1.12) 120.6 (1.35) 109.3 (1.23)	131.0 (1.47) 158.3 (1.78) 147.5 (1.66)