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Electric Vehicle Performance and Consumption Evaluation

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Abstract

In this article, the driving performance of two electric vehicles of the latest generation clean powertrain cars is evaluated. The vehicles under test are an electric Peugeot iOn, and an AGV electric version of the Ford Transit Connect. For different torque-speed operating conditions at wheel level, the vehicles are evaluated for their battery to wheel - electrical to mechanical - power conversion performance, with the help of chassis dynamometer testing. This generates an insight in the mapping of the consumption and efficiency value ranges for electric driving. The vehicles are also tested in real life on-road conditions, by following a pre-set representative track on public roads. Charging efficiency and consumption of auxiliaries is considered too. These tests give insight and realistic values to judge consumption, driving range and efficiency. With these results, further calculations and accurate simulations of realistic scenarios are possible.

Keywords: electric vehicles, chassis dynamometer, energy efficiency

1 Introduction

Electric vehicles (EVs) are increasingly appearing on the market and on our roads. Due to their beneficial effects on health and environment, and as a means to further optimize energy use for personal transport, electric cars are of crucial importance for transportation [1].

Characterization of the energy efficiency of the vehicles [2], by means of chassis dynamometer testing in the laboratory is one of the main objectives of this work. While measuring vehicle wheel torque and speed, for a number of operating points, electrical quantities at battery level are measured with dedicated monitoring systems.

Furthermore, the efficiency from power supply plug to traction battery of the vehicles is measured during the charging cycles.

Also the consumption of main auxiliary systems in the vehicle, like that of the heating and cooling installations, is investigated.

The electrical quantities’ measurement and monitoring is performed with different mobile on-board acquisition systems, by acquiring access to the vehicle’s CAN bus or by installing electrical measurement equipment in function of the needs. Both commercial data loggers as well as dedicated developed systems are employed.

Since the measurements in the vehicle are collected with compact on-board systems, they can easily be performed while driving on-road. Each vehicle is also tested on-road, following a prescribed path, while traction battery quantities are monitored. As such, realistic consumption of the vehicles can be measured and comparison to dynamometer testing can be evaluated. The gathered information can contribute to system understanding and model building [3], [4].

2 Vehicles and setup

The vehicles under test are briefly characterized in Table 1.

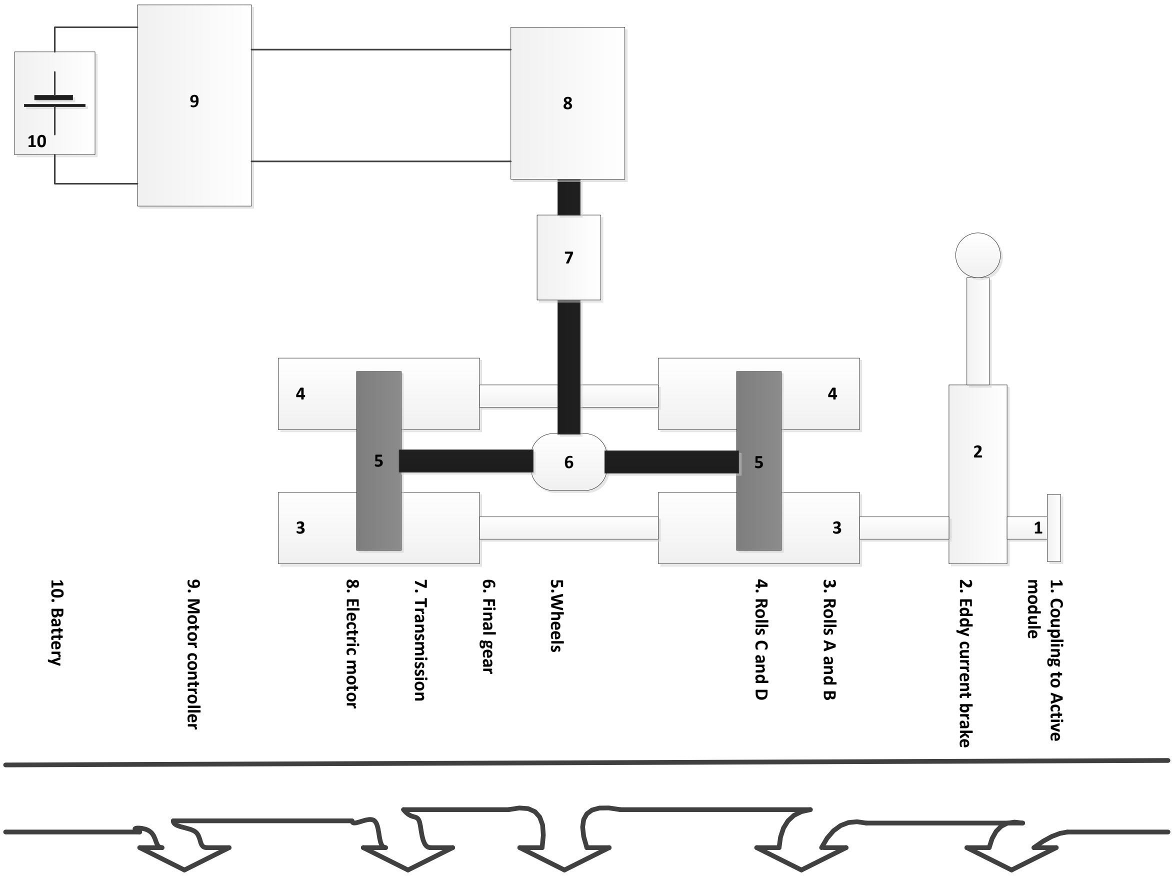

Figure 1: Vehicle on chassis dynamometer test bench, with flow diagram of the losses.

Table 1: Main characteristics of the EVs tested

	iOn	AGV
Curb weight [kg]	1080	1625
E-Motor Power [kW]	47	86
Battery energy [kWh]	16	25
Electric range (NEDC) [km]	150	160

Chassis dynamometer testing is performed at a number of different vehicle speeds and for representative tractive force levels acting on the driving car. Hereby measuring the encountered operating range of the electric vehicle.

For the on-road test, a trajectory encompassing urban, sub-urban and highway traffic conditions is driven, covering a distance of 50 km. The trajectory in the Brussels area is shown in Figure 2 (GPS tracking data).

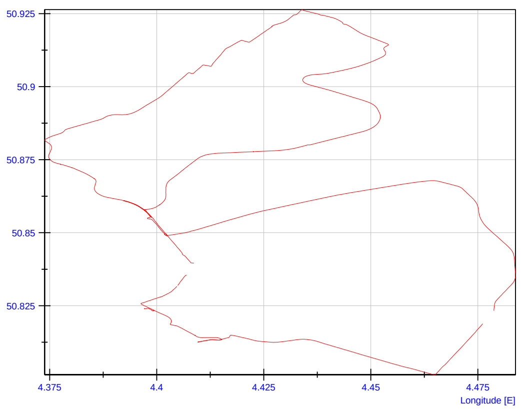

Figure 2: Trajectory of the on-road test.

3 Vehicle dynamics

The required motor torque and the power delivered by an electric vehicle is determined by the forces acting on the vehicle while it is driven along the road. These forces, that are simulated on the chassis dynamometer test bench, are discussed here.
Energy losses in the test installation as well as in the electric vehicle are considered in the calculations.

When a vehicle is driven along the road, a dynamic equilibrium exists between the tractive effort between the wheels and the road on the one hand and the total running resistance on the other. The surplus force accelerates the vehicle. In case of deceleration or driving downhill, the acting forces can drive the movement of the car.

$$\begin{aligned} F = {} & M\cdot g\cdot\left(f_r\cdot\cos\alpha+\sin\alpha\right) \\ & +\frac{1}{2}\rho\cdot C_D\cdot A\cdot v^2 \\ & +\left(M+m_f\right)\cdot\frac{dv}{dt} \end{aligned} \tag{1}$$

With:

F = total resistive force [N]
M = vehicle mass [kg]
g = gravitational acceleration (9.81 m/s^2)
fr = coefficient of rolling resistance [-]
α = road gradient angle [°]
ρ = air density (1.226 kg/m^3)
A = max. vehicle cross section [m^2]
C_D = drag coefficient [-]
v = vehicle speed [m/s]
m_f = fictive mass of rolling inertia [kg]

This is the total resistive force acting on a vehicle with linear speed v and acceleration dv/dt. One can recognize the expressions for rolling resistance, climbing resistance, aerodynamic drag and inertial resistance. Components that are ignored in this relation include resistance due to wind velocity (relatively low wind speeds and low average contribution assumed during on-road testing) and bearing friction.

4 Results

Using the same symbols as introduced under eq.1, vehicle parameter values found from manufacturer and test specifications are listed in Table 2.

Table 2: Vehicle parameters

	iOn	AGV
fr [-]	0.012	0.012
C_W [-]	0.35	0.4
A [m^2]	2	2.8

4.1 Peugeot iOn

4.1.1 iOn chassis dynamometer tests

Calculating eq.1 for fixed vehicle speeds, i.e. cancelling the inertial term in that relation, yields the resistive forces illustrated in Figure 3 for the considered climbing gradients (0 – 2 – 4 %) in the case of iOn.

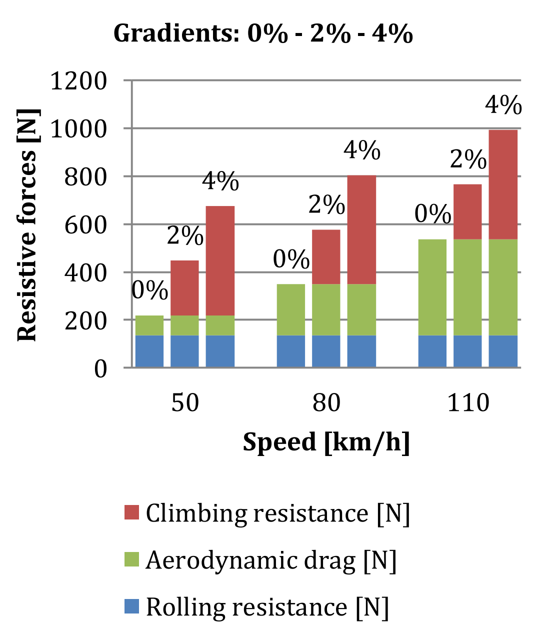

Figure 3: iOn resistive force distribution for different speeds and road inclination.

For different speed operating points, measurements are taken for relevant resistive force values, and mechanical power is calculated. For iOn the dynamometer measurements around 80 km/h are shown in Figure 4. Similar graphs are obtained at other speeds.

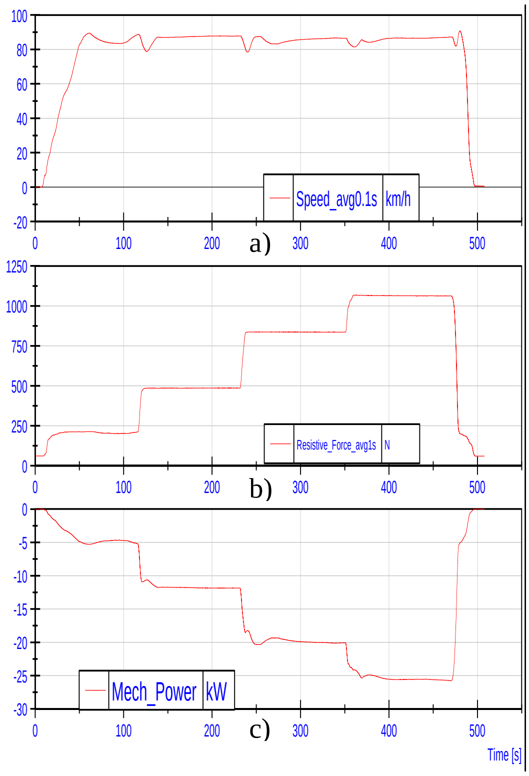

Figure 4: iOn measured a) speed, b) resistive force and c) (inversed) mechanical power at wheels during roller bench test at +- 80km/h.

The associated electrical battery quantities are measured simultaneously (Figure 5), out of which battery power is calculated and compared to the mechanical power (Figure 6) for retrieving efficiency values.

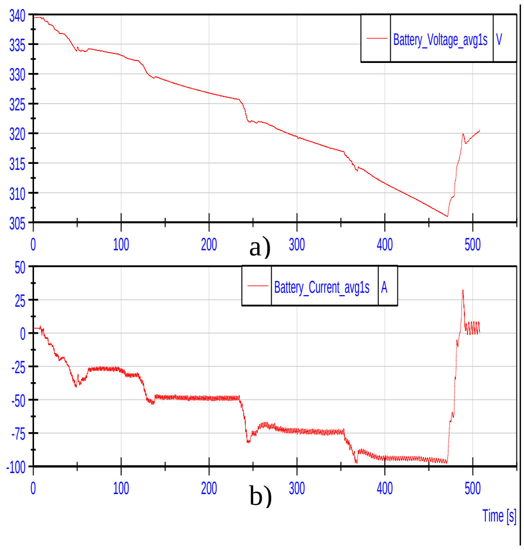

Figure 5: iOn measured a) battery voltage and b) battery current during +-80km/h roller bench test.

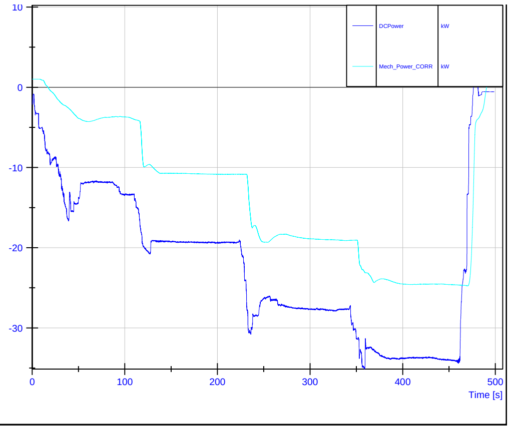

Figure 6: iOn electrical battery power (dark) and mechanical wheel power (light) at 80km/h test.

Resulting iOn efficiency at speeds of around 50 km/h and 80 km/h at different power levels is presented in Figure 7.

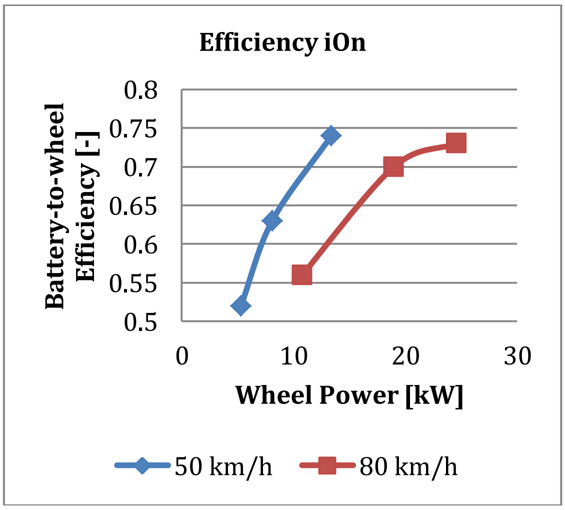

Figure 7: iOn battery-to-wheel efficiency tends to increase with the tractive effort.

Vehicle efficiency has the tendency to increase with increased tractive effort, as noticeable from the constant speed curves of Figure 7. For a given power, the efficiency is best at lower speed. At lower speeds, the friction is also less.

4.1.2 iOn on-road test

For the on road test a specified trajectory in Brussels is driven (Figure 2), including city, sub-urban and highway driving styles. During this 50 km trip, following details are observed: see Table 3.

Table 3: iOn on-road test result

ODO trip distance [km]	Vehicle Range Decrease [km]	Battery SoC Decrease [%]	Battery Energy Decrease [kWh]	Consumption [Wh/km]	Peak powers [kW]
50.1	53	53	7.3	138	[-30 … 50]

4.1.3 iOn auxiliaries: heating and airco

When pushing the auxiliaries to the limit, drawing maximum heating and cooling power, average auxiliaries electrical consumption of over 5 kW is observed for the iOn. This means that the comfort systems show good performance since power levels are high, so the user has to take care that this energy is not wasted. When the vehicle windows are closed as should be the case, desired temperature can be reached quickly and total auxiliary power consumption will drop to around 1 kW and lower.

4.1.4 iOn battery charging

A plug to battery charging efficiency of 80% has been observed for iOn. The measurement has been performed for a complete charging cycle from an empty battery to full state of charge at 13 A current level (AC), using mode 2 charging.

4.2 AGV Connect

4.2.1 AGV chassis dynamometer tests

Using eq.1 again for fixed vehicle speeds, yields the resistive forces illustrated in Figure 8 for the same climbing gradients in the case of AGV.

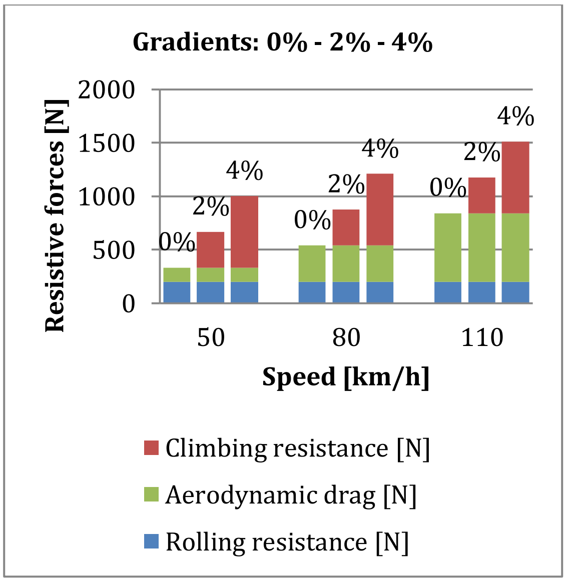

Figure 8: AGV Connect resistive force distribution for different speeds and road inclination.

For different speed operating points, measurements are taken for relevant resistive force values, and mechanical power is calculated. For iOn the dynamometer measurements around 80 km/h are shown in Figure 9. Similar graphs are obtained at other speeds.

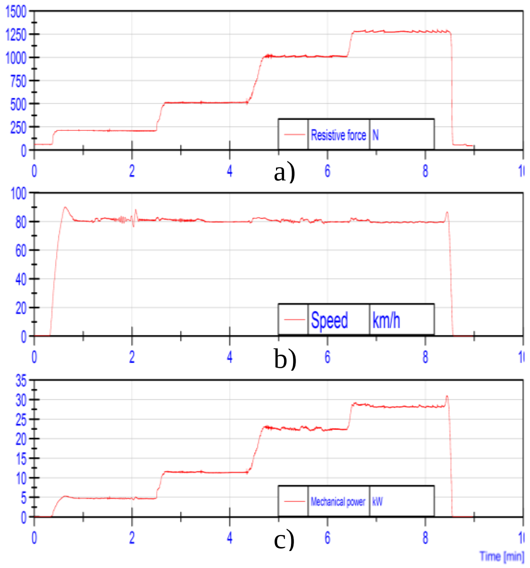

Figure 9: AGV measured a) resistive force, b) speed, c) mechanical power, during roller bench test at 80km/h.

The associated electrical battery quantities are measured simultaneously (Figure 11), out of which battery power is calculated and compared to the mechanical power (Figure 10) for retrieving efficiency values.

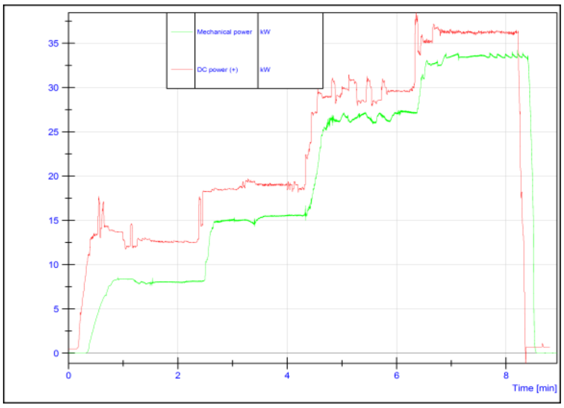

Figure 10: AGV electrical battery power (red) and mechanical wheel power (green) at 80km/h test.

Table 4: AGV on-road test result

ODO trip distance [km]	Vehicle Range Decrease [km]	Battery SoC Decrease [%]	Battery Energy Decrease [kWh]	Consumption [Wh/km]	Peak powers [kW]
48.9	NA	40	9.4	192	[-16 … 40]

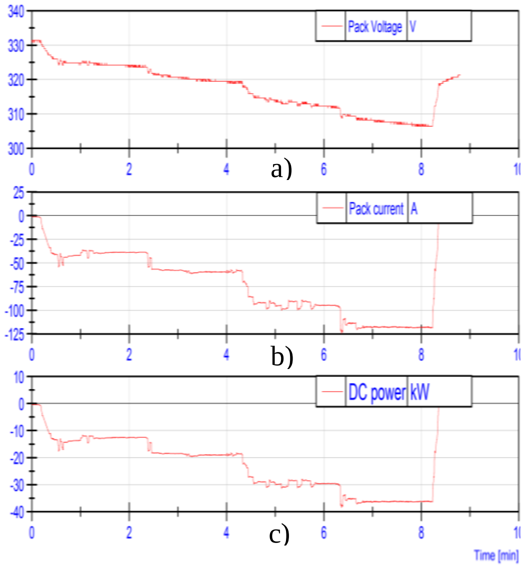

Figure 11: AGV measured a) battery voltage, b) battery current, c) resulting battery power, during 80km/h roller bench test.

Resulting AGV efficiency at speeds of around 50 km/h and 80 km/h at different power levels is presented in Figure 12.

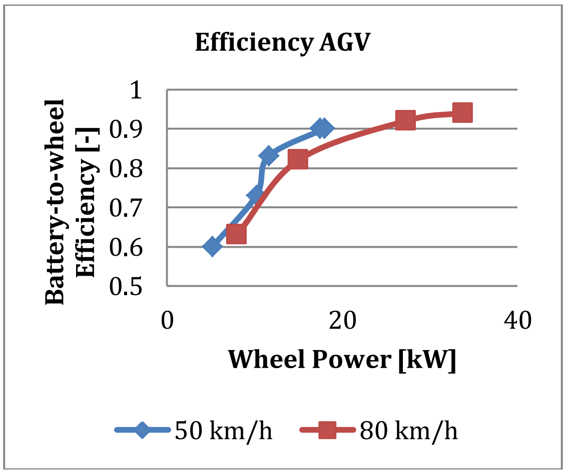

Figure 12: AGV battery-to-wheel efficiency tends to increase with the tractive effort.

Observed trends are similar as those observed for iOn (see Figure 7).

4.2.2 AGV on-road test

For the on road test the same trajectory as introduced in Figure 2 is driven. The results are listed in Table 4.

4.2.3 AGV auxiliaries: heating

When pushing the heating auxiliary to the limit, drawing maximum power, average auxiliaries electrical consumption of over 4 kW is observed for the AGV. Sustained heating, or when the passenger seats aren’t isolated from the back cabin, considerable consumption can occur. This AGV doesn’t have an airco installation.

4.2.4 AGV battery charging

A plug to battery charging efficiency of 88.6% has been observed for the AGV. The measurement has been performed for a complete charging cycle from an empty battery to full state of charge at 16 A current level (AC), using mode 3 charging.

4.3 Discussion

The efficiency curves for both vehicles show tendencies that are familiar for electric vehicles.
At a given speed, the efficiency tends to improve with higher torques (powers). The low power region extremes are the least efficient. For increased speeds, the efficiency deteriorates due to increased losses. Uncontrolled auxiliary consumption, inherent to driving, is also considered in the losses. This can amount to a considerable share, especially at low power operating range.
The AGV shows a better propulsion efficiency. It is likely that the (thermal) management of vehicle components, of which the battery is a key concern, differs for both vehicles and is the main cause for significant efficiency difference. Also the technology and components of the drivetrain is different for both vehicles.

The dynamometer tests illustrate how for different driving, i.e. different speeds, road loads, and thus vehicle mass/occupancy, geographical topology, aerodynamic disturbances, acclimatization, etc. the efficiency and consumption are influenced. These values are further used for calculations estimating the total well-to-wheel efficiency of the electric vehicle and in vehicle simulators. By using more realistic efficiency, load and consumption values in electric vehicle drive train simulations running given drive cycles, accurate results are obtained for various situations.

The chassis dynamometer test bench has a functionality to subject the vehicle to follow a given speed cycle too, as has been used in the past. At the time of testing this module was not operational, and for this study it was not the objective to test according to (known) drive cycles. As can be seen from Table 1, the electric range of these vehicles according to NEDC is known from official manufacturer data (or other certified institutions). The problem is that these stated ranges are not realistic for normal use of the vehicle on road, let alone for additional loading. Therefore the operating point chassis dynamometer tests on one hand are proposed to obtain the necessary values to be used in optimized simulation models. On the other hand an on-road test has been performed in an area where the vehicle experiences real world urban, sub-urban and highway driving.

According to the on-road data of Tables 3 and 4, the electric range of the iOn is 100 km, and that of the AGV is 122 km.
These values are not only in line with the use experience with these cars, they also correspond very well with more realistic official values.
For the iOn, the electric range according to the US EPA cycle is 100 km.
A more realistic electric range for the AGV, provided by the manufacturer (calling the NEDC value a ‘gross’ value) states a value of 130 km.

The values obtained for vehicle acclimatization and charging efficiency are interesting to learn the differences between vehicles and where potential optimization is possible. They will be used in further calculations too.
One has to be wary however, for heating and cooling for example, high peak powers (although may sound negative) are not only beneficial for thermal performance, but it is also important to have attention for associated properties like vehicle insulation and volume, climate control strategy and user behaviour.
Also, a good charging efficiency is a must, but when a given battery technology needs adequate cooling for example to prolong its life, one should not draw too early conclusions.

5 Conclusions

In this paper two electric vehicles, Peugeot iOn and AGV Connect, have been tested in lab conditions and on road.
In the lab, chassis dynamometer tests have been performed for different constant speed and wheel torque operating points, and also vehicle acclimatization and battery charging has been evaluated.
On-road, a specific route under real world driving conditions, including urban, sub-urban and highway driving portions is presented. Different vehicles are tested along this same trajectory.

Various propulsion efficiency values are obtained from the roller bench tests. Further, driving consumption values, charging efficiencies and auxiliary consumption are obtained.
The observed driving range and consumption from these tests are more realistic than the overestimated NEDC values, and are very well in line with e.g. more accurate US EPA values.

The obtained data is and will be further used in optimized efficiency calculations and accurate driving simulations for various scenarios under different conditions.

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