EVS24
Stavanger, Norway, May 13-16, 2009

An investigation on the raw energy consumption and the energy efficiency of the electric CargoScooter

Summary of the Graduation Thesis by

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Abstract

Since the issue in Italy of the Ministerial Decrees on 24th April 2001, electrical energy and gas distributors have had to promote energy efficiency for the final uses; therefore it is interesting for the manufacturers of electrical and gas equipment to offer energy saving products: this is a benefit to the environment, a reduction of the fossil fuels which can contribute to decrease the dependence on fossil sources in our country, while it also has commercial advantages for the manufacturers themselves.

The savings, expressed in tons of oil equivalent (toe), with a conversion coefficient that is established from time to time by the Italian Authority for electric energy and gas, are measured as a difference between the consumption of innovative plants or devices and that of the most diffused technologies or the best ones available in the market.

Therefore, we have thought to test the *CargoScooter* by *Oxygen* in order to measure the electrical energy absorption from the network and then deduce the primary fuel consumption by the conversion coefficient adopted by the Authority: this datum is easily comparable to that of vehicles of the same category.

This analysis is only related to the operational phase of the vehicle: so, it does not take into account the evaluation of the life cycle of batteries and other components of the scooter.

From the above-mentioned test, we also deduce the performance of the various scooter components in order to have a general idea how the scooter's total performance is affected by the components themselves.

Keywords: energetic efficiency, primary fuel consumption,

1 Introduction

This study was developed as a Graduation Thesis at the Engineering Faculty of the University of Padua on behalf of Oxygen S.p.A. and aims at checking the primary fuel consumption of the *Cargoscooter*, which is this company's top product: it is a scooter powered by a lithium-ion battery and moved by a DC *brushless* motor.

The company, with headquarters in Padua, was born in 2001. In 2004, thanks to the direction of new management, the company developed the *Cargoscooter*, with Ni-Zn batteries, co-financed by the Dutch government.

In October 2006, the company decided to shift to lithium-ion technology for the battery and it created a completely electrical vehicle that would have been offered to the market of delivery services. The characteristic of this means is the patent of the *Direct Drive Propulsion System*, which allows for the reduction of the supply costs and lowers maintenance expenses; furthermore, it increases the scooter's total efficiency, reduces the atmospheric pollution and eliminates acoustic pollution.

More specifically, the scooter is equipped with two, three or four 100Ah lithium-ion batteries with open-circuit voltage of 18 or 12 Volts on the electrodes; a mass, while running, that can vary from 120 to 170 kg and is driven by an electrical *brushless* motor with a maximum power of 4 kW and managed by the electronic equipment on board. The scooter can cover a distance from 60 to 120 km depending on the number of batteries it is equipped with. Other characteristics are the absence of emissions so that the scooter can also ride in limited traffic areas and run despite traffic limitations.

This configuration makes the scooter interesting in the market of last mile deliveries, including postal services.

If this electrically driven vehicle shows a consumption of raw energy, expressed in toe, which is lower than that of vehicles of its own category equipped with an endothermic engine, it would not only be a valid alternative for eliminating the local emission of polluting gas, but also for a reduced consumption of fossil fuels, which would place the scooter in an interesting position as regards the Ministerial Decrees of April 24th, 2001.

Therefore, to determine if this saving is real, we decided to test the vehicle in the dynamometric bench under controlled conditions and through the use of certified instruments. We decided to entrust the test to TUV Italia, a certification body that identified the technical reference regulations to carry out the test. At the end of the tests, the body issued a technical report that specifies the consumption of electrical energy from the network to re-establish the initial charge level of the scooter after it has carried out a trial cycle simulating urban traffic. During this test, a few operational parameters of the scooter were monitored and recorded by means of a proper diagnostic software developed by the battery manufacturer. These data allow one to carry out further observations relevant to the performance of the batteries, battery charger and motor (including its ignition).

2 The Ministerial Decrees of 24th April 2001

One of the reasons why we wanted to measure the *Cargoscooter's* consumption of primary fuel is that it would offer, besides local pollution advantages, a benefit that makes it even more appealing for potential buyers if it consumed less than an endothermic engine vehicle of the same category..

The Authority for electrical energy and gas (hereinafter the Authority) foresees that every distributor aims at saving energy. This goal can be achieved by realizing "projects" that are described by the Decree itself. The distributors that reach these targets will be awarded by the Energy Efficiency Certificates that will declare that these distributors have engaged in decreasing the consumption of primary fuels. The following sections will describe the contents of the decrees more deeply.

2.1 Involved people and projects

The document for the fulfilment of the Ministerial Decrees of 04/24/01 for the promotion of energy efficiency in the final uses shows the proposals of the Authority as to the definition of guidelines for project preparation, realization and final assessment and for the issue of energetic efficiency certificates.

Every distributor of electrical or gas energy has the specific target to save raw energy: 50% of this obligation refers to the savings in the final uses. The distributors must meet their specific targets by carrying out operations or projects that save raw energy, even if they can imply an increase of the consumption of the distributed (electrical) energy.

The results of these projects, relevant to the raw energy saved, are assessed according to the criteria and methods specified in the Guidelines.

There are three assessment methods:

a) **standard assessment** according to the amount of equipment with high efficiency that are currently installed and on the basis of standard parameters that take into account the conditions of use;

b) **engineering assessment** relevant to the parameters of use measured on the basis of pre-defined algorithms for the calculation of raw energy savings;

c) **final assessment**, in case neither the standard assessment methods nor the engineering assessment methods are available, on the basis of the measurements of consumption carried out according to the energy monitoring plans.

The project results, as concerns the saved energy, help the distributor achieve the final goal for a maximum period of five years. The Authority proposes that the assessment relevant to energy savings takes into account, by the means of proper coefficients, the persistence over time of the obtained savings, and, for a few types of projects, the assessment should consider the amount of non-additional savings (which are the savings that would be obtained even if the projects were not created, thanks to the spontaneous diffusion of high efficiency equipment).
The projects for the increase of energetic efficiency consist of actions and measurements that imply the installation of high efficiency equipment.
It is interesting to observe that the distributors are obliged to achieve the energy saving targets in the final uses: in fact, they are less interested in maximising the volumes of sold energy and, therefore, they are more inclined to promote savings.

The categories that take advantage of the projects are the following:

- **final customers or consumers:** thanks to a reduction of their energy bill.
- **energy sellers:** can use the energy saving projects as a *marketing* instrument to acquire and keep customers.
- **the equipment and component manufacturer and services suppliers:** can increase the sales of more efficient equipment.

2.2 National quantitative targets and specific target of each distributor

The Ministerial Decrees fix the national quantitative goals for the increase of energetic efficiency expressed in terms of primary energy saved (Mtoe): the conversion factor of the kWh in toe was initially fixed in 0.201 toe/MWh_e in 2009; but the Authority, in the Consultation Document on February 20th, 2008, has proposed to change it to 0.187 toe/MWh_e, after checking the average increased performance of the national thermoelectric equipment during the last few years. The national target to be achieved in 2009 is fixed at 1.60 Mtoe. For the single distributors, half of the annual target must be achieved through projects bringing a reduction of the final consumption of distributed energy. The other half (at a minimum) is to be achieved by means of increased energy efficiency projects, even if these projects do not imply a reduction of the final consumption of distributed energy.

2.3 Admissible projects to achieve the targets

The project typologies are listed in Attachment 1 of each Ministerial Decree. They are divided into the following:

a) actions for the reduction of the final consumptions of distributed energy;
b) other actions for the reduction of the consumptions of primary energy (Table B attached to each Ministerial decree: the typology of action 13 is relevant to vehicles supplied with electricity or natural gas).

The projects can be carried out as follows:

a) by direct actions of the distribution companies;
b) by companies controlled by the same distribution companies;
c) by third parties operating within the service energy industry, including craftsmen and consortiums.

Among the proposed methods, the standard assessment is more suitable for mass produced equipment; in fact, it is possible to define the average obtainable savings for every reference unit; it is also an operation that can be repeated and the number of used charts for the standard assessment will be progressively expanded by the Authority, depending on the processing of new standardized methods.

2.4 Assessment of the project results

The energy savings are assessed according to the energy service provided to the final customers. For the standard and engineering assessments, the Authority specifies that the reference technology

used to assess the savings achieved by each project.
The reference technology will be the one that has been replaced by the new high efficiency equipment (for example, an electrical vehicle replacing an endothermic vehicle).
For typologies of projects for which standard assessment methods are available, the Authority defines the corrective coefficients of non-additional savings in order to take into account the energy savings that would have been achieved, in any case, if the project had not been realized due to market evolution and technological innovation.
Furthermore, the corrective coefficients are also defined for those delivery methods different from direct installation in case the projects do not foresee the direct installation of this equipment, but only their delivery or promotions to the customers; for example, by means of sales networks or through the dispatch of sales vouchers. Finally, a minimum size of the project has to be considered, which means a minimum number of vehicles specified from time to time by the particular project and the assessment method.
For quantifying the obtained results, the Authority proposes to consider the impact of technical and behavioural factors due to the possible decrease in performance caused by wear and tear, because of age and/or the way in which the equipment is used.
It is clear that, for example, referring to the vehicle in question, if the person that uses it does not periodically check and maintain the tire pressure, the scooter will consume more.
For this reason, for four years from outset, a persistence of savings will be assessed though specific coefficients and included between 100% and 95% in comparison with previous years. It would be correct to distinguish between active technologies, whose performance depends mainly on the use and maintenance conditions, and passive technologies, whose performance cannot be negatively affected by the behaviour of the final user.
It is worth considering that these assessment methods refer exclusively to the phase of product and equipment operation, similarly to the common results from the most important international experiences. In principle, the energy savings associated to the introduction of innovative products and equipment should be assessed "from cradle to grave", which means taking into account the energy consumption in the phases of production, installation, maintenance and its final disposal. But, since these products and equipment have quite a long life, the energy consumption during operation is prevailing with regards to the other phases of their life cycle. The whole life cycle of a few products or equipment can be experimentally considered for a few typologies of projects after the relevant assessment techniques are available.
For projects that ask for a final assessment, the reference technology is the replaced technology whose consumptions must be reported by the person carrying out the intervention. For projects that foresee additional measures, such as information, training, public awareness and promotional campaigns, the Authority proposes to assign a standard value before that of incremental benefits (defining the reduction of energy consumption).

2.5 Energy efficiency certificates.

To favour the achievement of the targets with the minimum overall cost, the ministerial decrees foresee the use of energy efficiency certificates. Energy efficiency certificates contain a value expressed in the unit of primary saved energy (toe). The decrees foresee that the energy efficiency certificates are issued annually by the Authority, in favour of the single distributors, after they have obtained the certification of the achieved results, confirming the attainment of energy efficiency projects. The certificates will also be issued in favour of the so-called ESCO (Energy Saving Companies) for projects they carry out autonomously.
The energy efficiency certificates can be negotiable: they can be exchanged among operators by bi-lateral agreements; the market of the certificates will be organized by the Electrical Market Manager, who will define the operations' regulations in agreement with the Authority.
The possibility of exchanging energy efficiency certificates allows the distributors, who would have had fairly high marginal costs, to save energy in the final uses through the realization of projects purchased instead of completing the projects themselves; energy efficiency certificates will be supplied by those with lower marginal costs and, thus, will have available opportunities to sell their certificates to the market. The development of the energy efficiency certificate market allows one to limit the costs that are, overall, supported by the distributors and ESCOs to achieve the quantitative targets fixed by the decrees.

3 Lithium-ion batteries

Lithium is the lightest metal; it even floats in water. It also has the highest electro-chemical potential, making it one of the most reactive metals. These properties make Lithium capable of storing great amounts of energy and specific power required in applications, such as *automotive*.

Many variations have been made on the basic chemical composition, both to fit specific needs or to avoid the patents relevant to original technologies.

Lithium reacts violently with water and can catch on fire. The first cells with lithium cathodes were quite unsafe in certain circumstances; in the modern cells, lithium is combined with less dangerous compounds that do not react with water.

The typical lithium-ion cell uses carbon for its anode and lithium-cobalt dioxide or lithium and manganese alloy for its cathode. Usually the electrolyte is a lithium salt solution.

These batteries are now the best alternative for rechargeable accumulators for consuming electronics. The prices, at first quite high, have decreased according to the increase of production volumes.

Advantages.

The above-mentioned cell offers many advantages for high and low power:

- high voltage of the cell (3.6V) allows smaller dimensions and, with the same voltage that is necessary for use, a lower number of in series/parallel cells with a relevant elimination of connections and management electronics;
- absence of the liquid electrolyte (in the case of lithium-polymers) prevents leakages;
- high energy density (about four times that of lead density). For example, one vehicle of 3.5 tons of mass uses less than 200 kg of lithium batteries instead of 750 kg of lead cells with benefit of the useful load. Alternatively, with the same weight of the accumulators, there is a life span four times longer with lithium;
- high power density
- possibility of optimising the capacity or current intensity;
- possibility of reaching the capacity of 1000Ah for each cell;
- capacity of supplying up to 40 times the rated current by allowing the use of small capacity batteries for hybrid vehicles that need high current with a short duration;
- high charging rate;
- high depth of discharge: the voltage remains constant up to over 80% of the discharge curve (versus 50% of the lead-acid batteries), meaning a higher amount of energy to be used with an equal rated capacity;
- extremely long self-discharging time;
- high efficiency (supplied energy/loaded energy);
- no memory effect;
- long life. The life cycle can be extended by preventing excessive depths of discharge;
- no need of *reconditioning*;
- large field of available capacities (500mAh to 1000Ah) and supplied by a large number of companies.

Disadvantages:

- higher internal impedance with regards to an equivalent Ni-Cd battery;
- high cost for the production of high power accumulators. The production volumes will increase slowly, thus decreasing the prices of these applications;
- special precautions needed to prevent danger due to a great reactivity of lithium by means of maintaining the battery within the operational limits. The lithium-polymer cells and their solid electrolyte solve this problem;
- more restrictive safety measures for transportation in comparison with other chemical configurations;
- long-term decrease of performance with high temperature;
- loss of capacity or overheating in the event of excessive charging;
- decrease in performance if discharged under 2 Volt;
- need of protection circuits;

- difficulty to establish the charge level by means of the voltmetric measurement: the very flat discharge curve of lithium makes the measure unreliable; therefore, over time, another additional measure of input/output current must be considered;
- even if low powered cells have been used for long time, there is no sufficient database to assess long term high power applications. Some experiments have been developed with accelerated life cycles: the results show that the lithium batteries have a similar or longer life span than the most common technologies.

It is correct to deduce that the advantages of lithium technology are far greater than its disadvantages.

3.1 The lithium-ion variant

This variant was created to solve safety problems caused by the great reactivity of lithium.
In this variant, lithium is never present in the metal form during any charging or discharging phase. Instead of lithium ions, there are ions that are in the positive electrode when the battery is discharged and in the negative electrode when the battery is charged. These ions move in the electrolyte from one electrode to the other.
These cells operate according to the *swing* effect, which involves the transfer of ions from and to each electrode. The anode is made with carbon, the cathode is a metal oxide and the electrolyte is a lithium salt in an organic solvent. Since the lithium metal, which might be produced in irregular conditions of recharge, is very reactive and can explode, some electronic protective circuits and/or fuses are integrated to prevent the polarity inversion.
The chemistry of the cell allows for the separation of the electrodes to be very thin and have a very large surface, thus allowing the passage of very high current. Thus the cells are suitable for powerful uses.
The elimination of extremely reactive and inflammable components allowed the elimination of an external safety case; as a consequence, costs were reduced and dimensions could vary.

3.2 Performance and typical curves

The rated voltage on the cell terminals depends on the electrochemical characteristics of the used reagents (the chemistry of the cell); the voltage that occurs at a certain instant, as in every cell, depends on the current and the internal impedance; it varies as a function of the temperature, the charge status and age.
The following graph (Figure 1) shows the typical discharge curve for a few types of chemical configurations that were obtained with a discharge current of 0.2C (where 1C is equal to the current that, supplied for 1 hour, gives capacity to the battery: for example, for one component of 200Ah, 1C=200A). As can be seen, every cell is characterized by a trend of the curve and by a rated voltage. The lithium cells have a quite flat curve, whilst the other cells, such as the lead cells, have a greater slope.

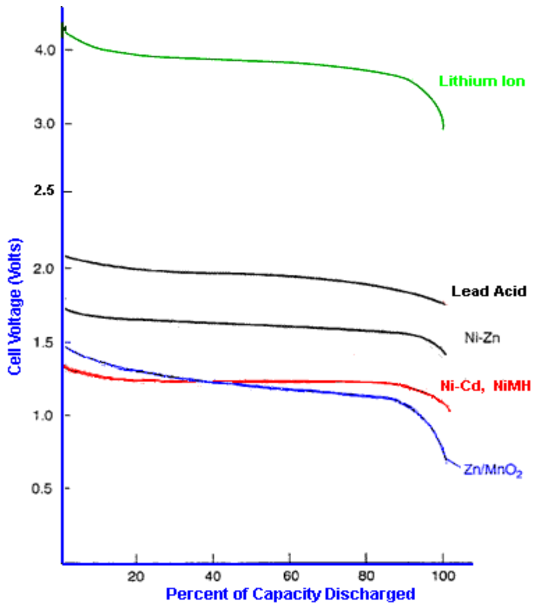

Figure 1: Discharge curves

The cell's performance can vary greatly according to the operational temperature.
At a low temperature, the electrolyte may freeze, limiting the effectiveness; at a very high temperature, the chemical reagents may lose their properties and shorten the product life.
The graph below (Figure 2) shows the decrease in performance in a Li-ion cell whilst the temperature decreases.

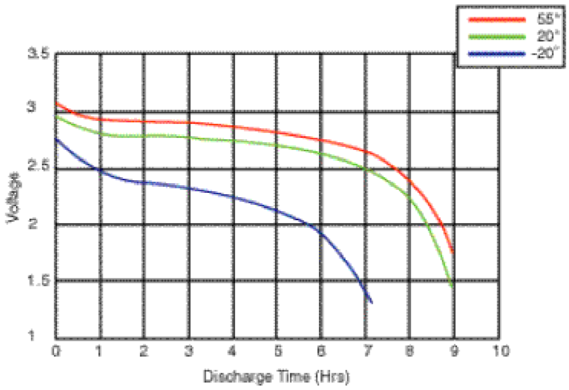

Figure 2: decrease in performance in a Li-ion cell whilst the temperature decreases

The self-discharge characteristics display the loss of a cell's charge as time passes. It depends on the chemistry of the cell and temperature. A few typical values of rechargeable cells are specified as follows:

- lead: from 2% to 6% per month.
- Nickel Cadmium (Ni-Cd): from 15% to 20% per month.
- Nickel metal-hydride (NiMH): 30% per month.
- Lithium: from 2% to 3% per month.

The discharge curve of a Ni-Cd battery in the graph below (Figure 3) shows the capacity dependence on the discharge rate, which is a common fact for many chemical configurations.

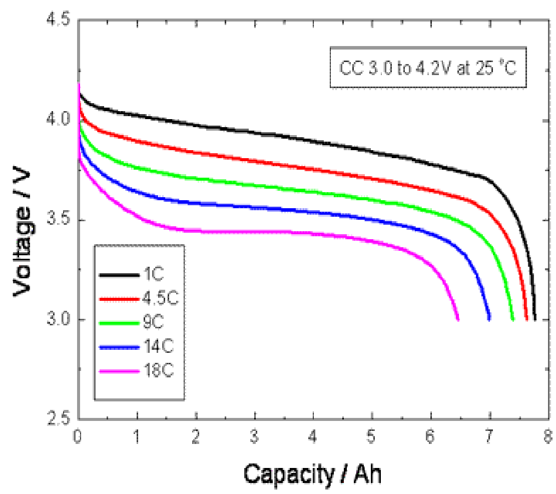

Figure 3: capacity dependence on the discharge rate

In automotive applications, where the discharge occurs for a long period, the capacity can be more than the double that of the C rate. This fact must be considered when very expensive batteries are designed for *automotive* use. The capacity of small power batteries for the consumption of electronic devices is usually referred to the discharge C rate, whilst, according to SAW, for electrical vehicles, the discharge time must be at least 20 hours, meaning C=0.05.

Similarly, the efficiency of the charge is affected by speed.

The graph below shows (Figure 4, for a lead-acid battery) that the capacity almost doubles if the performances at 1C and at 0.05C are compared.

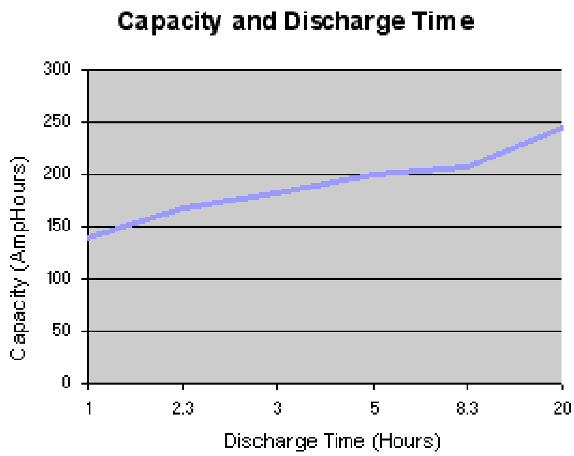

Figure 4: Capacity vs discharge rate

Therefore, it is possible to deduce that, if an electrical vehicle undergoes regular peaks of charge and long climbs, its range decreases.

The Peukert equation is a simple method to mathematically express the capacity of a cell according to the various discharge rates.

It is an empirical formula that relates the C quantities (a capacity expressed in Ah), current I and time t:

$$C = I^n t \qquad (1)$$

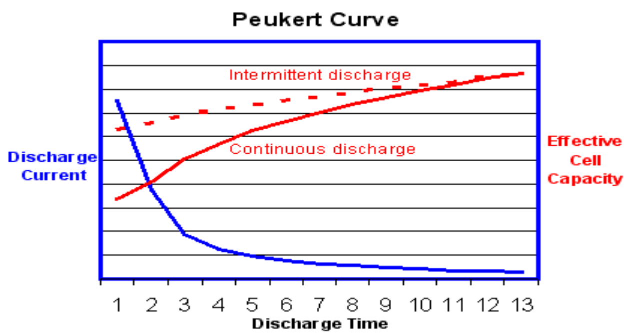

Figure 5: Peukert Curve

It is interesting to note that, during intermittent use, the cell has time1 to "rebuild" in the pause between one discharge and the next: this results in a temperature decrease and an increase in available energy; this behaviour is exactly the opposite to that of an internal combustion engine, which is more efficient when it operates at constant loads. Thanks to the great efficiency of the *brushless* motors, electrical vehicles are particularly competitive in the service of home deliveries where constant acceleration and deceleration are needed.

A battery is an electro-chemical device able to transform chemical energy into electrical and vice versa through chemical reactions controlled by a series of reagents; unfortunately, the reactions the battery depends on are accompanied by other unwanted reactions that consume the main reagents or prevent them from reacting. The Arrhenius law defines the relationship between temperature and speed in which the reaction develops: it shows that the link is exponential; as a practical rule we can assume that, with every temperature increase of 10° C, the reaction speed doubles. As a consequence, one hour of a unit at 35°C is equivalent to 2 hours of life at 25°C. Therefore, it is clear the great importance of cooling systems. The graph below shows (for the high capacity lead-acid batteries) that, at 35° C, the instantaneous performance improves, but the life is shorter; on the contrary, life will be extended at 15°C provided that a reduced performance is accepted.

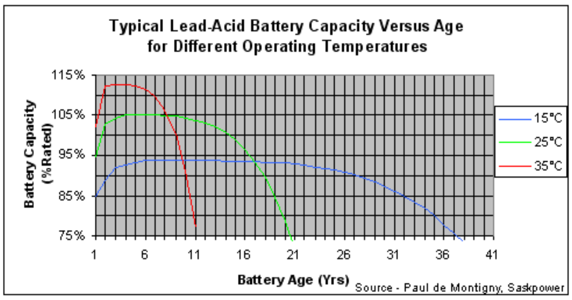

Figure 6: Capacity vs age at different operating temperature.

4 Report on the consumption test

On Thursday December 18th, 2008, in the laboratory of Dell'Orto (a company producing injection systems and carburettors) in Cabiate, a test was performed on Oxygen's "*Cargoscooter*" to check and certify its electrical energy consumption.

The test was supported by TUV, which issued a technical report certifying the obtained results.

4.1 The vehicle

The vehicle in question was the "*Cargoscooter* OX 4/ 0/ 02" with the following technical characteristics (Figure 7):

Performance	
max speed	45 km/.h - 28mph
acceleration	0-40 km/h - 0-24,8 mph = 6,0 seconds
reverse	adjustable speed
braking	regenerative braking front drum brake Ø 110m and rear disc brakes
tires	100/80 - 10 53J (front) 120/70 - 12 51P or 120/70 - 12 58P (rear)
fork	telescopic fork
suspension	Paioli shocks adj. in 4 clicks (15kg - 33lbs per click)

Configurator			
model	Postscooter	Postscooter Extended Range	Postscooter Long Range
nominal voltage	24 V	36 V	48 V
no. of batteries	2	3	4
range *)	60km - 38mi	90km - 56mi	120km - 75mi
charging time onboard charger	2 - 3 hrs	3 - 4 hrs	4 - 5 hrs
charging external fast charger	1 - 1,5 hrs	1,5 - 2 hrs	2 - 2,5 hrs
weight	121 kg - 266 lb	136 kg - 300 lb	151 kg - 333 lb

*) Urban driving cycle

Figure 7: CargoScooter characteristics

The tested vehicles were equipped with 3 Saphion® Phosphate Lithium-Ion (Li-Ion) batteries, 100Ah, made by the American company Valence. Moreover, the control software for the Valence Cycler batteries are available with voltamperometric sensors placed on the ends of the battery terminals.

The following figure 8 shows the main characteristics of the batteries:

Battery	
battery type	Saphion®Lithium-ion (LiIon)
rated battery capacity	100 Ah
rated battery voltage	12V
on-board charger	max power - 1kW; max absorbed current - 6,8 Aeff
recharge requirements	110V-220V (50/60Hz)
estimated battery life	in excess of 4 years

Figure 8: CargoScooter battery characteristics

The motor is a *DC brushless* with permanent magnets (number and type: 4195), a model produced by Selinsistemi from Genova; it supplies a maximum power of 3 kW (up to 4kW if not limited by the law in force).

Motor	
motor type	Direct Drive brushless electric motor
peak power	4 kW peak power at 200 rpm
max current	219 Amps
max torque	150 Nm
power booster	steady motor voltage / 65V

Figure 9: engine characteristics

The vehicle frame is a steel tubular frame with a front telescopic fork, rear single arm with Paioli suspension. The motor is located at the rear wheel with a rotation component that is integral with the wheel and which is static with the single arm where it is fixed. Therefore, there are no transmission components.
As it is known, the *brushless* motors need a control unit to operate and optimize their performance. The control unit is located in the single-arm, where the endothermic scooters have their clutch and transmission. The control unit allows the regenerative braking, meaning that the motor operates as a generator to charge the batteries with the amount of kinetic energy that otherwise would be consumed by the brakes. This configuration also allows one to connect a PC to the serial port of the single-arm to display the main parameters of the motor and the diagnostics. The following figure 10 shows the main characteristics of the control unit:

Electronics	
controller	DSP & MOSFET based all-digital electronic control and motor drive system
intrumentations	LCD display: speed, odometer, trip mileage, time, system status, battery status and charging status
communications	Controller Area Network (CAN) – RS 485 systems diagnostics and communication

Figure 10 : Control Unit characteristics

We will present (Figure 11) a general view of the scooter's three main components:

- **motor**
- **battery package**
- **control unit**

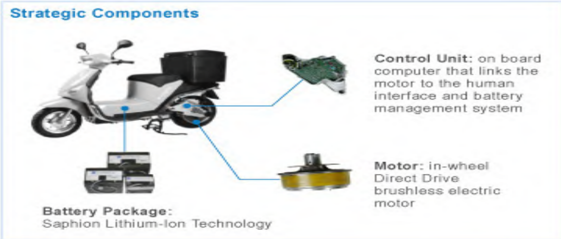

Figure 11: General wiew of scooter's main components

4.2 The test

As concerns the test's technical details, the reference regulations were ISO 7859, which establishes a method of measuring the motorcycle's consumption, and UNI EN 1986-1, which rules the analysis of consumption.
The scooter was weighed and its mass without load was 165 kg, whilst, in its running status with a tester on board, the mass was 240 kg. The maximum accepted mass is 336 kg.
This operation was necessary to calibrate the flywheel inertia of the bench that simulates the inertia of the vehicle under real conditions.
Later the *Cargoscooter* was placed on a roller bench made by the APIcom Company from Ferrara.
Regulation ISO 7859 establishes the load cycle to which the vehicle must be subjected to simulate the urban traffic; this cycle, defined by the line of speed, must be repeated twice in order to make the test effective. Furthermore, at least two tests must be completed where the detected consumption does not differ more than 5%. This cycle was repeated three times.

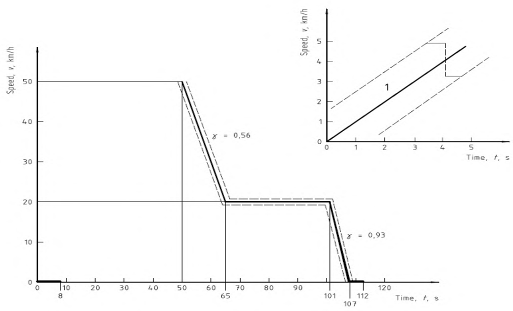

Figure 12: The line of speed according to ISO 7859

In the initial part, we did not define acceleration in an univocal way; in fact, in this case, we distinguish the vehicles with a transmission with the change of manual speeds and transmissions that do not need the user's operations, which are automatic transmissions.

The following table, reported by the regulation, shows the operations to be performed by the vehicles with automatic transmissions.
As can be seen from the figure, a tolerance of the speed and time values is allowed. This tolerance is ± 1km/h for the speed and ± 0.5 s for the time.
In order to calculate the performance in the tract chain battery – motor, a fourth test was performed. During this test, the bench supplied power to the rear wheel with the motor off and then at 10, 20, 30, 40 km/h to obtain four points of the characteristic tyre resistance and the bearing resistance. The four obtained points were interpolated with a quartic passing through the origin (Figure 13).

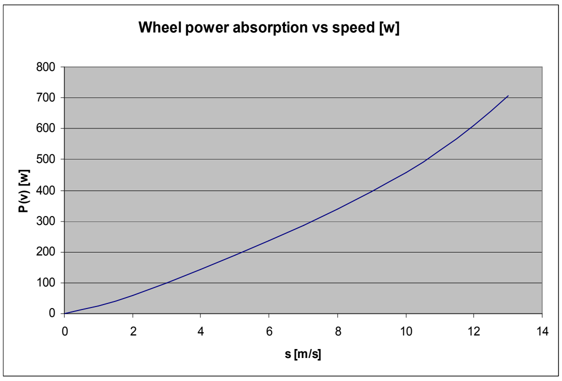

Figure 13: Wheel power absorption

Thanks to the data detected by the roller bench and the data provided by the *Valence Cycler* software, we were able to calculate the average performance of the various chain components, which are the battery charger, the battery and the motor with ignition.

4.3 Results

We obtained the supplied energy from the battery by integrating power (E^+):

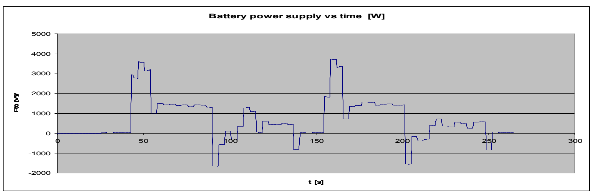

Figure 14: Battery power vs time

$E^+ = 56.18$ Wh

We obtained the power supplied by the motor, with L(t) equal to the power absorbed by rolling and aerodynamic resistance and $E_k(t)$ equal to kinetics energy:

$$P_M(t) = L(t) + \frac{dE_k(t)}{dt}$$

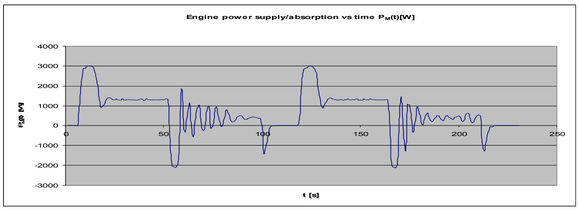

Figure 15: Engine power vs time

Integrating aerodynamic resistance, we obtain the energy supplied by the motor:

$E^+_M = 49.84$ Wh

From which we obtain the average performance of the cycle of the motor:

$$\eta_M = \frac{E_M^+}{E_B^+} = 88.7\%$$

Similarly, for the regeneration, the relationship of the energy supplied to the battery with the energy absorbed by the motor gives the average performance on the cycle of the machine that is operating as a generator:

$$\eta_G = \frac{E_B^-}{E_M^-} = 80.2\%$$

Now we can obtain the performance of the battery package, where Er is obtained integrating the power supplied to the battery under charge.

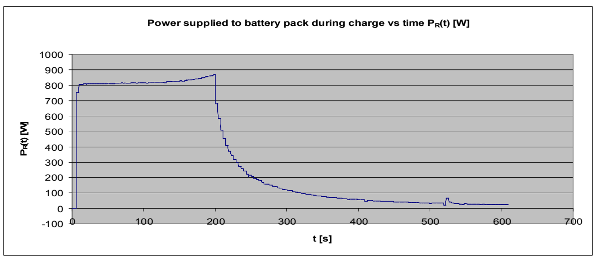

Figure 16: Power from charger to battery during charge

$$\eta_B = \frac{E_B^+}{E_R + E_G} = 90.4\%$$

We obtain the battery charger performance, using the TUV datum relevant to the absorption from the network (E_{AR} =67.95 Wh) and E_R:

$$\eta_{CB} = \frac{E_R}{E_{AR}} = 82.4\%$$

4.4 Power fluxes in the Cargoscooter.

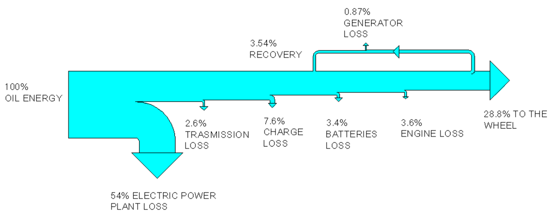

Figure 17: Power fluxes in the CargoScooter

4.5 Calculation of consumptions

Therefore, for the electrical vehicle:

$$\text{Specific consumption} = \frac{68.0\text{Wh}}{1.635\text{km}} = 41.6\frac{Wh}{km}$$

$$= 41.6\frac{kWh}{km}\cdot 0.187\cdot 10^{-3}\frac{toe}{kWh} = 7.77\cdot 10^{-6}\frac{toe}{km}$$

For a motorcycle equipped with an endothermic motor with direct injection (D-Tech technology), that, according to Motociclismo on 2/1999, covers 50 km with one litre of fuel, we obtain the following formula, using the conversion coefficient between petrol and toe equal to 1.2 toe/t_{petrol}

$$\text{Specific consumption} = 0.02\frac{l}{km} = 0.014\frac{kg}{km}$$

$$= 0.014\cdot 10^{-3}\frac{t_{petrol}}{km}\cdot 1.2\frac{toe}{t_{petrol}} = 16.8\cdot 10^{-6}\frac{toe}{km}$$

Therefore, as a result of the obtained data, the electrical scooter guarantees a 54% savings of primary energy during its operation.

These results should be assessed with the saving persistence coefficients for active technologies, but the poor maintenance that this vehicle needs makes these coefficients almost equal to the unit. The test did not take into account the fact that the charge was only made for the two final percentage points

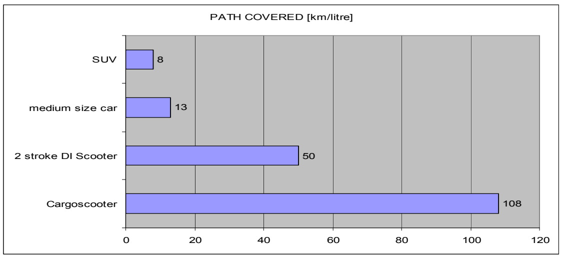

Figure 18: Petrol consumption of different vehicles

of the battery capacity, meaning when the performance of the battery is lower. Furthermore, these results only refer to the operational phase. An analysis of the life cycle of the batteries would decrease the value relevant to consumption.

4.6 Emissions of CO_2

By using Assoelettrica's data, which foresees an average emission of the national electrical equipment of about 500gCO_2/kWhe, the emission of electrical vehicles is about 20gCO_2/km.

A study by the Istituto Motori of the CNR reports the emissions from a set of samples of 16 2-stroke motorcycles: the average emissions are about 31gCO2/km.

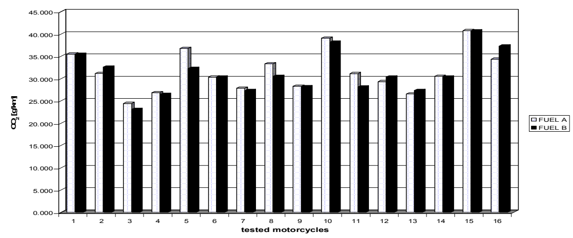

Figure 19: CO_2 emission of 16 mopeds with different fuels

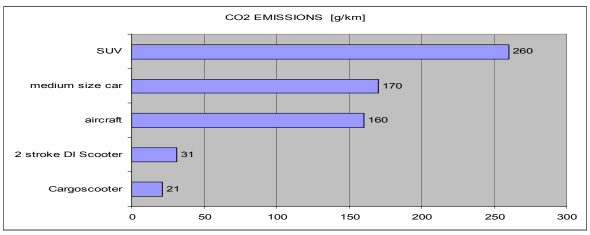

Figure 20: CO_2 emission of different means of transport

5 Conclusions.

The raw energy consumption shown by the Cargoscooter is 54% lower than that of the motorcycles equipped with a two-stroke direct injection engine: the datum that mainly affects this calculation is the conversion coefficient from toe to electrical kilowatt-hour, established by the Authority as 0.187 toe/MWh. This coefficient corresponds to a transformation efficiency of the Italian thermo-electrical equipment of 1870kcal/kWh, meaning a performance of 46%. If we observe the historical trend (see the figure 21) of this parameter, we realize the huge evolution over the last few years, largely justified by the Authority with the use of high-power combined cycles.

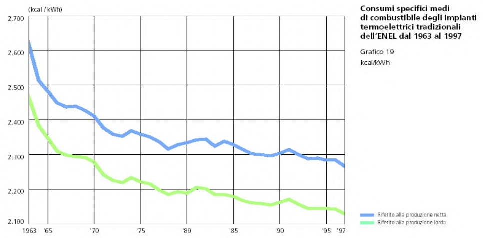

Figure 21: transformation efficiency historical trend (Italy 1963-1997)

Even if this datum can be criticized, it does not consider the use of renewable sources: in Italy 11.6% of electrical energy is produced from hydroelectric plants; this contribution reduces the raw energy consumption of electrical vehicles.
Another problem might be the use of nuclear power plants from which Italy imports energy and which is used in many European countries.
We have to underline that one of the characteristics of purely electrical vehicles, which is the range, has lower importance in comparison to cars and lorries: a range that varies from 60 to 120 km per charge (depending on the battery number) is an excellent range for a motorcycle.
Another positive datum in favour of the electrical vehicle concerns local **polluting emissions**; moreover, referring to carbon dioxide emissions, a **30% difference in favour of the Cargoscooter** has been checked, thanks to the efforts performed to reduce the polluting agents in the electric power plants. Moreover, due to the fact that the electric power plants must take care of this problem, a continuous control of the efficiency is guaranteed, also allowing for greater investments in its improvement. This is a difference with the endothermic motorcycles, where the combustion process takes place separately in every vehicle and, therefore, the adopted measures can not be as complex and efficient as the ones adopted by an electrical plant.

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