25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0257
DEVELOPING AN ELECTRIC MOPED PROTOTYPE

Rodrigo de Sá Leitão Martins
Graduate Program in Mechanical Engineering, PGMEC, Fluminense Federal University, Niterói – Rio de Janeiro, Brazil.
rodrigomartins@id.uff.br

Eduardo Artur dos Santos Filho
Electrical Engineering Department, Fluminense Federal University, Niterói – Rio de Janeiro, Brazil.
eduardoartur@id.uff.br

José Andrés Santisteban
Graduate Program in Electrical and Telecommunications Engineering, PPGEET, Fluminense Federal University, Niterói – Rio de Janeiro, Brazil.
josesantisteban@id.uff.br

Abstract. *The concerns regarding the climate change has been continuously growing since the 1990's and, at the same time, the improvement of computer models has confirmed the worst negative effects. In this sense, some international agreements have low-carbon emissions as target, which inspired several proposals reported around the world. For example, the replacement of internal combustion engines by other ones that use clean sources of energy, such as the electric motors. In fact, it is possible to highlight the rise of electrical mobility in urban areas around the world. Following this alternative, in this paper, the development of an low-cost electric moped prototype and the assembling of its mechanical and electrical components are shown. Hence, a conventional bicycle structure was appropriately adapted in order to be powered by a three-phase induction motor manufactured by the national industry. Additionally, the electrical system is comprised by a single-phase inverter, a commercial three-phase inverter and batteries. Finally, after the assembling of the prototype, it was possible to simulate its driving conditions according to the SAE J227a standard. In this way, the power and torque were evaluated. From this research, the authors believe that this proposal can leads to a profitable business with inexpensive investments.*

Keywords: *electric vehicle, finite difference method, prototype, computational simulation.*

1. INTRODUCTION

In the last decades, tighter environmental restrictions have been discussed. It seems to be a trend the substitution of energy based in fossil fuels into renewable and clean energy sources. During the early 1990's there was a conference in Rio de Janeiro, sponsored by the United Nations (Falkner, 2016), which established as a goal the reduction of greenhouse gas due to its harmful effects on human's health. After that, an international agreement in 1997, named the Kyoto Protocol, with a lifespan of 15 years, was implemented. In 2009, in Copenhagen, another conference was held and in 2015 the Paris Agreement was signed with new goals regarding the environmental agenda.

In this sense, comparing the life cycle analysis of different vehicles, which is done by evaluating the environmental impacts from its raw materials extraction until its recycling or disposal, measured in grams of CO2 per km, and according to Hagen et al. (2013), it is possible to highlight bicycles (21 g CO2/km) as an environmentally friendly choice for micro-mobility over vans (158 g CO2/km) and motorcycles (44.16 g CO2/km). Thus, efforts in order to convert fuel-powered vehicles in electrical-powered vehicles is an environmental friendly choice.

Furthermore, micro-mobility seems to be crucial for small business entrepreneurs in Brazil due to its cheap maintenance and it lacks mandatory driver's license. For example, the profile of the small entrepreneur in the city of Rio de Janeiro depends on this mean of mobility. In fact, Hagen et al., (2013) stated that 42% of business with this profile relies with the use of cargo bikes.

In this paper, inspired by other researchers such as Guedes (2008) and Costa (2009), the developing of an alternative electric vehicle prototype using electrical and mechanical parts available in Brazil, is described. According to CONTRAN (2013), this prototype is defined as an electric moped, given that for an electric bicycle its speed is controlled by a pedaling system while for an electric moped its speed is controlled by potentiometers. Furthermore, through simulations, the net torque and power of this prototype are shown.

2. DEVELOPMENT AND SIMULATION METHOD

2.1 Prototype Development

In order to encourage links between industry and university, the main goal of this study is to develop a low-cost vehicle, adapting a bicycle to get an electric moped prototype using an electrical system that includes a three-phase induction motor, inverters and batteries, as depicted in Fig. 1. Moreover, to build the prototype, its main components were obtained from Brazilian manufacturers.

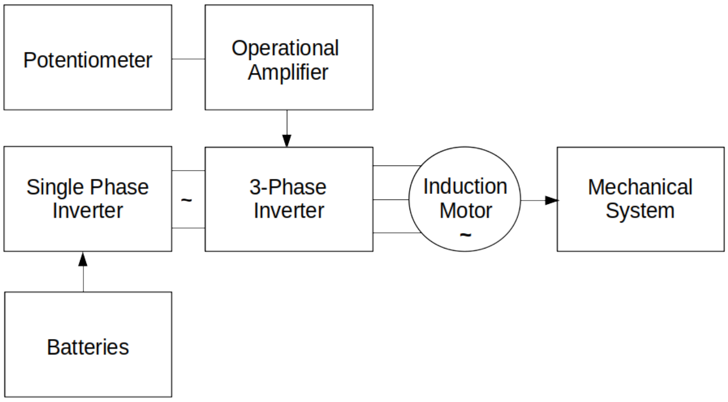

Figure 1. Schematics of the electric moped prototype.

As the electric motor, a 3 hp, 220/380 VAC, three-phase induction type was used. In order to supply it, four batteries connected in series, summing, 48 VDC, and two inverters were used. The first one is a single-phase inverter with constant output of 220 VAC/60 Hz and the second one is a variable frequency three-phase inverter whose input voltage range is 200 VAC to 240VAC and its output frequency range is from 0 to 300 Hz.

In order to select the batteries and aiming an economical prototype, Li-PO or Ni-Cd types were not considered. On the other hand, as the traditional lead acid type requires maintenance, due to the drawbacks of the electrolyte and water losses, it was preferred the valve regulated sealed lead acid battery (VRLA). According to Larminie and Lowry (2003), VRLA's batteries are designed to eliminate the emission of gases with a small volume of free electrolyte, therefore, there is no need for maintenance. The batteries were mounted on the rear bottom of the prototype, as shown in Fig. 2.

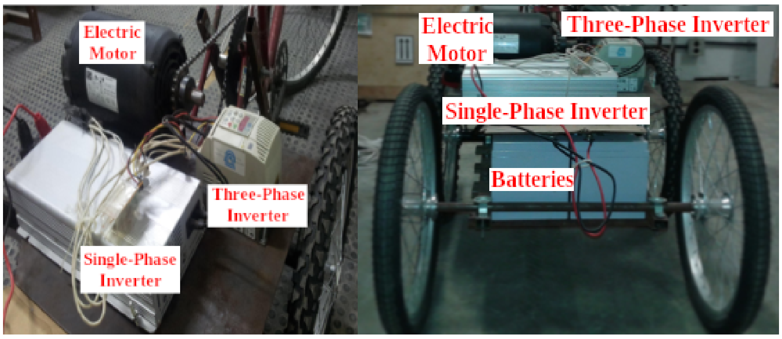

Figure 2. Two views of the electrical components.

As known, the inverters can change the electric supply from direct current to alternative current. In this work, the three-phase inverter allows the voltage and frequency to be controlled through external buttons or potentiometers. In this paper, the second option was preferred. Thus, the potentiometer of an automotive throttle butterfly was used and fixed in the front handlebar of the vehicle. Then, it was connected to a single operational amplifier in order to give the inverter frequency reference. This device is shown in Fig. 3.

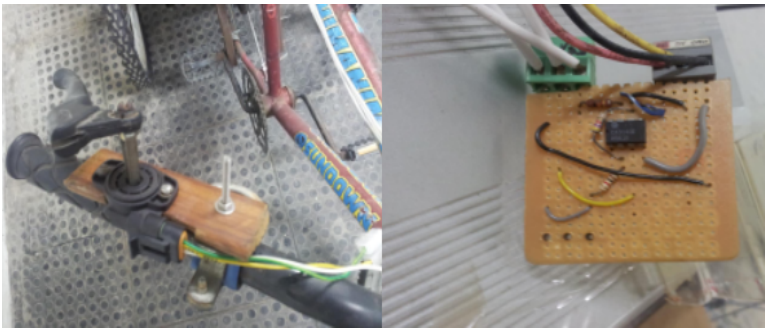

Figure 3. Automotive throttle butterfly (left) and operational amplifier (right).

The mechanical transmission system is comprised by a differential system coupled to two wheels. It was designed a reduction system with a ratio of 5.0555, as shown in Fig. 4**.** Moreover, with auxiliary support of the university mechanical laboratory, some mechanical parts were manufactured.

Figure 4. Mechanical Transmission System.

Finally, in Fig. 5, the final prototype is shown. The driver, with the potentiometer set at the handlebar, controls indirectly the energy supplied by the batteries, using inverters connected to the electric motor, which is converted into mechanic energy. Then, the speed is controlled through the mechanical transmission system. To conclude, tests on the laboratory have proven its feasibility with a person weighing 80 kg and a height of 1.78m.

Figure 5. Electric moped prototype assembled.

2.2 Methodology for power and torque simulations

According to Larminie and Lowry (2003), for modeling an electric vehicle the first step is to calculate the tractive effort (F_{total}) as in Eq. (1). This is divided in four components: rolling resistance force (F_{rr}), linear acceleration force (F_{la}), angular acceleration force (F_{aa}) and aerodynamics drag force (F_{ad}). They allow to get the maximum torque and power under a selected driving condition.

$$F_{total} = F_{rr} + F_{la} + F_{aa} + F_{ad} \tag{1}$$

All the forces are straightforward to calculate with exception of the aerodynamic drag force (F_{ad}), as seen in Eq. (2), where ρ_{wheel} stands for air density, $A_{frontal}$ stands for the vehicle-driver system area that suffers the aerodynamics drag, C_{drag} is the drag coefficient and $v(t)$ is the linear speed.

$$F_{ad} = \frac{\rho_{air} \times A_{frontal} \times C_{drag} \times v(t)^2}{2} \tag{2}$$

According to Debraux et al (2011), $A_{frontal}$ and C_{drag} can be calculated as in Eq. (3) and Eq. (4) respectively, where (h_{driver}) and (m_{driver}) are the height and mass of the driver.

$$A_{frontal} = 0.0293 \times h_{driver}^{0.725} \times m_{driver}^{0.425} + 0.0604 \tag{3}$$

$$C_{drag} = 4.45 \times m_{driver}^{-0.45} \tag{4}$$

Then, the rolling resistance force is due to the friction of the vehicle tyre on the road, as well as in bearings and the transmission system. However, Larminie and Lowry (2003) stated that this force is approximately constant, relying on the gravity constant (g), vehicle-driver system weight (m_{system}) and a coefficient of rolling resistance (μ_{rr}).

$$F_{rr} = m_{system} \times g \times \mu_{rr} \tag{5}$$

Another one, derived from Newton's Second Law, is the force due linear acceleration (Larminie and Lowry, 2003)

$$F_{la} = m_{system} \times a(t) \tag{6}$$

Finally, according to (Larminie and Lowry, 2003), the angular acceleration force (F_{oa}) can be calculated as it is shown in Eq. (8), where I_{rotor} stands for the inertia of the electric motor's rotor, gear efficiency, G is the gear ratio of the system connecting the motor shaft to the wheels axle, r_{wheel} stands for the wheel's radius, a for linear acceleration

$$F_{aa} = \frac{I_{rotor}}{\eta_{gear}} \times \frac{G^2}{r_{wheel}^2 \times a(t)} \tag{7}$$

Overall, the total torque (T_{total}) can be calculated basically recalling Eqs. (1) to (7), as shown in Eq. (8).

$$T(t)_{total} = \frac{F(t)_{total} \times r_{wheel}}{G} \tag{8}$$

Similarly, the total power (P_{total}) can also be calculated basically recalling Eqs. (1) to (7), as shown in Eq. (9).

$$P(t)_{total} = F(t)_{total} \times v(t) \tag{9}$$

Unlike the internal combustion engine vehicles, there is no standard driving cycle for either electric bicycles or electric moped to evaluate the driving performance. Nevertheless, following the approach found in Larminie and Lowry (2003), the adopted driving cycle was that given by the standard cycle of tests developed for electric vehicles, the SAE J227a. This standard is depicted in Fig. 6.

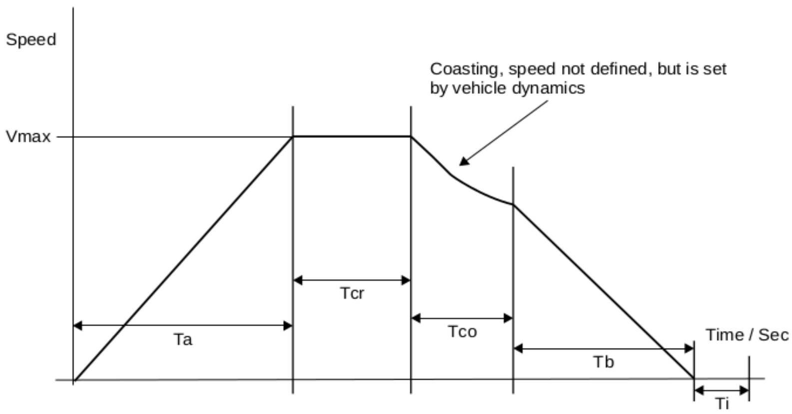

Figure 6. SAE J227a driving cycle (Larminie and Lowry, 2003).

As seen in Fig. 6, the coasting speed can be a setback while modeling, due its non-linearity. However, Larminie and Lowry (2003) stated that during coasting time the total tractive effort is null. Then, Eq. (1) becomes Eq. (10), where μ_{rr} states for the rolling resistance coefficient, g is the gravity constant and η_{gear} is the gear efficiency and m_{system} is the sum of the vehicle's mass and the driver's mass. Overall, from Eq. (10), the speed during coasting time (T_{co}) can be calculated using the finite difference method with the peak speed as initial condition. All the actual parameters to solve Eqs. (2) to (10) are found in Table 1.

$$0=\mu_{rr}\times m_{system}\times g+\frac{\rho_{air}\times A_{frontal}\times C_{drag}\times v(t)^2}{2}+\left(m_{system}+\frac{I_{rotor}}{\eta_{gear}}\times\frac{G^2}{r_{wheel}^2}\right)\times\frac{dv}{dt} \tag{10}$$

Table 1. Input data took from the prototype's components.

Component Property	Value
Electric motor mass	21.0 kg
Three-phase Inverter mass	1.0 kg
Single-phase Inverter mass	3.4 kg
Bicycle mass	15.0 kg
Shaft-Differential mass	15.0 kg
Shaft mass	13.0 kg
Four batteries mass	73.0 kg
Others parts mass	13.5 kg
Entire vehicle mass	154.9 kg
Driver mass (m_{driver})	80.0 kg
Vehicle-driver mass (m_{system})	234.9 kg
Driver height (h_{driver})	1.78 m
Wheel radius (r_{wheel})	0.2601 m
Air density (ρ_{air})	1.1839 kg m^{-3}
Gravity acceleration (g)	9.81 m s^{-2}
Inertia of electric motor's rotor (I_{rotor})	0.08153 kg m^2
Rolling Resistance Coefficient (μ_{rr})	0.005
Gear Efficiency (η_{gear})	80%
Gear Reduction (G)	5.0555

On the other hand, as seen in Fig. 6, the other speeds are straightforward to calculate and it just needs its time parameters as well as maximum speed, as shown in Table 2. Also, according to Larminie and Lowry (2003), the most commonly used cycle is SAE J227a-C, which is suitable for light-duty electric vehicles as is the case of the present electric moped prototype.

Table 2. Input data for the four variations of the SAE J227a driving cycles. (Larminie and Lowry, 2003).

Parameter	Cycle A	Cycle B	Cycle C	Cycle D
Maximum speed (V_{max})	16 km h^{-1}	32 km h^{-1}	48 km h^{-1}	72 km h^{-1}
Acceleration Time (T_a)	4 s	19 s	18 s	28 s
Cruise Time (T_{cr})	0 s	19 s	20 s	50 s
Coast Time (T_{co})	2 s	4 s	8 s	10 s
Brake Time (T_b)	3 s	5 s	9 s	9 s
Idle Time (T_i)	30 s	25 s	25 s	25 s
Total Time	39 s	72 s	80 s	122 s

2.3 Finite Difference Method

In order to solve Eq. (10), it is necessary a numerical method, due its non-linearity. From mathematics, it is possible to recall the Taylor Series, shown in Eq. (11).

$$f\left(x_0 \pm \Delta x\right) = f\left(\Delta x\right) \pm \Delta x \frac{df\left(x_0\right)}{dx} + \frac{\left(\Delta x\right)^2}{2!}\frac{d^2 f\left(x_0\right)}{dx^2} + \ldots + \left(-1\right)^{n-1}\frac{\left(\Delta x\right)^{n-1}}{\left(n-1\right)!}\frac{d^{n-1} f\left(x_0\right)}{dx^{n-1}} + O\left(\Delta x^n\right) \quad (11)$$

Then, with some simplifications it is easier to use a numerical method to perform a computer simulation of the mechanical parameters of the vehicle. In fact, from Taylor Series, shown in Eq. (11), it is possible to use the First Order Forward Finite Difference Method for the speed profile, as shown in Eq. (12), where O(Δt) is the error.

$$v\left(t_0 + \Delta t\right) = v\left(\Delta t\right) + \Delta t \frac{dv\left(t_0\right)}{dt} + O\left(\Delta t\right) \quad (12)$$

3. RESULTS

Using Eq. (1) to Eq. (10), Eq. (12), the driving conditions from Fig. 3 and the data from Tables 1 and 2, it is possible to find the speed profile of the system, as shown in Fig. 7. Furthermore, aiming a better fitness of the simulation, the effects of different time steps on the calculated speed at the end of the coast time, were evaluated. These are summarized on Table 3.

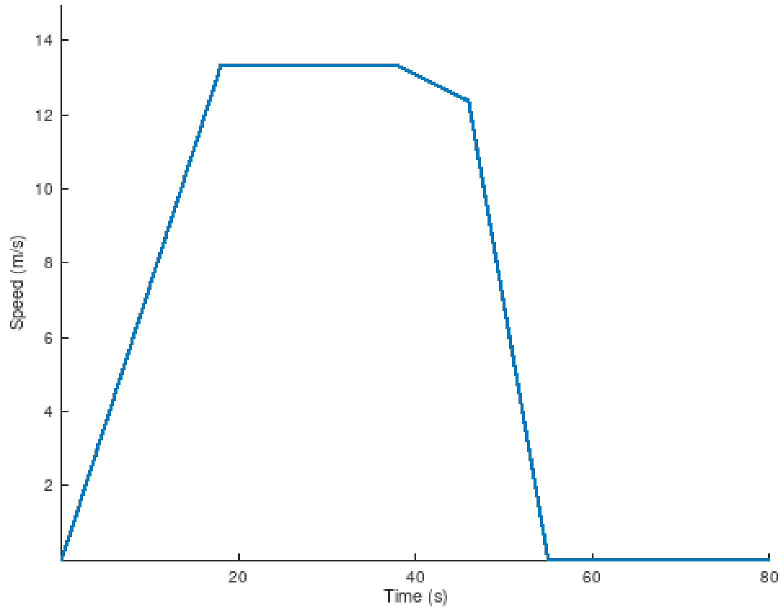

Figure 7. Speed profile.

Table 3. Speed at 46 seconds (at the end of the coast time), for different time steps (Δt).

Time steps (s)	Error	Speed (m s^{-1})
Δt = 0.1	O(Δt) = 0.1	12.3134
Δt = 0.01	O(Δt) = 0.01	12.3745
Δt = 0.001	O(Δt) = 0.001	12.3806
Δt = 0.0001	O(Δt) = 0.0001	12.3812

Finally, with the speed of 12.3812 m s^{-1}, shown in Table 3, it is possible to plot the system's power and torque as a time function yielded from Eqs. (8) and (9). They are shown in Fig. 8 and Fig. 9, respectively.

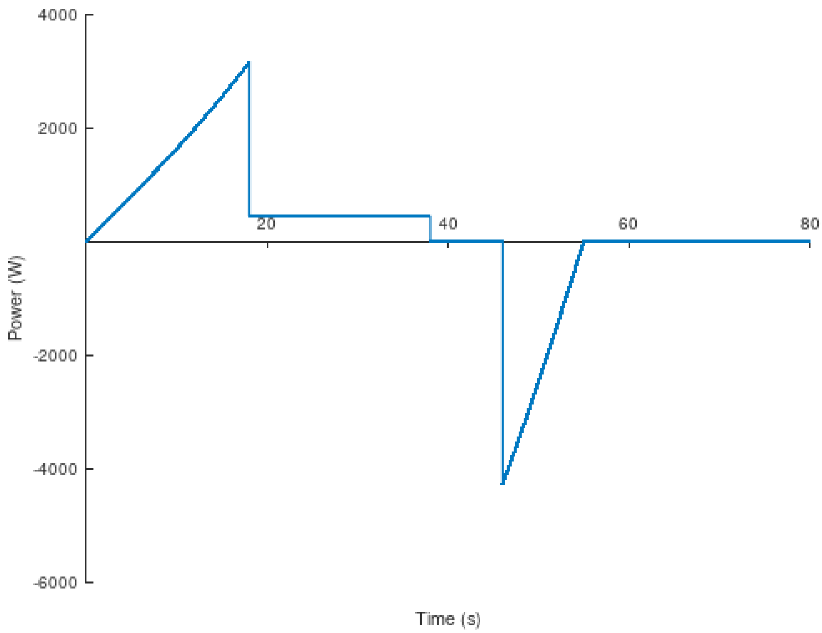

Figure 8. Power profile.

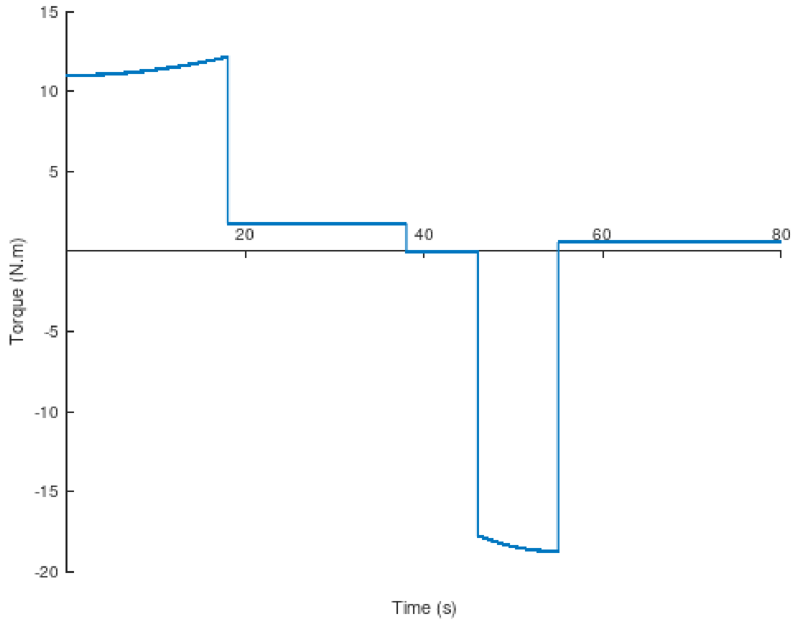

Figure 9. Torque profile.

4. CONCLUSIONS

In this paper, the development of an electric moped using inexpensive electrical parts to build it has been described. Its feasibility under laboratory conditions has been proven. Additionally, aided by mechanical equations and the finite difference method, a computational modeling of the electric vehicle behavior was developed. Then, it was possible to obtain the vehicle-driver system's plots of speed, power and torque as a time function.

Furthermore, for next studies, it would be desirable to verify the correlation between experimental results and the computer simulations. From the estimation of the speed, at the end of coasting time, using different time steps, the smaller the time step caused slight differences, only noted in the second decimal place, as seen in Table 3. Also, it was noted that the speed profile during coasting time of the vehicle depends on its own dynamics, described by SAE J227a. By instance, from Fig. 7, the present vehicle has a linear speed profile for the coasting time. Finally, with this study, more researchers are encouraged to profound in more aspects regarding electric mobility, and, at the same time, it is expected to motivate profitable business with inexpensive investments.

5. ACKNOWLEDGMENTS

The authors are grateful for the partial support of the Brazilian National Council for Scientific and Technological Development (CNPq).

6. REFERENCES

CONTRAN, Resolução Nº 465, 2013. Retrieved on February 22, 2019 <http://www.denatran.gov.br/download/Resolucoes/Resolucao4652013.pdf>

Costa, W., 2009. *Metodologia para conversão de veículos equipados com motores a combustão interna para tração elétrica: aplicação de motor síncrono de ímã permanente com fluxomagnético radial a um furgão*. Master's thesis. Universidade Estadual do Rio de Janeiro, Rio de Janeiro – RJ, Brazil.

Debraux et al. 2011. "Aerodynamic drag in cycling: Methods of assessment". *Sports Biomechanics*. Vol. 10, No. 3, pp. 197-218.

Falkner, R. 2016. "The Paris Agreement and the new logic of international climate politics". *International Affairs*, Vol. 92, No. 5, pp. 1107–1125.

Guedes, T. S. 2008. *Projeto de veículo elétrico para competição de eficiência energética*. Undergraduate thesis. Universidade Federal de Santa Maria. Santa Maria – RS, Brazil.

Hagen, J., Lobo, Z. and Mendonça, Cristina. 2013. "The Benefits of Cargo Bikes in Rio de Janeiro: A Case Study". In *Proceedings of the 13th World Conference on Transport Research - WCTR 2013*. Rio de Janeiro, Brazil.

Larminie, J. and Lowry, J. 2003. *Electric Vehicle Technology Explained*. John Wiley and Sons Ltd., Chichester, Southeast England, England.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.