Simulative Comparison between Electric and Thermal Powertrains on Different Real Road Missions

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Abstract: Pure electric mobility is still struggling to emerge in the present road vehicles scenario. This is mostly due to costs, nowadays still very high, and to battery range, which is intrinsically very limited with respect to the fuel tank of a traditional vehicle.

To be effectively competitive, e-mobility should not be thought as the mere substitution of the thermal powertrain with the electric one on the same vehicle; instead, a holistic approach comprehensive of the integration of a charging network within the territory should be adopted. The vehicles should be tailored on the missions to be accomplished promoting the lightness, simplicity and low cost, and should be integrated within a charging infrastructure and a car-sharing system implemented in the reference territory.

In this paper the authors aim at exposing their idea of e-mobility, justifying it by simulations carried out on three different vehicles (a Diesel-fuelled Renault Kangoo, an electric driven Renault Kangoo and an electric micro-vehicle Renault Twizy) and experimental data. The simulations were carried out with the help of a validated road vehicle model in different real road missions, namely a urban, an extra-urban and a mountain mission.

Keywords: Electric mobility, simulation model, comparative assessment, Matlab-Simulink, carbon dioxide Reduction, car sharing.

1. INTRODUCTION

Transport absorbs about 1/5 of world energy consumption, of which about 80% is imputable to road vehicles [1-3]. This sector has a high potential from the point of view of energy savings, being characterized by the presence of numerous energy converters (the single vehicles) spread over the territory, each operating with a rather low average overall efficiency.

In the context of road vehicles, pure electric mobility presently involves a very low number of sold vehicles, whereas in the last years an increase can be remarked in the selling of hybrid electric vehicles. Among the advantages of e-mobility there are: the more sustainable road mobility in densely populated territories; the containment of primary energy consumption; the improvement of CO_2 balance; the new high-tech productions. Moreover, e-mobility allows to take the pollution generated by combustion away from the densely populated centers and from the protected areas.

The main reasons for which pure electric mobility is still poorly employed are the vehicles costs and the limited range. The battery of an electric vehicle can store an energy amount ranging between few kWh to some dozens of kWh (between 150 to 700 kJ/kg according to the battery technology). In comparison, the fuel tank of a traditional vehicle can store several hundreds of kWh (for liquid fuels, the order of magnitude is about 40 000 kJ/kg). The normal “recharge power” for a traditional thermal vehicle is in the order of a dozen of MW. The power accepted during charging by the electrochemical storage systems is not comparable. For electric vehicles, these issues lead to: i) a range about 10 times lower than thermal vehicles; ii) a crucial dependence on infrastructures; iii) a time of unavailability for re-charging from 50 to 500 times higher than thermal vehicles.

Other aspects to be carefully analyzed when studying e-mobility are: i) the increase of stochastic electric loads on the low voltage grid [4-6]; ii) the effects of power distortion on the low and medium voltage electric sub-stations; iii) the impact on the consumption of raw materials such as copper, lithium, rare earths …; iv) the financial and economical impact for the community; v) the impact on employment.

In the authors vision, the present idea of electric vehicles, directly derived from series cars models just substituting the thermal powertrain with an electric one, is not the “killer application” of e-mobility. In fact, if the electric vehicle was intended as a total substitution of the traditional thermal or hybrid vehicle for private use, it could not satisfy all the customer’s requirements which are in general: i) comparable performance and comfort; ii) equivalent safety conditions; iii) competitive esthetic appeal; iv) equal availability of exercise.

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E-mobility can be seen as part of an inter-modal infrastructure of public interest (although managed privately and without state or regional incentives), aimed at pursuing the environmental reclamation of highly populated urban areas or severely protected territories. In this background, the electric vehicle must be completely re-thought in its conceptual design. In particular, the vehicle should be designed in terms of: i) performance strictly tailored on the missions to be accomplished; ii) maximum simplicity in the vehicle construction; iii) mass lower than 4-5 times the average payload; iv) maximum standardization, for costs reduction; v) improvement of the utilization coefficient through a car-sharing framework.

In this paper the authors aim at presenting and justifying through simulations (validated by experiments) their vision of pure electric mobility in a mountain territory context, represented by the Valle d’Aosta Italian region.

The paper shows the results of a simulation campaign carried out in order to study the behavior of two different electric powertrains on different missions, in comparison with a traditional Diesel fuelled powertrain. The simulations envisaged three different road missions: a urban, an extra-urban and a mountain mission. In such missions, three types of vehicles were tested: a Diesel-fuelled light truck (Renault Kangoo 1.5 dCi), an electric light truck (Renault Kangoo Z.E.) and a micro-electric vehicle (Renault Twizy).

The simulations were worked out by the use of a Matlab– Simulink model, able to correctly reproduce the powertrain of a generic road vehicle and calculate the main parameters involved in the energy chain, such as engine working data, energy flows, consumptions, pollutants emission. The simulator envisages a modular structure including the different powertrain components, of which the operational map knowledge is required. The model input data structure allows to easily define the configuration of the specific vehicle simulated, through the setting of parameters such as front area, mass, drag coefficient, engine characteristic curves, powertrain architecture (with hybridization degree ranging from ‘‘full thermal’’ to ‘‘full electric’’) and control logic parameters. The simulator was named VECTRA (VEhicle EConomy in TRAnsport).

The simulator was validated through an experimental campaign, which envisaged the use of a Kangoo Z.E. electric vehicle.

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2. METHODOLOGICAL APPROACH

In order to analyze the energy flows involved in road vehicles, the powertrain was divided into its main components [7]. From this point of view, it is possible to consider the vehicles as composed by a sequence of energy converters; each converter is qualified by an efficiency value, through which it is possible to identify the contribution of the different powertrain components to the total energy loss.

In the upper part of Figure **1** is depicted the general scheme of a traditional thermal engine-powered vehicular powertrain. From the fuel energy (flowing from the fuel tank to the wheels, as indicated by the arrows) are subtracted the losses in the engine thermodynamic cycle (calculated by the thermodynamic efficiency η_i), the losses related to friction in the engine parts in sliding contact (calculated by the mechanical efficiency η_m), the losses related to transmission (calculated by the transmission efficiency η_t).

The chain of energy converters composing the thermal vehicle powertrain is characterized by an overall efficiency averaged over the whole vehicle mission, as defined in Equation (1)

$$\eta_g = \frac{Motion\ Resistance\ Energy}{Primary\ Fuel\ Energy} = \gamma\eta^* \frac{1-R}{1+\varphi} \tag{1}$$

In Equation (1):

$\gamma = \bar{\eta}_d / \eta*$ is the “engine efficiency de-rating factor”, which accounts for the limited utilization of the engine design power; $\bar{\eta}_d$ is the direct chain efficiency (i.e. the average efficiency value calculated, over a mission, in the route from the fuel tank to the wheels) and η^* is the engine design efficiency. Internal combustion engines efficiency values depend in fact on the working conditions (in particular load and rotational speed), and can assume values between 0 and η^*. Engine efficiency [8] is a function of thermodynamic efficiency (η_i) and mechanical efficiency (η_m). γ values are around 0.35 for mixed driving cycles (urban cycle + extra-urban cycle), as emerging from simulations.

$R = |W_r| / W_d$ is the “reverse energy ratio” and represents the ratio between the negative energies and the positive energies exchanged with the road; W_d is

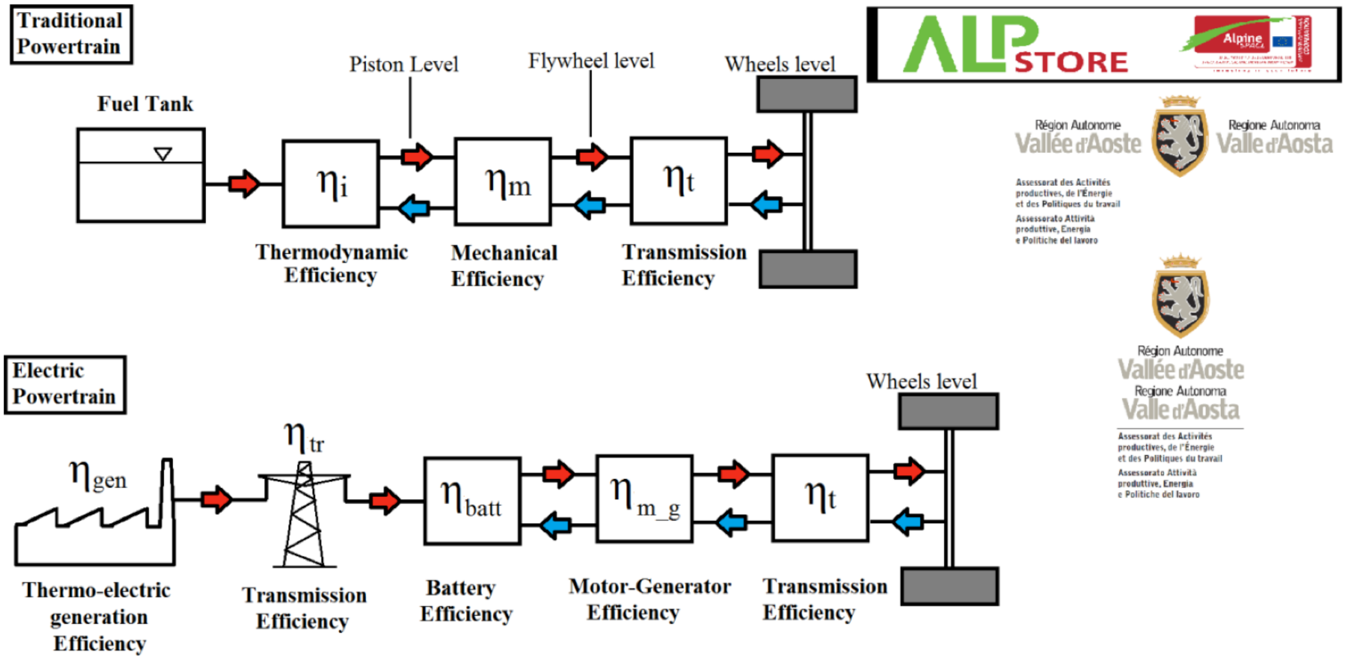

Figure 1: Chain of the energy conversions for thermal engine and electric engine powered vehicles.

the energy contribution directed from the engine to the wheels (direct) while W_r is the energy flowing in the opposite direction, from the wheels to the engine (reverse). The two contributions are widely explained in [9].

$\varphi = F^0 / F^+$ is the ratio between fuel consumption in idle condition, F^0, and fuel consumption during the positive power output phases, F^+. Typical values of φ for mixed driving cycles, for a vehicle without the stop & start function, are in the range between 0 and 0.1.

The electric powertrain scheme, characterized by a different configuration of the energy path, is represented in the lower part of Figure **1**. To compare the thermal and electric powertrains on equal terms, it is necessary to consider the whole energy chain from the primary fuel energy to the vehicle wheels, included the conversion into electric energy, the transmission across the electric grid and the battery crossing efficiencies.

It is important to remark that stochastic renewable energy sources (flow sources, with the exception of hydro-electric basins and biomasses), in Italy, provide a contribution of 20-30% to electric generation, while the remaining is provided by fossil sources. The power produced by stochastic renewable energy sources has priority in the grid and is mainly employed to satisfy the base load, whereas the power produced by fossil fuels is controllable and allows therefore to assure the grid stability.

The load represented by new electric vehicles is an incremental load with respect to the existing condition, and is moreover of stochastic nature, being imputable to mobility demand and not to electric system constraints.

For these reasons, the authors believe that every mile traveled by an electric vehicle (which substitutes the same mile traveled by a thermal vehicle) is fuelled by fossil source. This involves that the energy chain associated to electric mobility does not start from the renewable portion of power produced, but needs to be extended, for comparative reasons, up to thermo-electric generation.

For electric vehicles, an expression similar to Equation 1 can be written for the on-board conversion efficiency, in which the term regarding the energy recovery during negative power phases (decelerations or downhill) appears. Such expression is reported in Equation (2):

$$\eta_g = \gamma\eta * \frac{1-R}{1-R\bar{\eta}_d\bar{\eta}r} \tag{2}$$

being $\bar{\eta}_d$ the direct chain efficiency and $\bar{\eta}r$ the energy recovery efficiency i.e. the efficiency with which the reverse energy, directed from the wheels to the battery, is converted from kinetic/potential energy to electric energy and stored in battery as chemical energy.

3. THE VECTRA SIMULATOR

The exploitation of numerical simulation facilities, validated on a sufficient number of experimental tests [9], allows to understand the sensitivity of a complex system to different variables and parameters. Through simulation, it is possible to compare on equal terms different vehicles on the same mission or different missions for the same vehicle. This allows to optimize the sizing of the various components in function of pre-defined goals (performance, emissions, efficiency …) and to find the most robust logics and control algorithms.

Exploiting the Matlab-Simulink environment potentialities, the vehicular powertrains were represented through a cascade of blocks, each simulating one part of the traction system. In this manner, given a specific mission and a known vehicle, it is possible to obtain information about the energy flows involved and the consequent losses, as well as the value of fuel consumption and emissions. The model calculates said quantities starting from the resistance to motion at the wheels level, known from the mission data; once determined the power needed for motion, the simulator proceeds backwards along the energy chain up to the primary energy reservoir, calculating time by time the power involved. In Figure **2** is provided a graphic example of the model output, namely the Sankey diagram of a hybrid-electric vehicular powertrain compared to that of a traditional powertrain.

3.1. Model Description

The simulation model was conceived in order to be free from any reference to a specific vehicular configuration, and to be easily adaptable to different arrangements through the simple modification of the characteristic parameters. The input data files were divided into groups related to:

- **vehicle**: this group contains the information about the vehicle physical features needed to calculate the resistance to motion (mass, front area, drag coefficient, wheels radius …); and the engine design data (maximum power, maximum torque, efficiency maps, gearbox transmission ratios …);
- **mission**: this group includes the data related to the mission (vehicle speed and road elevation profile) and defines the begin and end instants of the mission;
- **energetic parameters**: this group is dedicated to the quantities connected to thermodynamic cycle efficiency and engine mechanical efficiency;

Figure **3** shows a scheme of the simulation model, including the blocks that represent the powertrain components. In the following is provided a description of each block.

Load: this block calculates the different contributions to vehicle resistance imposed by mission (tire rolling, aerodynamic resistance, inertia, up and downhill), and so the power required for motion, implementing the classical and well known equations of motion, rolling resistance and aerodynamic drag.

Gearbox (transmission): given a transmission efficiency, this block computes the energy lost into heat due to friction in the gears.

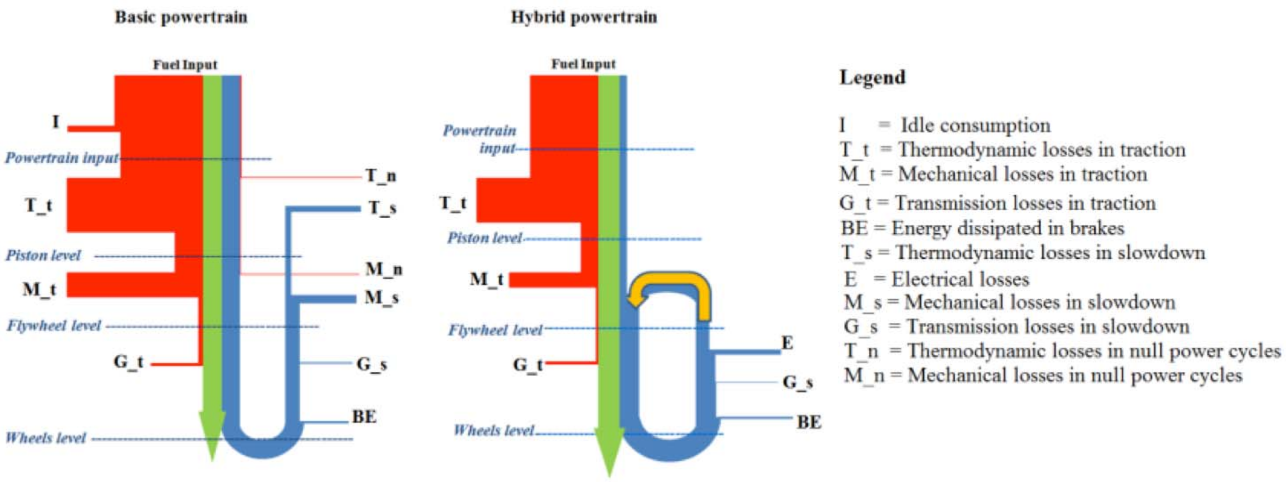

Figure 2: Sankey flow diagrams for a traditional thermal powertrain and for a hybrid powertrain.

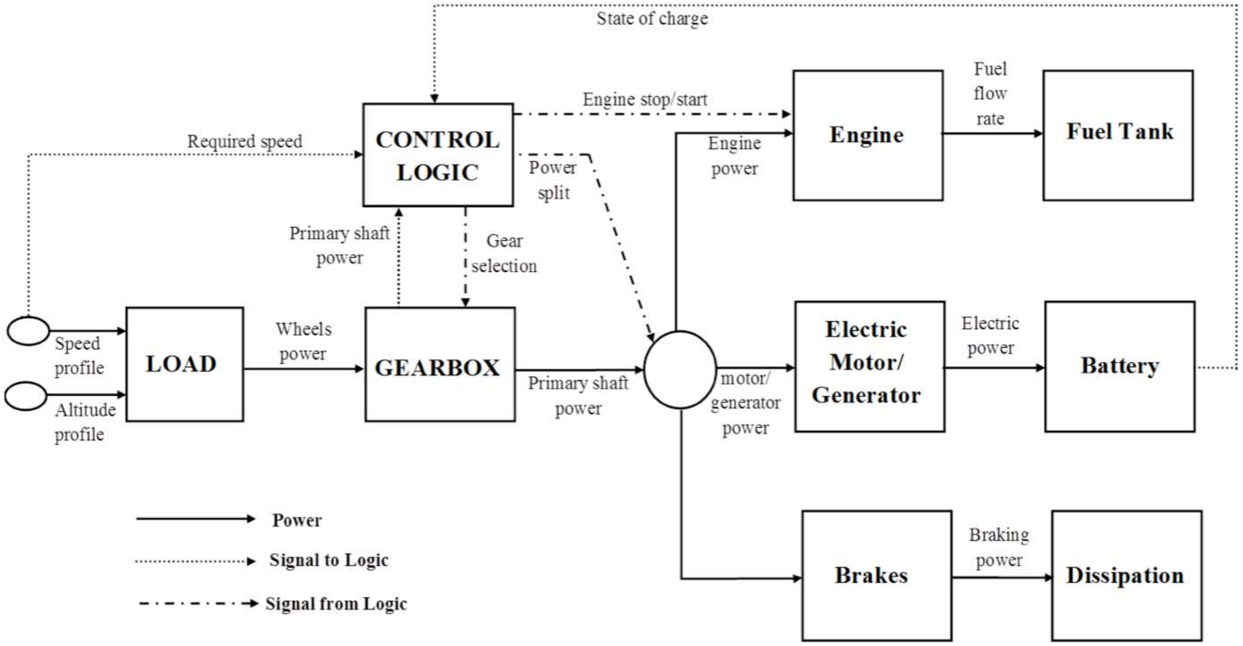

Figure 3: Scheme of the physical and logical connections in the VECTRA model.

Control logics: through a series of Simulink "Switch" items, based on the signals of required speed, primary shaft power and battery state of charge, this block controls all the functions of the proposed powertrain system. In particular:

- it allows to set the gearbox transmission ratio in function of vehicle speed and power required for motion. The gearbox transmission ratio is imposed on the basis of opportunely determined operational maps: the latter, associate to every couple of values (load, vehicle speed) a discrete value of the gearbox transmission ratio;
- it controls the engine stop/start function;
- it controls the subdivision of the power between engine, electric machine and brakes (power split).

Engine: the Engine block computes the thermal engine internal energy losses, of both mechanic and thermodynamic nature. The block implements efficiency maps in function of engine rotational speed and load required. These maps were derived from literature data [8] on Diesel engines, elaborated in the form of efficiency values normalized by engine power in order to be representative of the behavior of different size engines [10].

Electric motor-generator: this block contains the motor-generator system efficiency chart.

Battery: this block contains the operational map of the battery efficiency in function of the power to capacity ratio [11-15]. The battery block allows moreover to calculate the instantaneous battery state of charge.

Fuel tank, dissipation: these blocks integrate in time their respective input signals providing as output, respectively, the mass of fuel contained in the tank and the amount of energy dissipated in brakes.

4. SIMULATION CAMPAIGN

The simulation campaign envisaged the use of three different vehicles, two electric and one thermal, whose main features are reported in Table **1**.

The Renault Twizy can be thought as one example of micro-electric vehicle with limited weight and performance, finalized to a limited number of missions in a well defined territorial context such as the Valle d'Aosta landscape. The Renault Kangoo Z.E. is instead one example of a traditional electric vehicle, derived from the analogous model with thermal engine. Finally, the Renault Kangoo 1.5 dCi is the reference vehicle for the tests.

In the following, are presented the data of the three missions for which the simulation tests were worked out. The speed and altitude profiles were acquired by on-board GPS instrumentation.

Table 1: Features of the Tested Vehicles

	Kangoo 1.5 dCi	Kangoo Z.E.	Twizy
Mass [kg]	1280	1450	550
Storage Capacity [kWh]	580	22	7
Power [kW]	66	44	15

The first mission is a urban one. The journey was chosen as a round-trip, in order to have identical elevation at the beginning and at the end of the mission; the total length is about 22 km, with an average speed of 19 km/h, a top speed of 68 km/h and a total elevation difference of 250 m. The reverse energy ratio is 0.53 for the Twizy vehicle and 0.57 for the Kangoo vehicle; the difference is mainly due to the different vehicular masses.

The mission includes several stops owing to traffic lights. The diagrams in Figure **4** report the speed and elevation profiles of the urban route.

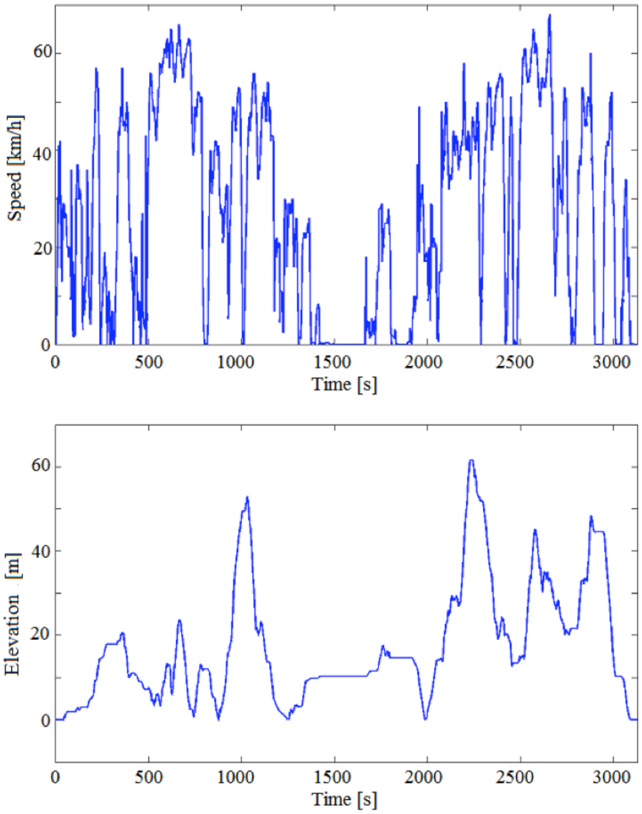

Figure 4: Speed and elevation profiles for the urban route.

The extra-urban mission profile is representative of the travel in the valley on provincial roads, with several crossings of inhabited centers. The mission is characterized by a total length of 36 km, an average speed of 45 km/h, a top speed of 81 km/h and a total elevation difference of 400 m. The reverse energy degree for this mission is 0.52 for the Twizy and 0.56 for the Kangoo. In Figure **5** are reported the speed and elevation profiles of the mission.

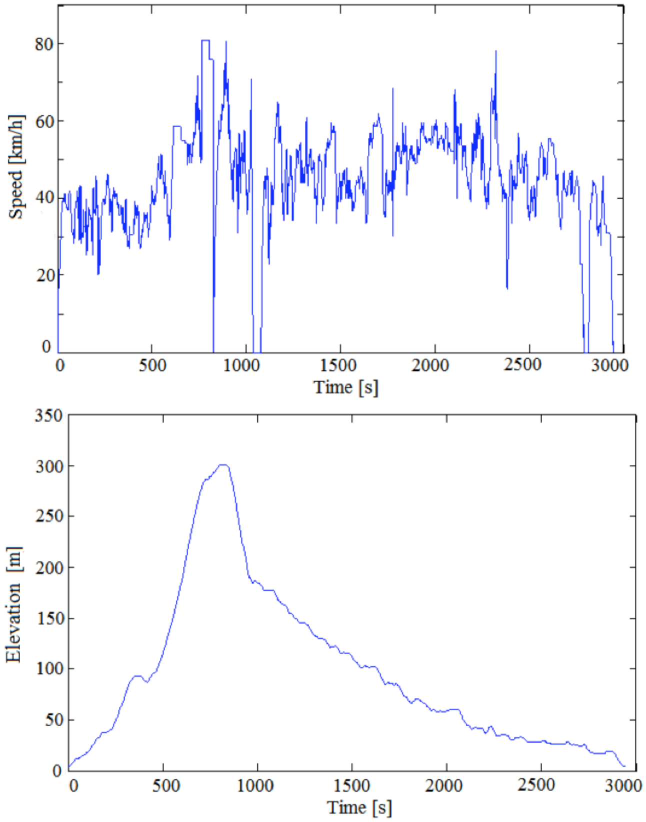

Figure 5: Speed and elevation profiles for the extra-urban route.

The mountain mission, representative of the travel in a track with high elevation differences, presents the following features: a length of 23 km, an average speed of 47 km/h, a maximum speed of 84 km/h and a total elevation difference of 750 m. The reverse energy ratio is 0.62 for the Twizy and 0.65 for the Kangoo. In Figure **6** are represented the speed and elevation profiles of the mission.

5. RESULTS OF THE SIMULATIONS

Figure **7** shows a schematic representation of an electric energy chain, emphasizing the energy flows involved during a mission. In particular, in the figure is represented the energy chain of the electric Kangoo vehicle in the mountain mission. The energy flows are expressed in Wh.

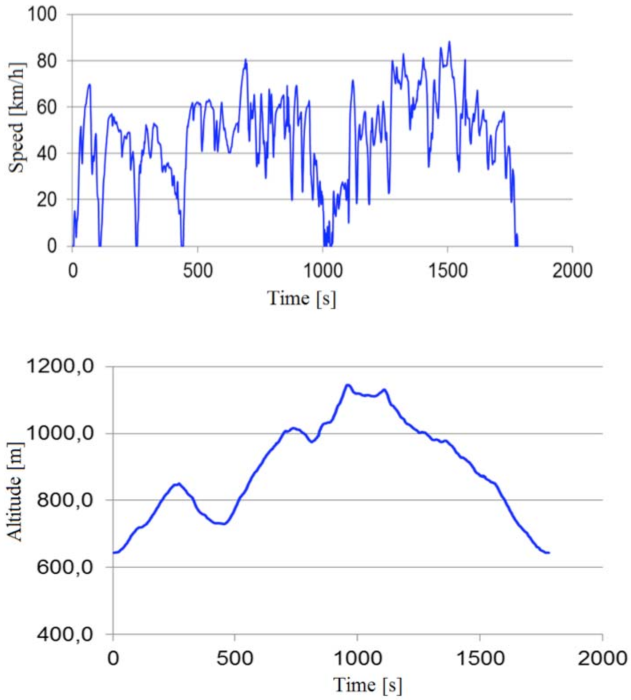

Figure 6: Speed and elevation profiles for the mountain route.

As visible, the energy chain starts from the thermo-electric power generation, characterized by an average conversion efficiency assumed as 0.447. The chain continues with the distribution grid characterized by a transmission efficiency assumed as 0.852.

The average battery charge and discharge efficiency value during the mission (respectively 0.91 and 0.84) so as the inverter-motor drive system efficiency (0.84), were calculated by the simulator through–the operational maps of the battery and of the motor-inverter system. The simulator provided also the calculated efficiency of the battery charging with the reverse energy flow over the mission, equal to 0.81. The vehicle transmission efficiency, 0.95, was calculated by the model basing on the transmission map.

The primary energy needed by the electric vehicle to accomplish the mission, upstream of its conversion into the thermo-electric system, is 21904 Wh. Downstream of such conversion, the generated electric energy is 9791 Wh, which still needs to pay for the distribution efficiency and the battery charging efficiency. The battery sees an energy input equal to 7587 Wh of effective chemical energy, plus the reverse energy flowing from the wheels to the battery.

In the figure also appears the battery balance: the chemical battery input (7587 Wh) is equal to the algebraic sum of the chemical battery output (9433 Wh, which comes from the net electric output, 7924 Wh, divided by the discharge efficiency equal to 0.84) and the reverse chemical energy recovered (– 1846 Wh, which comes from the conversion into chemical energy of the reverse electric energy coming from the motor-inverter system i.e. – 2279 Wh multiplied by 0.81).

The direct energy exchanged from the wheels to the road is equal to 6290 Wh. This energy is in part (2179 Wh) employed to win the resistance to motion (wheels rolling and aerodynamic drag) and in part is returned to the chain as reverse energy (4111 Wh). Such reverse energy is in part dissipated in the brakes (1240 Wh) and in part flows back from the wheels to the battery (2871 Wh); this is possible thanks to the energy

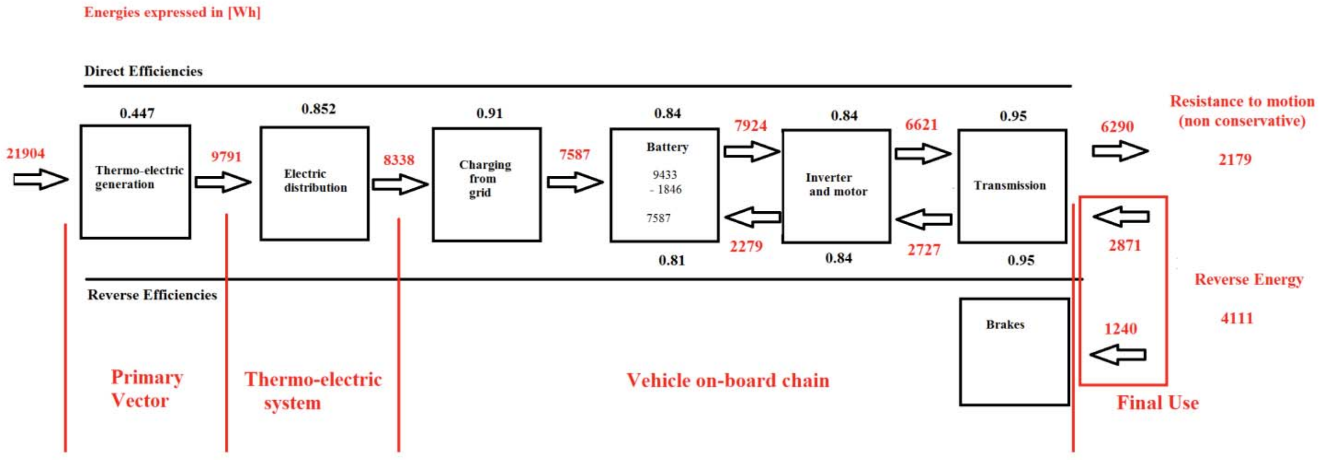

Figure 7: Energy flows and chain efficiencies for the Kangoo vehicle in the mountain mission.

recovery system equipping the electric vehicle. The reverse energy must pay again the transmission efficiency, the inverter and motor efficiency and the battery efficiency in the charging mode (0.81).

In the following sections are presented the results of the simulations for the chosen missions.

5.1. The Urban Mission

Table **2** reports the synthesis of the results obtained by simulations in the urban mission, for the three vehicles tested.

The table reports the primary energy, in Wh/km, consumed to accomplish the mission; the overall energy chain efficiency; the on-board energy chain efficiency (intended as the conversion efficiency obtained within the vehicle, without accounting for the conversion between primary fuel energy and electric energy); the consumption in km/l (for the electric vehicle, the equivalent consumption in km/l was considered); the CO_2 emissions during the mission. Of course, for the diesel-fuelled vehicle the chain efficiency is equal to the on-board chain efficiency since the conversion between primary fuel and motion occurs directly on-board.

As visible, the electric traction for the Kangoo vehicle allows, with respect to the diesel powertrain, a reduction of the required primary energy of 107 Wh/km (– 16.8%) and a reduction of the CO_2 emissions of 61 g/km (– 35%).

The substitution of the thermal Kangoo vehicle with the micro electric Twizy vehicle in the urban mission allows a reduction of the primary energy required of 432 Wh/km (– 68%) and a reduction of the CO_2 emissions of 129 g/km (– 75%).

5.2. The Extra-Urban Mission

In Table **3** is reported the synthesis of the results obtained in the extra-urban mission, for the three vehicles tested.

As visible in the table, the substitution of the Diesel-fuelled Kangoo vehicle with the electric one does not show a substantial variation of the primary energy amount required for the mission, but performs a reduction of the CO_2 emissions of 33 g/km (– 22%).

The substitution of the thermal Kangoo vehicle with the micro electric vehicle in the extra-urban mission allows a reduction of the primary energy required of 334 Wh/km (– 60%) and a reduction of the CO_2 emissions of 104 g/km (– 69%).

In the extra-urban mission, the thermal engine works much closer to its design power than in the urban mission, and for this reason its chain efficiency results significantly improved. The electric motor,

Table 2: Primary Energy, Chain Efficiencies, Consumption and Emissions for the Three Vehicles Tested in the Urban Mission

	Kangoo 1.5 dCi	**Kangoo Z.E.**	**Twizy**
Primary Energy [Wh/km]	636	529	204
Chain efficiency	0.086	0.104	0.115
On board chain efficiency	0.086	0.274	0.303
Consumption [km/l] (equivalent consumption for EV)	15.5	19.9	48.5
CO2 emission [g/km]	172	111	43

Table 3: Primary Energy, Chain Efficiencies, Consumption and Emissions for the Three Vehicles Tested in the Extra-Urban Mission

	Kangoo 1.5 dCi	**Kangoo Z.E.**	**Twizy**
Primary Energy [Wh/km]	554	561	220
Chain efficiency	0.102	0.101	0.104
On board chain efficiency	0.102	0.266	0.274
Consumption [km/l] (equivalent consumption for EV)	17.8	17.6	44.9
CO2 emission [g/km]	150	117	46

instead, has an efficiency rather constant with the load, but has a more complex energy chain which pays much for the conversions from primary fuel to battery electric energy. Also, it should be remarked–that the extra-urban mission has a reverse energy ratio lower than the urban mission, thus the electric vehicle is further penalized since lower regenerative braking is possible.

These are the reasons for which the thermal powered Kangoo vehicle, in extra-urban missions characterized by a high average speed, overcomes in efficiency and in fuel saving the electric Kangoo. The Twizy vehicle, instead, remains the most efficient mean thanks to its reduced weight, which allows lower consumptions.

5.3. The Mountain Mission

In Table **4** is reported the synthesis of the results obtained in the mountain mission.

The simulations results show that the substitution of the Diesel-fuelled Kangoo vehicle with the electric one in the mountain mission involves an increase of the primary energy required of 63 Wh/km (+ 9%), and a decrease of the CO_2 emissions of 30 g/km (– 16%).

The substitution of the Diesel-fuelled Kangoo with the Twizy micro electric vehicle involves a reduction of the primary energy required to accomplish the mission of 309 Wh/km (– 43%) and a reduction of the CO_2 emissions of 104 g/km (– 54%).

In the mountain mission, similar considerations as for the extra-urban mission can be made. This explains why the highest chain efficiency is reached for the diesel-fuelled vehicle. Thanks to the low weight, the Twizy micro-vehicle obtains the most advantageous results in consumptions and emissions.

6. MODEL ASSESSMENT ON REAL MISSIONS

The vehicle employed for the assessment of the simulation model was an electric-powered Renault Kangoo Z.E., utilized for the REVE VdA project and equipped with a data acquisition system realized by Politecnico di Torino. The data acquisition system was composed by an interface with the vehicle engine control unit (ECU), a buffer memory and a data transmission system *via* GPRS. The data acquisition system allowed to monitor the vehicle main operational quantities with a frequency of 1 Hz. The parameters made available by the ECU display were:

- vehicle speed, in km/h (integer number);
- position in terms of GPS coordinates and altitude;
- battery state of charge in percentage (integer number);
- electric motor/generator output power in kW (integer number);
- electric motor/generator output energy in Wh (integer number);

To carry out the analysis, three missions were considered: one urban mission, one extra-urban mission and one mountain track, whose main data (distance, average speed, elevation difference) are reported in Table **5**.

The missions were simulated through the VECTRA model. The model outputs considered for the validation were the motor electric energy output and the battery state of charge variation during the whole missions.

The battery energy balance was verified indirectly, through SOC acquisitions on the basis of the design energy amount obtainable by the battery.

Table 4: Primary Energy, Chain Efficiencies, Consumption and Emissions for the Three Vehicles Tested in the Mountain Mission

	Kangoo 1.5 dCi	**Kangoo Z.E.**	**Twizy**
Primary Energy [Wh/km]	714	777	405
Chain efficiency	0.133	0.118	0.121
On board chain efficiency	0.133	0.311	0.318
Consumption [km/l] (equivalent consumption for EV)	13.8	12.7	23.4
CO2 emission [g/km]	193	163	89

Table 5: Results on Real Missions

	Urban Mission		Extra-Urban Mission		Mountain Track	
Distance [km]	11.7		50.12		23.3	
Average speed [km/h]	25.4		50.7		47.3	
Elevation difference [m]	60		250		680	
	Acquired	Simulated	Acquired	Simulated	Acquired	Simulated
Energy consumption	2180	2352	9910	10293	7736	8082
SOC difference	9.0	9.7	41.0	42.6	32.0	33.4

Considering the acquired data sufficiently reliable, it is possible to remark that the simulated results are in sufficient accordance with the experimental results.

7. CONCLUSIONS

This paper focused on the assessment of the fuel economy and emissions performance of thermal and electric vehicles on different road missions.

The assessment was carried out from a simulative point of view, with the help of a simulation tool specifically dedicated to the energetic breakdown of road vehicles. The simulator, which has undergone a thorough validation procedure over three missions experimentally acquired by an instrumented Renault Kangoo Z.E. vehicle, is able to represent any type of road vehicle on any type of mission, provided that the vehicle data and the speed and elevation profiles are known.

In the simulation campaign, three vehicles, namely a Diesel-fuelled Renault Kangoo, an electric driven Renault Kangoo and an electric driven Renault Twizy, were simulated on three different road missions: a urban mission, an extra-urban mission and a mountain mission.

The work aimed at demonstrating the authors point of view on electric mobility, which should not be intended as the pure substitution of a traditional powertrain with an electric one within the same vehicle; to be effectively applicable, e-mobility should be thought as composed by an infrastructure of charging points connected to a specific territory (e.g. urban centre or, as in the present paper, a mountainous region), with small, light and simple vehicles specifically thought for the limited number of missions to be accomplished. Possibly, to improve the fleet utilization factor, a car-sharing framework should be implemented.

The main results found are listed in the following:

- The substitution of the diesel vehicle with an electric-driven Kangoo provides advantages only in the urban mission in terms of primary energy consumption.
- The substitution of the Kangoo with the Twizy micro vehicle provides good energy savings in all the missions, owing to the limited weight of the micro-vehicle.
- The electric powertrain, both the one based on the traditional vehicle and the one based on the micro-vehicle, assures a reduction of the CO_2 emissions, since the average CO_2 emission of the thermo-electric generation is low due to the high conversion efficiency and to the mix of fuels employed.

The results confirm the author's vision regarding electric mobility: the substitution of the thermal powertrain with the electric one made equal the vehicle, is not advantageous, in energetic terms, in all the missions owing to the high weight of the vehicle itself.

The–use of a light and simple vehicle, specifically designed to accomplish a limited number of missions with performance featured on the missions, can instead obtain good results in terms of primary energy and emissions savings. This is mostly due to the higher powertrain degree of exploitation.

NOMENCLATURE

Symbol	Description	[Units]
F	Fuel consumption	[kWh]
R	Reverse Energy Ratio	[-]
W	Energy	[kWh]

Greek

γ	Efficiency derating factor	[-]
φ	Idle consumption ratio	[-]
η	Efficiency	[-]
$\bar{\eta}$	Average efficiency during a mission	[-]
η^*	Design Efficiency	[-]

Subscripts

d	Direct (from engine to road)
g	Global
i	Internal
m	Mechanical
r	Reverse (from road to engine)
R	Related to resistance forces

Superscripts

0	Related to idle condition
+	Related to positive power output

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