Advances in Modelling and Analysis A
Vol. 55, No. 3, September, 2018, pp. 121-127
Journal homepage: http://iieta.org/Journals/AMA/AMA_A

From GREen ENErgy to green LOGistic: A joint analysis of energy, accessibility and mobility

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https://doi.org/10.18280/ama_a.550304

Received: 15 February 2018
Accepted: 21 April 2018

Keywords:
fully electric vehicles, mobility services, path generation, vehicle routing

ABSTRACT

The paper presents a joint-analysis of energy consumption by electric vehicles, accessibility from a port to its catchment area and passengers and freight mobility. The main objective is the optimal design of the transport services using the green energy produced inside the port by sea waves. The research is developed inside the GRE.ENE.LOG. project and considers two main interconnected aspects: the electrical energy production by a "sea-to-grid" technology; the transport services evaluations based on the use of electric vehicles. The focus of this paper is relative to the second aspect. The service's design requires the application of the most advanced models and procedures for the services design considering optimal path and vehicles routing problems. It requires the specification, validation and calibration of passengers and freight demand models. The paper presents the preliminary results relative to the port area of Roccella Jonica (Italy).

1. INTRODUCTION

One of the main objectives of the transport planning is the definition of a sustainable mobility. The sustainable mobility is connected to emission vehicles and to energy produced with low environmental impacts [1].

The two aspects have to be considered as a whole problem: the electrical energy has to be produced by renewable system [2]; the transport vehicles have to produce low emissions.

This paper is relative to a research project concerning: The energy production by the sea waves without any impacts on the environment; the transport services operated by means of Fully Electric Vehicles (FEVs).

The idea (that is the innovation of this research) is to transfer the energy produced from the sea waves in a port to FEVs for passenger and freight services nearby the port area [3].

The research is developed inside the project GRE.ENE.LOG. (from GREen ENErgy to green LOGistic: from the port of Roccella Jonica to the Locride area). The experimental test site is the port of Roccella Jonica (Italy).

The paper reports the specific problem relative to land side, where energy consumption of transport vehicles, accessibility to potential places of interest and passengers and freight mobility are jointly analysed. The aim is to design optimal transport and logistic services for freight and passenger sustainable mobility. The description of energy production is reported in other papers [4].

The transport services design with renewable energy [5-8] requires the use of FEVs considering constraints relative to user's behaviour and vehicle (i.e. autonomy).

One common element to passenger and freight is the optimal generation of paths with the objective of the minimization of cost and energy consumption. Paths can be generated [9-10]: from one origin to one destination, with the traditional minimum paths procedure; from one origin to many destinations, with the traditional Vehicle Routing Problem (VRP). Recently VRP is solved using FEVs [11-13] and adopting macroscopic fundamental diagram [14-15].

In the freight case, the VRP is sometimes studied in combination with optimal Urban Distribution Centre (UDC) location [16-17]. The problem may be continuous or discrete [18-19] in the space, by considering simulation or optimization approach [20-21]. This problem is similar for passengers, considering that the optimal parking area for passengers' FEVs has to be located.

VRP and UDC are subjected to several technical, normative and behavioural constrains. Technical and normative constraints are external to the design problem, as they are fixed and defined outside the transport problem. Behavioural constraint belongs to the transport problem and it is estimated by means of travel demand models.

As far as concerns travel demand estimation, there are different approaches for passenger and freight.

Passengers mobility is related to nautical tourism, considered as a set of leisure activities [22]. Nautical tourists travel along maritime routes reaching different ports with their inland territories [23]. Port users are generally classified in: stationary port users, with boats permanently moored at a port; seasonal users, with boats moored in the port in some periods of the year; in-transit users, that occasionally use port infrastructures and services [24-25]. The first two classes use private or public transport modes to reach (depart from) the port. In-transit users travel by boat to reach the port from the sea. From the port, these users could extend their trip on the land side by means of infrastructures and mobility services to perform some activities in the closer area of the port [25-27].

For what concerns freight, studies on urban freight models can be classified according to different criteria: integration with land use models [28], transport actors modelled (end-user, retailer, wholesaler, carrier…); structure of choice dimensions of transport actors (multi-step or joint), reference unit (commodity/quantity, delivery, truck/vehicle), aggregation level (aggregate or disaggregate), basic assumptions (descriptive or behavioural models). Detailed state-of-the-art are presented in [29-31].

In this context an integrate approach for transport services design is required. It requires to jointly consider accessibility to potential places of interest, passengers and freight mobility and energy consumption of vehicles operating transport and logistic services.

The paper investigates the following elements: supply models, based on graph theory; iso-energetic curves of vehicles; data related to passenger and freight mobility. They are considered in relation to the test area of port "Porto delle Grazie", located in Roccella Jonica (Italy).

The paper is divided into four sections. After this introduction, the method adopted is reported in section 2. Section 3 reports the aggregate results obtained in the pilot area. Some conclusions and further developments are reported in section 4.

2. METHOD

The methods presented in this paper are the consolidated ones used in order to design mobility services for passengers and freights near a port a port area. The general objective is to design a sustainable transport system by using renewable energy generated in the port by sea waves.

The whole problem can be formulated as an optimization problem defined as (the symbols are described below):

$$Minimum_y\ \boldsymbol{\varphi}(\mathbf{y}) \quad (1)$$

Subject to: $y \in \psi$

The objective function φ to be minimized has the three components of sustainability: economic, social and environment. For each component one or more indicators can be defined. The objective function can be defined in a: mono-criterion approach, considering the sum of the indicators with a pre-defined weight; multi-criteria approach [32]. In the mono-criteria approach one solution is obtained; in the multi-criteria approach the pareto-optimal boundary of solutions is obtained.

The objective function is evaluated in relation to the decision (or control) variable y. The decision variable considers the following components: for passengers the parking location area and the path/route chosen by the users following the behavioral approach (e.g. bike and car); for freight the UDC area and the route followed by vehicles (e.g. van).

The control variable can assume values inside a feasible set ψ. It is defined in term of economic and monetary, environmental, social, technical, normative and behaviour constraints. The constraints are specified in relation to the location problem and to the path/routing problem.

The solution is obtained considering the simulation or the optimization approach. The problem is divided in two levels:

(1) outer level for the location problem (parking area for passenger and UDC location for freight) solved with a simulation approach;

(2) inner level for the paths and routes solved with an optimization approach.

For the application of the methodology a system of models has to be specified in a pilot study for a pre-validation. These models will be extended in all the project area. The model is relative to the: supply, passenger demand and freight demand.

2.1 Supply: Energy

The supply is built considering the graph approach. The main and relevant topologic elements are represented with nodes and links.

To each link ij a cost function γ is specified for each demand flow component m (e.g. bike, car, van…). The cost function depends on: the traffic flow f_{ij}, considered as a weighed sum of all traffic flow component; link characteristics l_{ij} (i.e. length, slope, number of lanes, ..); link cost parameters α_m relative to the component m. The cost for the link ij and the component m can be expressed as:

$$c_{ij,m} = \gamma(f_{ij}, l_{ij}, \alpha_m) \quad (2)$$

To each link ij an energy consumption function η is specified for each demand flow component m (e.g. bike, car, van, …). It depend on the same variables of the link cost function (2), but considering specific parameters βm. The energy consumed for the link ij and the component m can be expressed as:

$$e_{ij,m} = \eta(f_{ij}, l_{ij}, \beta_m) \quad (3)$$

For each origin-destination pair (r, s) the path cost and energy consumption can be evaluated with an additive link-path function. Given this value the design method can be applied at network level.

In the pilot study section, an iso-energetic map is reported considering the port as the origin of one to one trip.

2.2 Passengers' accessibility and demand

In the territory around the port there are goods, services and activities that could be interesting for in transit port users. In the following, cultural heritage sub set is considered. Transport infrastructures and services (transport supply) allow port users to perform activities in the territory near to the port. Activities and transport supply are the two main component of accessibility for passenger mobility related to the port. To obtain transport-energy choice sets for passenger mobility related to cultural heritage, the following three steps can be performed:

a) *classification* step to individuate the exhaustive choice set (H) comprehending all cultural heritages potentially reached in the area where the port is located;

b) *selection* step to individuate selective choice set (H_s) comprehending the subset of H potentially interesting for in-transit port users; to obtain this set a demand model has to specified, calibrated and validated;

c) *simulation* step to simulate routes performed by FEVs from port to selective choice set obtained in step b), in relation to the following hypotheses:

- in-transit port user's choice a destination ss belonging to the set H_s and perform a round-trip between the port and ss choosing the path with minimum path (*one-to-one path*);
- in-transit port user's choice a sub set of destinations S^i_s

belonging to the set Hs and perform the route that link the port to all elements of S^i_s choosing with minimum path (*one-to-many path*).

In these hypotheses and considering and transport-energy parameters, the path choice set (H_s^E) that includes elements of cultural heritage reachable with a specific FEV (e.g. e-car, e-bike) and with quantity of energy.

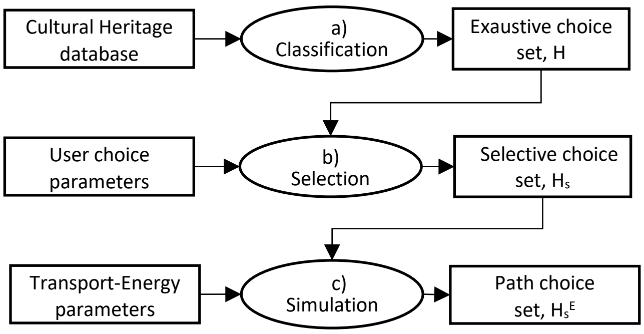

Figure 1. Steps to obtain transport-energy choice sets for touristic passenger mobility

2.3 Freight accessibility and demand

Freight demand flow in urban area is mainly generated by two types of trips: Shopping (attraction) and restocking (acquisition) trips. The former is made by end-consumers (residents, workers) that travel from a residential (working), or consumption, zone to a purchasing zone. The latter are made by retailers, carriers, forwarders, that allow delivering the freight to the warehouses and shops, or directly to the end-consumer.

According to the above main trip patterns, urban freight demand flow can be simulated by a two-levels model.

The commodity level simulates both the attraction movements, as the results of end-consumer choices, and the acquisition movements, as the results of retailers, carriers, wholesalers' choices.

The vehicle level focuses both on the shopping (by end-consumer) and restocking (by retailer) processes. It allows converting quantity flows into vehicle flows. This level provides the service, the vehicle and the time window as well as the path chosen for shopping and restocking.

For what concerns the commodity level, the following variables are defined:

(1) o, zone where the end-consumer (e.g. family) is resident and consumer goods;

(2) d, zone where the end-consumer (e.g. family) purchases the goods which retailers sell;

(3) w, zone where the retailer can bring goods sold in his shop.

The attraction model estimates two quantities.

The first quantity is the good purchased by families in zone o, Q_o, as:

$$Q_o = \Theta(\boldsymbol{\delta}, \mathbf{y}_o) \tag{4}$$

$\mathbf{y}_o$, vector of attributes of families, who resident in zone o related to good s;

$\boldsymbol{\delta}$, vector of parameters.

The second quantity is the percentage/probability of purchasing good in a zone d conditional upon departing from *o*, p_{do}:

$$p_{do} = \pi(V_{do}) \tag{5}$$

where V_{do} is the elementary accessibility related to the d-o couple of zones for purchasing goods in zone d (in case of random utility models, V_{do} is defined as systematic utility including the parameters of probability distribution).

The elementary accessibility, in general, could depend on two type of attributes:

$$V_{do} = \varsigma(\boldsymbol{\gamma}, c_{do}, a_d) \tag{6}$$

where

$\boldsymbol{\gamma}$, vector of parameters;

c_{do}, travel cost attribute between zones d-o couple (i.e. minimum travel time on the road network between d-o);

a_d, attraction attribute related to zone d (i.e. number of employees and firms belonging to a retailer sector).

The acquisition model estimates two quantities.

The first quantity is the amount of good restocked by a retailer located in d, Q_d, as:

$$Q_d = \Sigma_o \, p_{do} \, Q_o \tag{7}$$

The second quantity is the percentage/probability of choosing the restocking zone *w* for a retailer located in zone d, p_{wd}, estimated as:

$$p_{wd} = \pi(V_{wd}) \tag{8}$$

where V_{wd} is the elementary accessibility related to the w-d couple of zones for restocking goods in zone w (in case of random utility models, V_{wd} is defined as systematic utility including the parameters of probability distribution).

The elementary accessibility, also in this case, could depend on two type of attributes:

$$V_{wd} = \varsigma(\boldsymbol{\eta}, c_{wd}, a_w) \tag{9}$$

where

$\boldsymbol{\eta}$, vector of parameters;

c_{wd}, travel cost attribute between zones w-d couple (i.e. minimum travel time on the road network between w-d);

a_w, attraction attribute related to zone w (i.e. number of employees of warehouses).

3. PILOT STUDY: DATA FOR ENERGY, ACCESSIBILITY AND MOBILITY ANALYSIS

The main objective of the study is to develop a system of models in a pilot area in order to evaluate the possibility of design passengers and freight transport services.

The pilot study is in the backward (sub-)urban area the port of "Porto delle Grazie" of Roccella Jonica. It is a touristic port located in Calabria (Italy) and in a central position in the Jonian Sea.

A potential catchment area has been identified, including several coastal and hilly municipalities (see Figure 2). The catchment area is subdivided into three parts:

(1) a core area, which is the municipality of Roccella Jonica;

(2) a first set of municipalities around Roccella Jonica (I circle), M. di Gioiosa, Gioiosa Jonica, Martone, Caulonia and

Nardo di Pace;

(3) a second set of municipalities (II circle), Stignano, Placanica, S.G. di Gerace, Grotteria, Mammola, Siderno, Locri, Gerace, Canolo, Agnana Calabra and Riace.

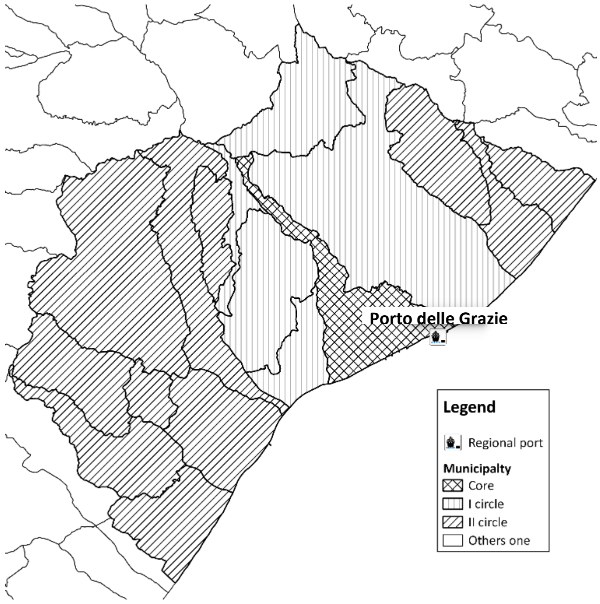

Figure 2. Study area: extended area and pilot area with zoning

3.1 Supply: Energy

Supply sub-system is represented using fundamentals of graph theory. The classes of components making up the graphs are:

(1) centroids, these nodes represent the origin and/or destination of the trips of all users crossing the considered area;

(2) network nodes, these are located at each potential change of direction along a generic path or at significant variations in geometric and/or functional characteristics of a trunk;

(3) real links, these represent the connection between two network nodes; they coincide with sections of the road network;

(4) connector links, these represent the connection between a centroid and a network node.

To each link are specified length, number of lanes, percent of slope, number of secondary intersections, functional road class, speed to calculate the cost for each demand flow component.

Figure 3 shows the road network by functional road class.

Later, it is calculated the amount of energy consumed by an electric car (see Eq. (3)), with parameters obtained from a market survey. Figure 4 shows different iso-energetic curves related to an electric car, which represents the energy requirement to travel from the port “Porto delle Grazie” to reach different inland areas. The same calculation could be done for other type of electric vehicles (bike, van). Figure 4 shows different curves and how many heritages can be reached according to available energy. To visit 36% of heritage user’s need 2 kWh, but with 4 kWh they can visit all heritage.

Using a bike, the consumption of energy is less and users can visit same heritage with 0.5 kWh.

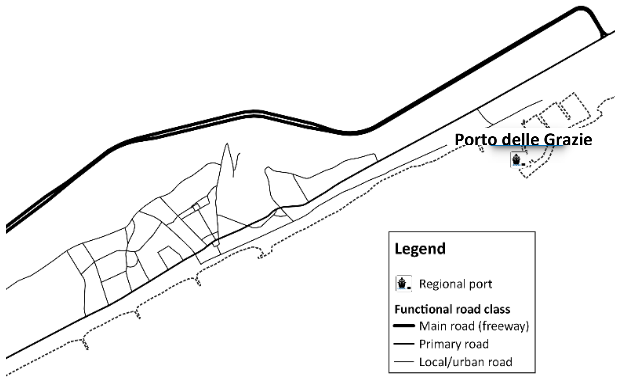

Figure 3. Road network of pilot area

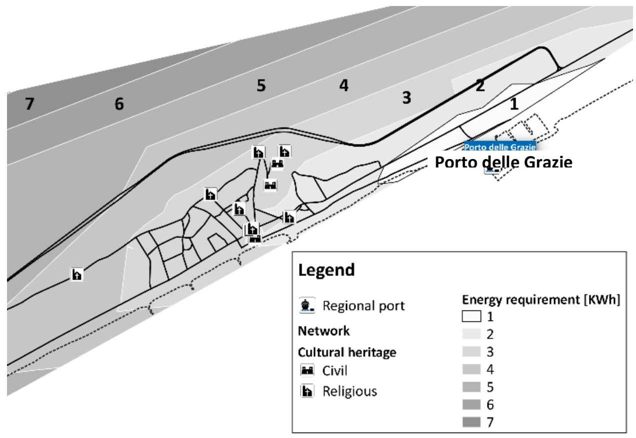

Figure 4. Iso-energetic curves for a car based on Roccella Jonica port

3.2 Passengers’ accessibility and demand

Steps introduced in the section 2.2 are followed in the pilot study.

In the step a) it is individuated the exhaustive choice set (H) comprehending all cultural heritages potentially reached in the area near the pilot area (catchment area) (see Figure 5).

Table 1 shows civil heritage (palaces, castles, towers, ruins, archaeological areas) and religious heritage (churches, shrines, convents, monasteries, abbeys) available in Calabria. About 9% are located in pilot area.

Table 1. Number of cultural heritage in Calabria and in the pilot area

	Civil heritage	Religious heritage	Total
Calabria	1,054	1,468	2,522
Pilot area	101	114	215

In relation to step b), referring to the year 2017, "Porto delle Grazie" has registered more than 400 permanent contracts and about 1,600 transit users.

Considering the total number of in-transit port users, about 11% has used transport services (car and bicycles rental) offered inside the port area. The great part of these users (67%) has rent a bicycle (see Figure 6).

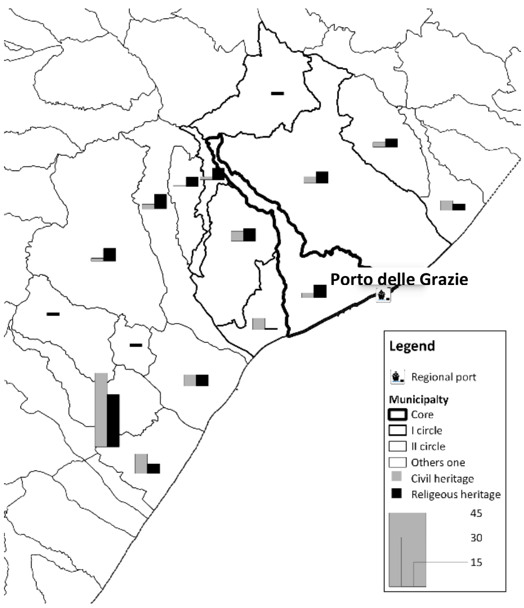

Figure 5. Potential catchment area and number of cultural heritage (elaboration from [33])

For this reason, selective choice set (H_s) includes the subset of H potentially interesting for in-transit port users.

To simulate routes performed by FEVs from port to selective choice set obtained in step b), it is considered that in-transit port user's choice a destination belonging to the set Hs and perform a round-trip between the port and heritages choosing the path with minimum path (*one-to-one path).*

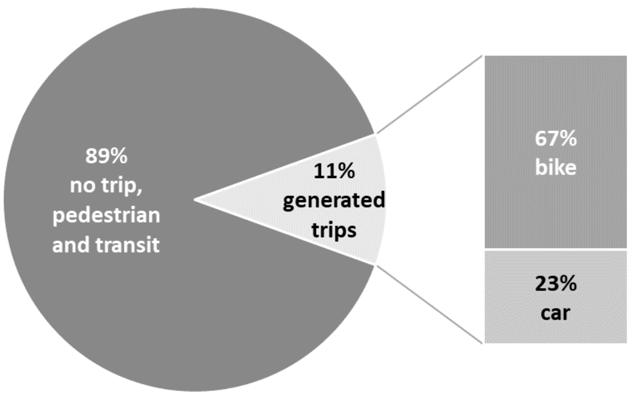

Figure 6. In-transit port users' trips to land side: generation and modal choice

3.3 Freight accessibility and demand

This paragraph presents data related to attraction attributes of zones (attribute a_d in Eq. (6)). They are socio-economic data concerning the municipalities belonging to the study area, obtained from Italian Statistic Institute (ISTAT) [34].

Figure 7 shows the population, the number of households and workers of each municipality of the potential catchment area. Figure 8 shows the number of employments and firms.

In general, the total number of inhabitants of the potential catchment area is about 73,086, while the total number of employees is 9,881 in all sectors and about 3,812 in retail sector.

The municipalities along the coast are the most populated (Siderno, Locri, M. di Gioiosa, Roccella and Caulonia) and are the ones with highest number of employees.

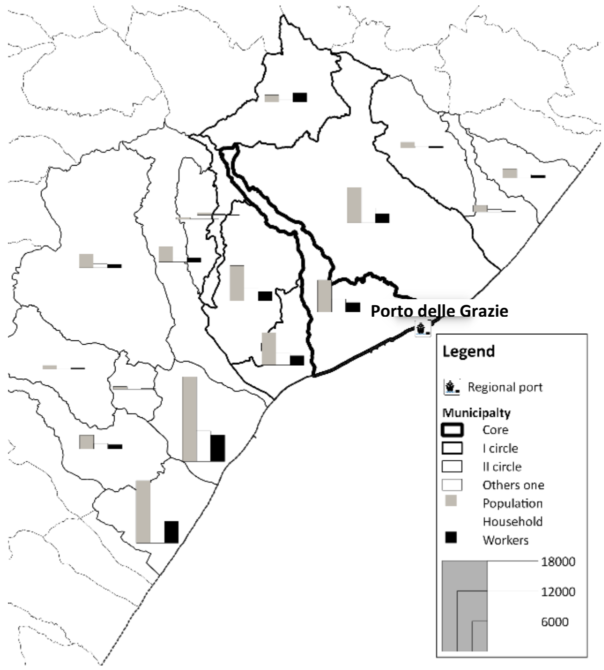

Figure 7. Population, households and workers in the pilot area

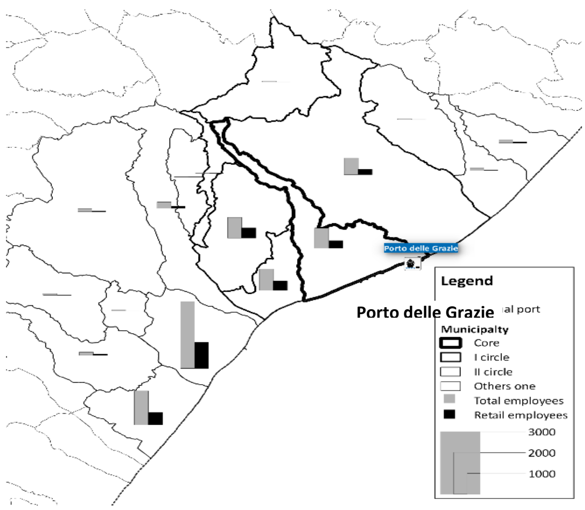

Figure 8. Employments and firms in the pilot area

4. CONCLUSIONS AND FURTHER DEVELOPMENTS

The paper represents a first step towards the joint estimation of energy of electric vehicles, of accessibility to potential places of interest and of passengers and freight mobility. The aim is to design optimal transport and logistic services for freight and passenger sustainable mobility.

For passengers' mobility, trips generated from the port towards inland points of interests for tourism purposes are considered. In particular, a set of trips is obtained which is consistent with the amount of energy required for their displacements.

For freight mobility, the variables that influence production and consumption and goods have been analysed.

In the next future, it is necessary to remove some simplifying hypotheses, for example to improve the energy consumption function by introducing the slope of the path that greatly influences the autonomy of the vehicle.

ACKNOWLEDGMENT

This research is partially supported by the project GRE.ENE.LOG., funded by Calabria Region via POR CALABRIA FESR - FSE 2014 – 2020, Prog. 2894, Prot. SIAR 52115, date 17/02/2017.”

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