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Passengers and freight mobility with electric vehicles: A methodology to plan green transport and logistic services near port areas

Giuseppe Musolino[a]*, Corrado Rindone[a], Antonino Vitetta[a]

aDipartimento di Ingegneria dell'Informazione, delle Infrastrutture e dell'Energia Sostenibile -DIIES, Università Mediterranea di Reggio Calabria, Reggio Calabria, Italy

Abstract

The paper describes a research, named GRE.ENE.LOG. (from GREen ENErgy to green LOGistic: from the port of Roccella Jonica to the Locride area), which aims to integrate the production of green-energy inside port areas and its consumption to feed Electric Vehicles (EVs) for transport and logistic services. The system is composed by: (i) a "sea-to-grid" technological component harvesting and producing electrical energy from sea waves; (ii) a "green" logistic services based on the use of EVs.
This paper is relative to part (ii). One of the main challenge is to promote the use of green-energy resources for freight and people mobility planning involved in the port area. The main task concerns the location of a parking area/distribution center and the optimal design of mobility services, operated by means of EVs, connecting a port with a closer extended (sub)urban area. The mobility services by EV bikes and cars are oriented to the port users; the freight services are oriented to the extended port area.
In this context, the paper presents a methodology for the definition of freight logistics and passenger transport services in order to pursue sustainability goals, and a data analysis in the pilot study of Roccella Jonica port, South of Italy.

Keywords: freight and passenger mobility services; planning methodology; Electric Vehicles (EV); pilot study in a port area.

* Corresponding author. Tel.: +39-0965-169-3272; fax: +39-0965-169-3247.
E-mail address: giuseppe.musolino@unirc.it

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1. Introduction

The general objective of the research concerns the design and the experimentation of a system able to develop a green energy production-consumption chain composed by the “sea-to-grid”, called green-energy, and by mobility services operated by means of Electric Vehicles (EVs), called green-logistics, near port areas.

This paper is relative to the green-logistics near port areas. The mobility services by EV bikes and cars are oriented to port users; the freight services aim to connect a port with a closer (sub-)urban area. In the green-logistics context, the paper presents a methodology for the design of freight logistic and passenger transport services to pursue sustainability goals. The main objective is to promote the use of alternative energy resources for freight and people mobility planning. Sustainable transport connections to a port influences its performances (Russo and Rindone, 2011). The main task concerns the location of parking areas/distribution centers and the optimal design of mobility services, operated by means of EVs, connecting a port with a closer (sub-)urban area.

In scientific literature, the design of freight/passenger mobility services is solved by means of vehicle routing methods, which consists in designing the best routes from/to a hub node to/from a set of destinations/origins, subject to constrains (Laporte, 2009). The objective is the minimization of the generalized cost, subject to technological and performances (e.g. EVs) constrains.

The problem can be solved with: one-to-one optimization methods, if the best path is searched from one origin and one destination (this is typical, but not exclusive, of passenger services); one-to-many (or many-to-one) optimization methods, if the route is searched from one origin and many destinations (this is typical, but not exclusive, for freight services).

The innovation reported in this paper relates to the design of services in the extended port area, by producing green energy from the sea. The idea is to transfer energy directly from Waves to Wheels, which is an enhancement of the traditional approach Well to Tank-Tank to Wheels.

The following part of the paper is articulated into four sections. Section 2 presents a state-of-the-art on methodologies of freight and passenger service design. Section 3 describes the components of the methodology and the research contribution respect to the consolidated approaches. Section 4 describes the pilot study and some preliminary results concerning the requirements for services design and aggregate evaluation of feasible sets of energy consumptions. Finally, the research perspectives are reported in section 5.

2. State of the art

In the sphere of sustainability, one of the main challenges is to promote the use of renewable energy resources in freight and people mobility planning (Cirianni et al., 2013; Russo et al., 2016; Nuzzolo et al., 2016; Caggiani et al., 2017). The main task concerns the optimal design of passengers and freight transport services, operated by means of EVs, connecting a port with a closer (sub-)urban area. The problem is solved by means of Vehicle Routing (VR) methods, which consist in designing the best routes from/to a central node (distribution center for freight and parking area for the passengers) to a set of destinations/origins, subject to constrains (Laporte, 2009). The objective is the minimization of the generalized cost, subject to constrains, such as technological and performances ones (e.g. EV).

For what concerns freight mobility planning in relation to the management of Urban Distribution Centers (UDCs), the literature focuses on two problems: the UDCs location problem and the Vehicle Routing Problem (VRP). The UDCs location problem (Yang et al., 2007; Sun et al., 2008, Żak and Węgliński, 2014) involves the design of one (or more) intermediate physical node(s) between the points of origin (suppliers, warehouses, ...) and the delivery points (end-consumers, customer deposits, retailers, ...), taking into account the internal and external constraints of the logistic firm. The problem is a p-median one consisting of locating a number of facilities in an area minimizing the distance (it is often weighted respect to the demand) between the demand points and the nearest facility (Daskin and Maass, 2015). The approach to the analysis can be continuous (any position in the space), or discrete (nodes of a network) (Brimberg et al., 2015; Fazayeli and Kamalabadi, 2017). The methodological approach can be “what-to” (Sopha et al., 2016, Wang et al., 2014; Awasthi et al., 2011), or “what if” (Kinnear et al., 2015, Russo et al., 2013). The VRP has been extensively studied in literature (see Laporte, 2009, Polimeni and Vitetta, 2013; 2014). Recently, the problem was reformulated to take into account the use of electric vehicles, particularly to incorporate the charge/discharge of the batteries (Lin et al., 2016; Hiermann et al., 2016; Keskin and Çatay, 2016). Recent VR methods take also into account Network Macroscopic Fundamental Diagram (NMFD) (Alonso et al., 2017; Musolino et al. 2018a), in order to represent spatial average traffic conditions at network level.

In the context of passenger maritime mobility, the segment of nautical tourism is analyzed. Nautical tourism comprehends different leisure activities (e.g. cruising, private maritime tourism, yachting and coastal leisure shipping) (Diakomihalis, 2007). Differently to other forms of tourism, nautical tourism offers to tourists' active mobility, wider travel radius, connection to other activities (Maravić et al., 2016). Nautical port users, and their specific needs, can be classified into three main segments: stationary users, with boats permanently moored at a port; seasonal users, with boats moored at a port in some periods of the year; in-transit users, that occasionally use port infrastructures and services (González et al., 2015). Stationary and seasonal users reach the port from land using private or public transport modes. In-transit users reach the port from the sea by boats. This class could use land infrastructures and mobility services to carry out activities (e.g. for leisure) in the area close to the port (Luković, 2012; González et al. 2015). In this context, it is useful to study how mobility services connecting land to the port have to be planned optimizing energy consumptions (Dalla Chiara and Pellicelli, 2016).

3. Methodology for freight and passengers' mobility planning

The\ methodology proposed in this paper has the main objective to design a mobility services for passenger and freight with origin or destination in the port area, considering the surplus of energy produced in the port. This energy is shared with other port services. The idea is to transfer the energy directly from Waves to Wheels (W-W) with the energy consumption at km zero. This approach is an enhancement of the traditional approach Well to Tank – Tank to Wheels: Well to Tank (Well – Produce primary fuel – Transport primary fuel – Produce road fuel – Distribute road fuel); Tank to Wheels (Burn fuel in vehicles – Wheels).

The energy is produced by Waves in the sea and it is distributed inside port area in order to feed passenger and freight Electric Vehicles (EVs). The new chain is the following: Waves to Wheels (Waves – Produce primary fuel – Transport primary fuel – Accumulate fuel in vehicles – Wheels).

The chain reduction, due to the use of electric vehicles, allows to: increase the efficiency of the process; produce zero emission in energy production and energy consumption.

The general methodology is developed by means of an optimization model.

The *design* (or control) variables are: the hub location closed to a port and the routes of EVs, both for passengers and freight mobility. The design variables are:

$$\mathbf{y} = \{\mathbf{y}_{\mathbf{FL}}, \mathbf{y}_{\mathbf{PL}}, \mathbf{y}_{\mathbf{FR}}, \mathbf{y}_{\mathbf{PR}}\} \quad (1)$$

with y indexes adopted for freight (F), passenger (P), hub location (L), route (R). The hub location and the routes are different for the two mobility components, considering the different characteristics required for each type of service. For hub: freight requires a warehouse; passenger require a parking area at pedestrian distance from the harbour. For routing: freight requires routing design, controlled by a central operator: passengers are free to use the vehicles for touristic, or personal, purpose.

The objective function is defined in term of minimization of a function which has three terms; each term is associated respectively to economic, social and environmental elements of sustainability. The three terms can be considered into a mono criterion approach with a weighted sum, or in a multi criteria and/or DEA approach (Musolino et al., 2017). The problem formulation in term of objective function is:

$$\boldsymbol{\varphi} = \{\varphi_E(\mathbf{y}), \varphi_A(\mathbf{y}), \varphi_S(\mathbf{y})\} \quad (2)$$

with $\boldsymbol{\varphi}$, vector of objective function values; $\varphi_E(\mathbf{y})$, $\varphi_A(\mathbf{y})$, $\varphi_S(\mathbf{y})$ respectively the economic (E), environmental (A), and social (S) terms; $\mathbf{y}$, vector of design (or control) variables.

For the objectives the following indicators could be specified: travel times or users' surplus, for economic term; amount of greenhouse emissions, for environmental term; number of road accidents, for social term.

The *constraints* can be divided into several categories. A scheme of classification is reported in Table 1.

The optimal configuration is obtained with (deterministic or frequentist probability) scenarios approach (Musolino et al., 2018).

For what concerns the solution procedure, the method is applied with (Figure 1):

- (outer level) a priori identification of different potential sites for hub location (solution with simulation approach);
- (inner level) vehicle routing optimization for freight (solution with optimization approach); user behavior approach for passenger routes (solution with simulation approach).

Table 1. Constrains for location and routing problems

Constraints	*Location*	*Routing*
Economic and monetary	Monetary budget (€), Available energy (kw/h)	Management contracts (€)
Environmental	Greenhouse emissions (g)	Vehicle unitary emissions (g/km)
Social	Social risk	Drivers risk (individual)
Technical	Territorial characteristics (km^2)	Range of electric vehicles (km), Recharge battery time (h), Max number of vehicle (n.), Vehicle capacity (ton, pass.)
Normative	Time windows (hh.mm), Spatial restrictions (km^2)	Freight classes restrictions (e.g. dangerous goods)
Behaviour	Max revenue (€)	Max utility (generalized cost)

The European Commission indicated that the optimization of mobility and freight services, energy and information and communication technologies contributes to achieve sustainability goals. The proposed procedure assumes that: outputs deriving from ICT planning (information technologies tools) are given (gray element in Figure 1); output deriving from energy (energy grids, EVs) is a variable in the project but it is given in this paper; the freight and passenger mobility planning is presented in this paper. Figure 2 reports the inner and outer levels in details. At outer level: a set of feasible solution sites for the location of freight and passenger hubs are defined; demand scenario for passengers and freights are defined. Considering pre-defined objective and constraints (relative to public authority), sustainability indicators are evaluated inside inner level. At this level, some possible hub locations are evaluated and compared with a simulation approach. At the inner level for the defined (at outer level) hub location and demand scenario and considered pre-defined objectives and constraints (relative to private service management) the best route for freight and the route for passenger are evaluated. For freight optimization approach is adopted, for passenger behavioral simulation approach is adopted. The solution that gives the best sustainability indicators is adopted.

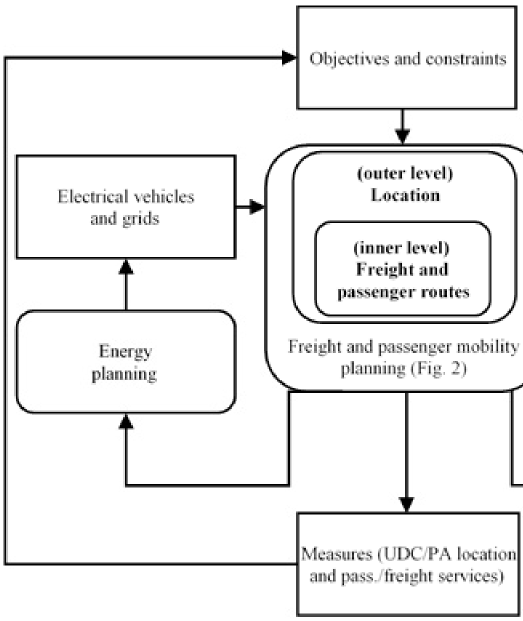

Figure 1. Whole procedure

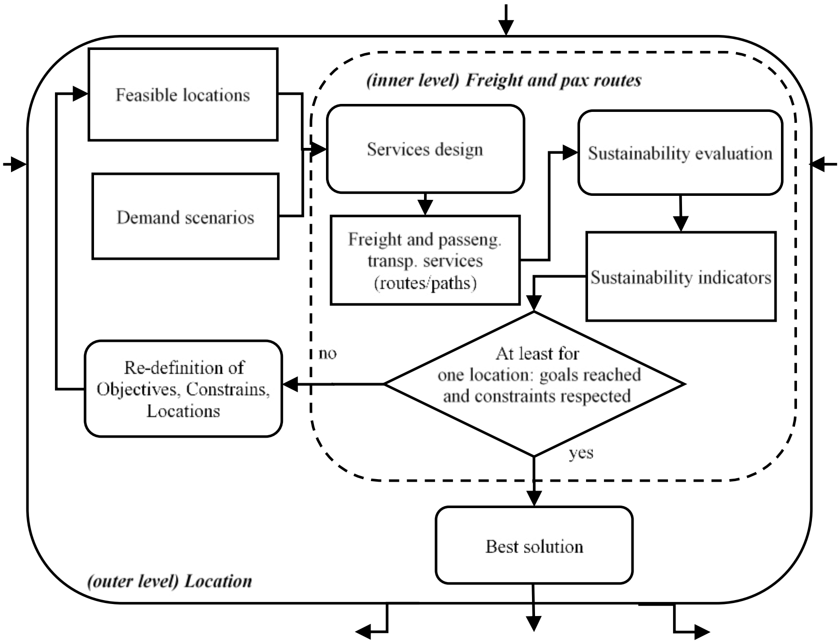

Figure 2. Details of the procedure for freight and passenger mobility planning

4. Pilot study

A pilot study is performed in a backward (sub-)urban area of an Italian port, and it is composed of the following activities: a direct survey concerning potential demand (passengers and freight) of logistic and transport services close to the port area; a real experimentation of the designed routes and paths, operated with EVs.

The selected area for the pilot study is the "Porto delle Grazie" of Roccella Jonica (Figure 3a), a touristic port in the south of Calabria Region (Italy). The port is connected to the national and local road network. There is a bicycle path near to the port.

The port offers 450 moorings distributed in a water mirror with an extension of 69,250 m^2 and in a total berth length of 716 meters (Regione Calabria, 2016). Referring to the year 2017, the port has registered more than 400 permanent contracts, of which 47% annual users and 53% seasonal users (31% in summer, 22% in winter), and about 1.600 transit users. Considering permanent users, more than the 70% lives in the territory near to the port. Considering in transit users, more than 85% uses the port from May to September (Figure 3b); about 86 % of these users travel from Italy (Porto delle Grazie, 2018).

a

b

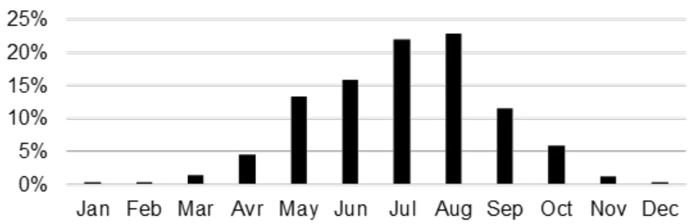

Figure 3. (a) View of the port of Roccella Jonica; (b) Distribution of annual transit users in the port of Roccella Jonica

Considering passenger mobility, the segment of in-transit port users is considered. The pilot study focused on the mobility needs related to potential touristic activities performed by a generic user in the territory near to the "Porto delle Grazie". The specific segment of cultural heritage in Calabria region and the Locride area is considered. Calabria region includes about 2,500 places to visit comprehending civil and religious cultural heritage covering a regional surface of 15,222 km^2 (Balbo et al. 1993).

The municipality of Roccella Jonica belongs to the wider area of Jonian territory (named "Locride"), where several municipalities are present. By considering a radius of 30 km from the port: in the south, there is the Archaeological Park of Locri Epizefiri that preserves evidences of the Greek colony of Locri; in the north there are the excavations of the ancient Kaulon, today's Monasterace. Other centers of interest are the historic centre of Gerace and Stilo's "Cattolica". In the territory near to the port there are 215 cultural heritages.

In particular, in the proximity of the port ("I circle"), there are 53 cultural heritages comprehending 31 religious and 22 civil; in the rest of the study area ("II circle") there are 156 cultural heritages comprehending 77 religious and 79 civil. (see Tab. 2).

Considering the total number of transit port users, about 11% has used transport services (car and bicycles rental) offered inside the port area. The great part of these users (more than 60%) has rent a bicycle.

For what concern freight mobility, a potential catchment area has been identified, including several coastal and hilly municipalities. The catchment area is subdivided into three parts:

- a core area, which is the municipality of Roccella Jonica with about 6,500 inhabitants;
- a first set of municipalities around Roccella Jonica (I circle, with about 21,000 inhabitants);
- a second set of municipalities (II circle, with about 41,000 inhabitants).

In general, the total number of inhabitants of the potential catchment area is about 68,500, while the total number of employees is 6.400 in all sectors and about 3.700 in retail sector. The coastal (c) municipalities are the most populated and the ones with highest number of employees.

A feasible set of required EVs to provide passenger and freight services is calculated in this section, considering the potential catchment areas as defined previously. The feasible set of EVs depends on the two considered transport mobility components: passengers' demand that uses bikes and cars; freight demand considering light freight vehicles (e.g. vans). According to the above elements, the following ranges of full recharge cycles (or vehicles, if it is assumed one full recharge cycle per day) for an average day:

- Passengers, [0; 20] full recharge cycles / equivalent passenger vehicles, with the split of 70% of bikes and 30% cars (1 equivalent passenger vehicles ≡ 0.7 car + 0.3 bikes);
- Freight, [0; 4] full recharge cycle / vehicles.

For the amount of necessary energy to recharge batteries, average values obtained from some EVs available on the market are assumed.

The energy produced in the port is used for port activities and to recharge EVs. In order to avoid fault tolerance issues, the system is also powered by energy deriving from traditional source.

Table 2. Cultural heritage in the study area

	Town	Religious heritage	Civil heritage	Total
I circle	Roccella Ionica	8	3	11
	Marina di Gioiosa Ionica	1	7	8
	Gioiosa Ionica	8	6	14
	Martone	7	2	9
	Caulonia	7	4	11
	Sub total I	31	22	53
II circle	Agnana Calabria	2	-	2
	Canolo	2	-	2
	Stignano	4	6	10
	Placanica	5	3	8
	San Giovanni di Gerace	6	1	7
	Grotteria	9	3	12
	Mammola	8	2	10
	Siderno	7	7	14
	Locri	6	12	18
	Gerace	32	45	77
	Nardodipace	2	-	2
	Sub total II	77	79	156
	TOTAL	108	101	209

Figure 4 reports the energy required in a day in relation to the different combinations of passengers and freight vehicles used to provide services. A combination of freight and passenger vehicles more consistent with the designed mobility services will be defined in future step of the research, after the estimation of the available energy that can be used for mobility services and of the demand for freight and passenger services.

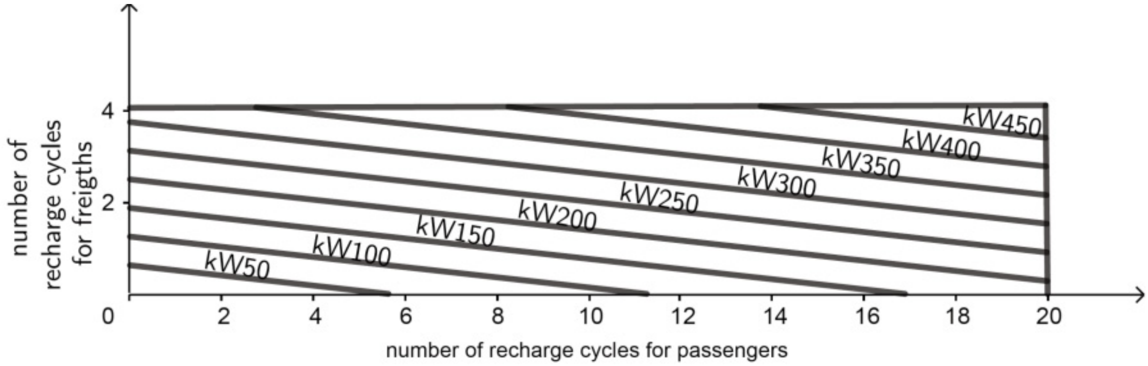

Figure 4. Feasible set and energy requirement per day in relation to the number of full recharge cycles/vehicles.

5. Conclusions

The research project GRE.ENE.LOG. aims to integrate the production of green-energy inside port areas and its consumption to feed Electric Vehicles (EVs) for transport and logistic services.

The integrated system is composed by: (i) a "sea-to-grid" technological component harvesting and producing electrical energy from sea waves; (ii) a "green" logistic services based on the use of EVs.

This paper describes the part (ii) of the system and it presents two main elements. The first one concerns a methodology for design freight/passenger mobility services by means of vehicle routing (VR) approach, which allows defining best routes from/to a hub node to/from a set of destinations/origins, subject to constrains connected to the use of EVs. The second one deals with a pilot study and some preliminary results concerning the requirements for services design and aggregate evaluation of feasible sets of energy consumptions.

Further steps of the research concern the following three directions. The definition of the extension of the catchment areas of passenger and freight services consistently with the limitations of EVs. The segmentation and the quantitative estimation, by means of modelling approach, of potential demand of the passenger and freight services operated by EVs. The development and implementation of the VR methodology to design optimal paths/routes of passenger/freight services operated by EVs. Finally, it is necessary to verify if the variations profile of renewable energy produced by waves matches to the variation of energy demand for mobility.

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