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From green-energy to green-logistics: a pilot study in an Italian port area

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Abstract

An ongoing two-year research is performing with the general objective to assess the feasibility of a system integrating the production of green-energy and its consumption inside and close to port areas for mobility services. The system is composed by two elements: (a) a "sea-to-grid" technological component harvesting and producing electrical energy from sea waves; and (b) a "green" logistic service based on the use of Fully Electric Vehicles (FEVs). A pilot study will be conducted near an Italian port area supporting passengers and freight mobility between a port and a backward (sub)-urban area.
The proposed system is within the environmental goals set by the EU (Europe 2020 Strategy) and the Italian Government (National Energy Masterplan). Indeed, the energy-producing technology reduces dependence from traditional energy sources (coal, gas, oil) and consequently reduces their negative effects (greenhouse gases, air pollution, etc.). Considering that the energy is produced by sea waves, the system transfers the entire amount of produced (green) energy to the electric vehicles. The system will be experimented in a medium size urbanized area and the energy will be produced in a small size port.

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1. Introduction

A two-year research is performing with the general objective to assess the feasibility of a system integrating the production of green-energy and its consumption inside and close to port areas for mobility services.
The system is composed by two elements:

(a) a "sea-to-grid" technology, harvesting and producing electrical energy from sea waves; and
(b) a "green" logistic service, based on the use of Fully Electric Vehicles (FEVs).

(a) Several devices where proposed in the open literature for harvesting wave energy (Falcão, 2010), thanks to the significant amount of ocean wave energy available worldwide (Cruz, 2008). However, only a few of them reached the stage of full scale prototype. In this context, Oscillating Water Columns (OWC) are one of the most reliable solutions. They are composed by a water column and an air pocket connected to the atmosphere through a turbine. In operational conditions, the water column surface oscillates under the incident sea wave action, thus compressing/expanding the air pocket with a corresponding flow in the turbine duct, which is exploited for producing electrical energy. This working principle was revisited by Boccotti (2003, 2014), who proposed a Resonant Wave Energy Converter 3 (REWEC3), also known in the scientific literature as U-OWC, which is an OWC equipped with a small vertical duct on the wave beaten side. Such a small element improves the performance of the device as it allows designing a water column with the desired natural frequency. The U-OWC was proposed in conjunction with classical maritime structures, such as submerged breakwaters and vertical breakwaters (Boccotti 2007). This last configuration was recently tested at prototype scale in Civitavecchia (Rome, Italy) (Arena, et al. 2013).

(b) Resource optimization and reduction of energy consumptions are fundamental contributions to environmental sustainability. Thus, one of the main challenges is to promote the use of alternative energy resources in freight and people mobility planning (Russo et al. 2016; D'Agostino et al. 2015). The main task concerns the optimal design of passengers and freight transport services, operated by means of FEV vehicles, 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, 2007). The objective is the minimization of the generalized cost, subject to constrains, such as technological and performances ones (e.g. FEV). The most advanced methods include real-time congested travel times (i.e. Ando and Taniguchi, 2006), which can be observed (i. e. Haghani and Jung, 2005) or estimated (i. e. Polimeni and Vitetta, 2013; Polimeni and Vitetta 2014).; Recently, the problem was reformulated in order to take into account the use of electric vehicles (Lin et al., 2016; Hiermann et al., 2016; Keskin and Çatay, 2016), and to represent spatial average traffic conditions at network level by means of Network Macroscopic Fundamental Diagram (NMFD) (Alonso et al., 2017; Musolino et al., 2018)

This paper disseminates a research project proposed by two research groups of the Mediterranea University of Reggio Calabria (Italy). It combines experiences in the field of marine engineering and transport engineering by proposing a system producing energy from sea waves via a REWEC3 system equipped with turbines, which feeds FEVs for passengers (cars and bikes) and freights (vans) via a small storage system.

The innovation consists in the direct use of the energy produced in the port for mobility services of port users; the energy production in a small size marina; the design of passenger and freight services in the extended port area; the experimentation in a small-medium size port and urbanized area. The proposed system is within the environmental goals set by the EU (Europe 2020 Strategy) and the Italian Government (National Energy Masterplan) to reduce cost and dependency from traditional sources.

The impacts of the research concerns the support to local administrations, public authorities to propose local enhancements, improved services and accessibility to different areas, increased competitiveness, enhanced infrastructure, based on technological innovation and economic, social and environmental sustainability.

A pilot study will be conducted near an Italian port area (Roccella Jonica) supporting passengers and freight mobility between a port and a backward (sub)-urban area.

The paper is articulated as follows. Section 2 illustrates the structure of the research. Section 3 describes the methodology and section 4 reports some indications about the pilot study and the expected results.

2. Structure of the research

The research concerns the design and experimentation of a green energy production-consumption chain composed by the "sea-to-grid", called in this paper "green-energy", and by the transport services operated by means of FEVs, called in this paper "green-logistics". The system will be experimented in a pilot study involving a port and a surrounding (sub-)urban area. The energy produced by sea waves will feed FEVs to operate logistic and transport services for freight and passengers (Fig. 1).

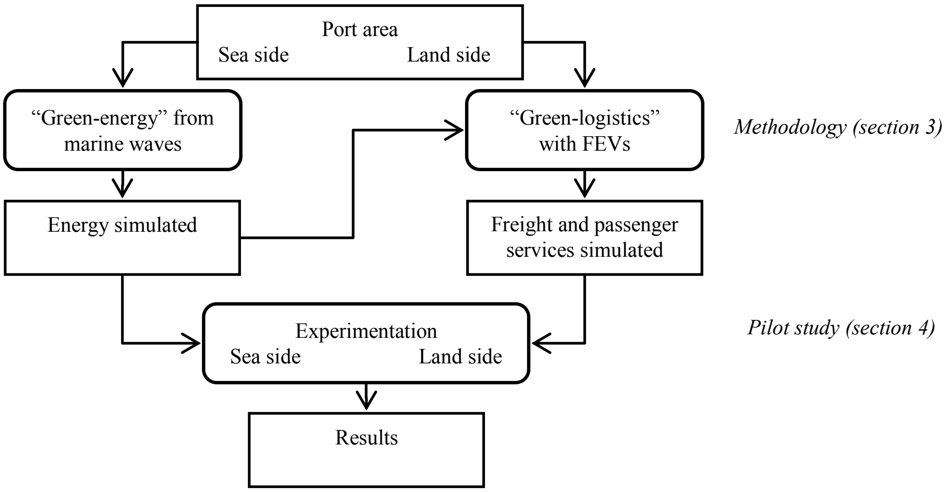

Fig. 1 – Scheme of the whole activity

The expected results of the project are: (a) determination of the optimal REWEC3 configuration for the port of Roccella Jonica (Italy) and the estimation of the average annual/seasonal energy produced by a single REWEC3 chamber; (b) methodology for the routes' design of freight vehicles and for the design of services for passengers' mobility and cost evaluation.

The device adopted for converting the energy from sea waves is the REWEC3 (Resonant Wave Energy Converter 3) vertical breakwater. These plants allow converting the energy propagated by the sea waves, thus contributing to the energy needs of the surrounding areas. Most of the produced energy will be used to feed passenger and freight vehicles used for tourist/residents trips and freight distribution (transport and logistic) in the area. In this context, a methodology will be set up for the routing of freight vehicles and the simulation of passenger pathways in the area near the port.

Sea waves can be described reliably only by a statistical point of view. Thus, a first part of the energy-wise description of the project relates to the determination of the sea wave statistics and the calculation of the REWEC3 response statistics in a variety of sea states. In this context, a number of REWEC3 configurations are considered by assuming different turbine characteristics. Further, annual downtime is calculated. That is, the average number of hours per year in which the plant is not able to work due to insufficient incoming energy. Considering the prevalent utilization of statistical methods a validation of the numerical results is pursued via the experimental data obtained via pilot test plant.

The green-energy produced can be used to fuel electric vehicles for operating mobility services.

The methodology is finalized to design hub location and routes of mobility services in a (sub-)urban area close to a port, subject to technological and performance constrains (e.g. FEVs). The resulting locations and services optimize the use of energy resources. The optimal configuration will be obtained by considering some (deterministic or frequentist probability) scenarios related to the FEVs type and land use characteristics. Some criteria are adopted for the evaluation in DEA or multi-criteria contexts (see Musolino et al., 2017).

3. Methodology

3.1. Green-energy

Considering the need of determining a preliminary estimate of the available energy provided to the port area, the paper adopts the methodology described by Arena, et al. (2015b) and Malara, et al. (2017) for characterizing the wave climate and predicting the U-OWC performance. The wave climate is statistically characterized by processing wave data recorded via buoy measurements near the port area. It provides the power matrix of the incident wave field and the expected downtime of the plant. For this purpose, the Equivalent Storm model is used for determining relevant return values (Arena, et al. 2015a; Laface et al. 2015, 2016; Laface and Arena, 2016; Satish et al., 2017).
Given the statistics of the incident wave field, estimates of the U-OWC response are obtained by utilizing Monte Carlo data. For this purpose, a recently developed semi-analytical formulation of the wave field surrounding the structure is used for estimating the wave excitation in a diffracted wave field, the infinity frequency added mass and the retardation function rendering the hydrodynamic memory effect.
The plant performance is numerically tested with a variety of self-rectifying turbines in order to identify the optimal turbine – U-OWC coupling. Specifically, absorption coefficients and power outputs are quantified.
A pilot test plant is utilized for validating the proposed estimates and verifying the reliability of the service provided by the infrastructure. A scheme is shown in Fig. 2.a.

3.2. Green-logistics

The methodology is composed of two levels:

- an outer level, where potential locations of an urban hub nodes in terms of one (of more) distribution center(s) for freight (DC)-and one (of more) parking area(s) (PA) are identified;
- an inner level, where routes of mobility services are designed by means of vehicle routing procedures for each UDC/PA location, in order to obtain quantitative estimation of sustainable mobility indicators.

The main task is the design and management of sustainable mobility services for passenger and freight in a backward (sub)-urban area of a port. It allows an efficient process of energy production and consumption with zero emission. The objective function, φ, contains economic, social and environmental criteria/components with mono or multi criteria optimization method (Musolino et al., 2017; 2018). The indicators are different for the inner and the outer levels (i.e. for economic component, energy for the outer level and management cost for the inner level).
The main design variables, **y**, are the optimal location points of distribution center(s), in the case of freight, and of parking area(s) in the case of passengers; the optimal paths for passengers FEVs and the optimal routes for freight FEVs.
The optimal problem is subject to several constraints, ψ: economic and monetary (i.e. monetary budget); environmental (i.e. greenhouse emission); social (i.e. drivers accident risk); technical (i.e. territorial characteristics); normative (i.e. local planning rules); behavior (i.e. user utility maximization).
The model can be formulated as:

$$\textit{Minimum}_y\ \varphi(\mathbf{y})$$
$$\text{Subject to: } \mathbf{y} \in \psi$$

The solution methodology is composed by the following main elements:

- identification of different potential sites to locate UDC/PA and comparison among location scenarios (outer level);
- design of freight vehicles routes, based on the defined UDC location scenario, and path generation of passengers vehicles, based on the defined PA location scenario (inner level);
- before (modelling estimation) – after (experimentation) evaluation;
- ex-ante estimation of mobility service costs operated by means of FEVs.

A scheme is depicted in Fig. 2.b.

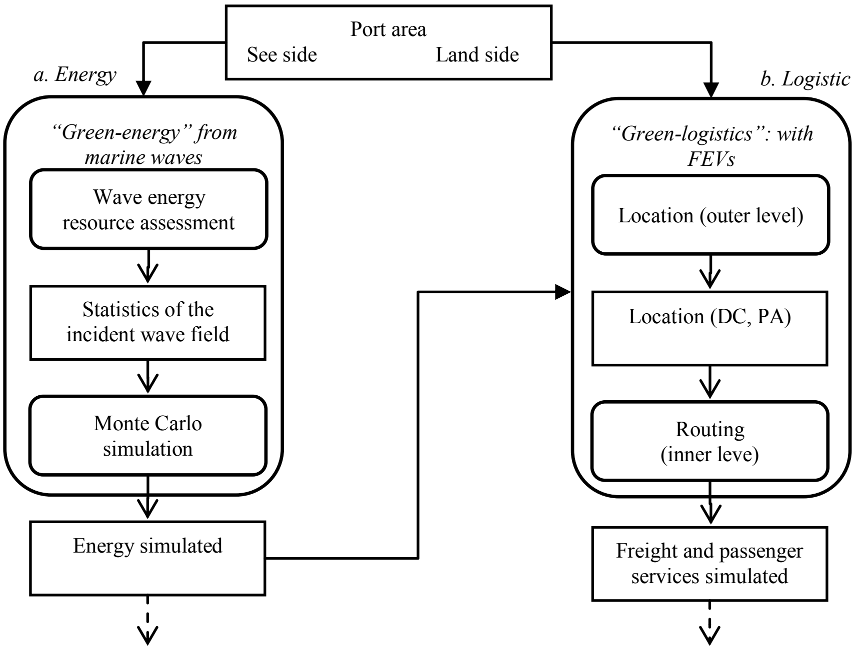

Fig. 2 – Methodology

4. Pilot study and developments

A pilot study is performed in an Italian port area by the following activities: a direct survey concerning potential demand simulation (passengers and freight) of logistic services in the port area; real experimentation of the routes designed with FEVs.

The pilot study is the port (with its backward urban area) of Roccella Jonica (Italy), known as "Porto delle Grazie" (Fig. 3.a), a touristic port in the Southern Italy. It may hosts up to 450 boats in an area of 69250 m^2 and a total berth length of 716 meters. The port is connected to the national and local road network. There is a bicycle path near to the port. The first phase of the study is pursued within the municipality of Roccella Jonica, belonging to the wider area of Jonian territory (named "Locride") where several municipalities are located. The Locride is populated by about 50,000 inhabitants and it has several cultural and touristic destinations (Fig. 3.b). The area is located in front of the "Jasmine Coast" on the Ionian sea. There are about 215 cultural heritage sites in the proximity of the port, which include civil and religious buildings, as well as archaeological areas (e.g. Archaeological Park of Locri Epizefiri). This heritage constitutes an attraction factor for the port users and, in particular, for the in-transit segment.

Currently, the port layout is based on the use of rubble mound breakwaters for protecting the basin. The REWEC3 plant is introduced, in this context, by replacing a part of the existing breakwater. The pilot plant installed in the port of Roccella is used for retrieving information about the performance of the REWEC3 system. The plant is equipped with sensors for measuring relevant response parameters. In this context, the experimental data allow: validating the numerical model used for performing preliminary estimates of the system response; evaluating the performance of the coupled REWEC3 – turbine system; quantifying the power output of the system.

To reach these objectives, the pilot study follows these activities relative to sea and land sides (Fig. 4).

In relation to sea side the activities are direct measurement of the REWEC3 response via sensors measuring air pressures and water column oscillations; observational study regarding the available wave energy, the absorbed wave energy and produced wave energy.

a) Map of the port of Roccella Jonica (sea side) *b) Sub-urban area close to the port (land side)*

Fig. 3 – The Jonian territory area and the port of Roccella Jonica

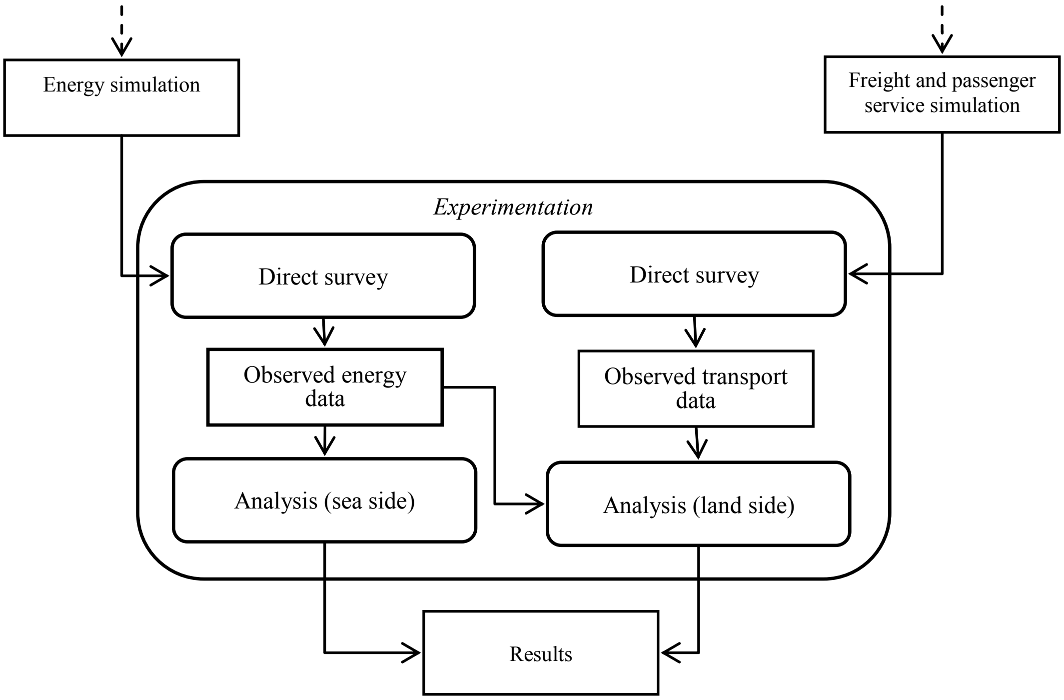

Fig. 4 – Pilot study

The following activities are performed in relation to land side. (i) A direct survey finalized to collect and to elaborate observed data related to passenger mobility (e.g. distribution of touristic destinations), freight mobility (e.g. distribution of commercial activities), infrastructures and services (e.g. characteristics of road network or available logistic centers). (ii) A real experimentation of the designed mobility services with FEVs for freight, in relation to specific production/consumption sets, and passengers, in relation to specific touristic itineraries.

At this stage of the research, some results of survey have been obtained.
Preliminary estimates of the produced energy have been obtained by considering REWEC3 plant composed by 3 caissons, each incorporating 5 independent chambers connected to a Wells turbine as in the classical OWCs. These preliminary estimates show that the plant may produce, on the average, about 200 MWh/year of energy.
Some data concerning freight and passenger mobility and energy requirement are estimated. In relation to freight mobility demand, a proxy variable of freight consumption is the total number of inhabitants of the study area (about 68.500); the total number of employees in all sectors (about 6.400) and in retail sector (about 3.700) are assumed as proxy variables for freight production.
In relation to passenger mobility demand, the segment of touristic mobility is focused. In particular, the potential mobility of about 1.600 in transit port users is considered. During year 2017, about 11% of these users used transport services (car and bicycles rental) supplied inside the port area.
The two activities of the pilot study allow measurement of Green-energy-Green logistics interchanges in terms of amount of space and of time covered by Fully Electric Vehicles (FEVs) with the energy produced by the maritime waves. The obtained results support the evaluation of integrated system feasibility.
The first results provide aggregate indications about energy requirement per day; in particular, about the number of full recharge cycles/vehicles, used for freight and passenger mobility. A combination between 1-2 recharge cycles per freight FEVs and 6 cycles per passenger FEVs corresponds to an energy requirement comprised in the range 50 – 150 kWh.
Further steps of the research in the next two years concern: the definition of the catchment areas of passenger and of freight services in relation to the FEVs limitation; the development and implementation of the VR methodology to design optimal paths/routes of passenger/freight services operated by FEVs; a comparison between experimented and simulated routes and relative performances will (land side experimentation).

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References

Alonso B., Ibeas Á., Musolino G., Rindone C., Vitetta A., 2017. Network Fundamental Diagram (NFD) and Traffic signal control: first empirical evidences from the city of Santander. Transportation Research Procedia, 27, 27–34.

Ando N., Taniguchi E., 2006. Travel time reliability in vehicle routing and scheduling with time windows. Networks and Spatial Economics, 6, 293-311.

Arena, F., Laface, V., Malara, G., and Romolo, A., 2015a. Estimation of Downtime and of Missed Energy Associated with a Wave Energy Converter by the Equivalent Power Storm Model. Energies, 8(10), 11575.

Arena, F., Laface, V., Malara, G., Romolo, A., Viviano, A., Fiamma, V., Sannino, G., and Carillo, A., 2015b. Wave climate analysis for the design of wave energy harvesters in the Mediterranean Sea. Renewable Energy, 77, 125-141.

Arena, F., Romolo, A., Malara, G., and Ascanelli, A., 2013. On design and building of a U-OWC wave energy converter in the Mediterranean Sea: a case study. 32nd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2013Nantes, France.

Boccotti, P., 2003. On a new wave energy absorber." Ocean Engineering, 30(9), 1191-1200.

Boccotti, P., 2007. "Comparison between a U-OWC and a conventional OWC." Ocean Engineering, 34(5-6), 799-805.

Boccotti, P., 2014. Wave Mechanics and Wave Loads on Marine Structures. Butterworth-Heinemann, Elsevier, 1-344.

Cruz, J., 2008. Ocean wave energy: current status and future perspectives, Springer.

D'Agostino, P., Lanciano, C., Musolino, G., Scattarreggia, T., Polimeni, A., Vitetta, A., 2015. Freight transportation in regional logistics: Pick-up, consolidation and delivery operations of a road carrier. 13th International Industrial Simulation Conference 2015, ISC 2015, 63-67.

Falcão, A. F. de O., 2010. Wave energy utilization: A review of the technologies. Renewable and Sustainable Energy Reviews, 14(3), 899-918.

Haghani A., Jung S., 2005. A dynamic vehicle routing problem with time-dependent travel times. Computers & Operations Research, 32, 2959-2986.

Hiermann, G., Puchinger, J., Ropke, S., Hartl, R.F., 2016. The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows and Recharging Stations. European Journal of Operational Research, 252(3), 995-1018.

Keskin, M., Çatay, B., 2016. Partial recharge strategies for the electric vehicle routing problem with time windows, Transportation Research Part C: Emerging Technologies, 65, 111-127.

Laface, V., Arena F., Guedes Soares C., 2015. Directional analysis of sea storms, Ocean Engineering, Vol. 107, 45–53.

Laface, V., Arena F., 2016. A new equivalent exponential storm model for long-term statistics of ocean waves, Coastal Engineering, Vol. 116, 133–151.

Laface, V., Malara, G., Romolo, A., Arena, F., 2016. Peak Over Threshold vis-à-vis Equivalent Triangular Storm: return value sensitivity to storm threshold, Coastal Engineering, Vol. 116, 220-235.

Laporte, G., 2007. What You Should Know About the Vehicle Routing Problem, Naval Research Logistics 54(8), 811 - 819.

Lin, J., Zhou, W., Wolfson, O., 2016. Electric Vehicle Routing Problem. Transportation Research Procedia, 12, 508-521.

Malara, G., Gomes, R. P. F., Arena, F., Henriques, J. C. C., Gato, L. M. C., and Falcão, A. F. O., 2017. The influence of three-dimensional effects on the performance of U-type oscillating water column wave energy harvesters. Renewable Energy, 111, 506-522.

Musolino G., Rindone C. and Vitetta A., 2017. Evaluation in Transport Planning: A Comparison between Data Envelopment Analysis and Multi Criteria Decision Making Methods. Modelling and simulation 2017, The European Simulation and Modelling Conference 2017, Esm®2017. Edited by Paulo J.S. Gonçalves. October 25-27, 2017, Lisbon, Portugal. EUROSIS-ETI, 238-243.

Musolino, G., Polimeni, Vitetta, A., 2018. Freight vehicle routing with reliable link travel times: a method based on network fundamental diagram. Transportation Letters: the International Journal of Transportation Research. Vol.10, Is. 3, 159-171.

Musolino G., Polimeni A., Rindone C., Vitetta A., 2018. Planning urban distribution center location with variable restocking demand scenarios: general methodology and testing in a medium-size town. Transport policy (accepted 9 April 2018). doi.org/10.1016/j.tranpol.2018.04.006.

Polimeni, A., Vitetta, A., 2013. Optimising Waiting at Nodes in Time-Dependent Networks: Cost Functions and Applications. Journal of Optimization Theory and Applications, Volume 156, Issue 3, 805-818.

Polimeni, A., Vitetta, A., 2014. Vehicle routing in urban areas: An optimal approach with cost function calibration. Transportmetrica B, Volume 2, Issue 1, 1-19.

Russo, F., Rindone, C., Panuccio, P., 2016. European plans for the smart city: from theories and rules to logistics test case. European Planning Studies, 24, (9), 1709-1726. DOI: 10.1080/09654313.2016.1182120.

Satish, S., Laface, V., Sannasiraj, S.A., Arena, F., Sundar, V., Gavrilovich, P.V., 2017. Comparative assessment of extreme wave prediction models, Natural Hazards Earth Syst. Sci., Vol. 17, 409–421.