Procedia
Environmental Science, Engineering and Management
http://www.procedia-esem.eu

Procedia Environmental Science, Engineering and Management **3** (2016) (3-4) 165-172

20th International Trade Fair of Material & Energy Recovery and Sustainable Development, ECOMONDO, 8th-11th November, 2016, Rimini Fiera, Italy

A WEB-APP FOR IMPLEMENTING A ‘CARBON FOOTPRINT CALCULATOR’ FOR SMART WASTE MANAGEMENT SYSTEMS*

Salvatore Digiesi, Giorgio Mossa, Giovanni Mummolo, Rossella Verriello**

Politecnico di Bari, DMMM - Department of Mechanics, Mathematics and Management, 182 Viale Japigia, Bari 70126, Italia

Abstract

Nowadays, being “smart” is fundamental to achieve sustainable objectives and targets set by the European Union. Providing smartness to waste management systems deserves considerable attention. Indeed, it is a sector that has experienced remarkable organizational and technological progresses. Much more can be done to involve smart actors who cooperate in decision-making on public or social services. Stakeholders include also citizens whose behaviours strongly affect system performance. Consistently, in the frame of the European project “RES NOVAE”, the authors developed a web-app named “Smart Waste - Carbon Footprint Calculator (SW-CFC)”. SW-CFC is conceived to evaluate and monitor direct and avoided emissions of municipal solid waste management systems. The web-app has two different users profile: public decision makers and citizens. The public decision-makers can use the app to assess the carbon footprint of the *‘status quo’* systems and to evaluate the impact of potential changes in different technical and organizational choices. On the other hand, the use of SW-CFC can stimulate citizens’ consciousness leading their actions on right collection practice. By a short survey section, the app calculates and shows citizen' green attitudes and habits in terms of avoided emissions. Due to the formative and informative purpose of the app, the increase of social involvement is an expected result too.

Keywords: carbon footprint; smart city; waste

*Selection and peer-review under responsibility of the ECOMONDO
** Corresponding author: e-mail: rossella.verriello@poliba.it

1. Introduction

Rethinking the urban spaces focusing on citizens' need, streamlining resources and making more efficient services and utilities play a key role in the achievement of a city' sustainable development. Consistently, the theme of the 'Smart City' is the center of an intense debate. According to the definition of (Batty et al., 2012) "*Cities are becoming smart not only in the way we can automate routine functions serving individual persons, buildings, traffic systems but in ways that enable us to monitor, understand, analyse and plan the city to improve the efficiency, equity and quality of life for its citizens in real time*". Indeed, Smart City development implies continuous innovations not only supplying 'smart objects or smart services' but also ensuring closer involvement of citizens in governance processes and closer monitoring of needs and services (CDP, 2013).

Among the different urban action areas, the waste management systems deserve considerable attention. Undoubtedly, this sector has experienced a steady progress in recent years. It mainly relates technical and organizational innovative solutions from waste collection to waste treatments and valorisation. Indeed, the scientific panorama widely faces waste management issues tailored to technical (Dutta et al., 2007; Massaro et al., 2015), economic (Gnoni et al., 2008) and environmental (Caponio et al., 2015; Gentil et al., 2010) aspects to both support decision making process and to assess systems performance. Greater efforts can be done to involve 'smart actors' who cooperate in decision-making on public or social services. Stakeholders include citizens whose behaviours strongly affect system performance. Consistently, in the frame of the European project "RES NOVAE", the authors developed a web-app named "Smart Waste - Carbon Footprint Calculator (SW-CFC)". SW-CFC is conceived to evaluate and to monitor direct and avoided emissions of municipal solid waste management systems. Giving a clue of other examples allows to gather the core of the topic and to capture the innovative aspects of the proposed solution.

The U.S. Environmental Protection Agency (EPA) developed the Waste Reduction Model (WARM) to assess savings in greenhouse gas (GHG) emission resulting from waste management practices. The tools works on a collection system already defined. To allow the GHGs emissions evaluation, the users enter the amount of waste flows handled for the different treatment options and by means of material-specific emission factors for each management practice, GHGs emissions and energy savings are calculated. Furthermore, in the context of European project "Zero Waste", a carbon footprint tool for municipal solid waste management is developed (Sevignè et al., 2013). The calculator is addressed to solid waste managers, academics and consultants. According to the IPCC guidelines, the calculator allows to inventory and to monitor GHGs emissions starting from the total amount of waste generated, waste composition, waste fraction collected, biogas captured in landfill. In contrast to those examples, the web-app proposed stands as a service planning tool as well as an environmental assessment tool for a pivotal phase, which is that of the municipal waste collection. In Section 2, the main objectives of the developed app are highlights. Materials and methods for the planning and the carbon footprint evaluation are provided in Section 3. The description of the SW-CFC is in Section 4, while conclusions are in Section 5.

2. Objectives

The web-app 'Smart Waste - Carbon Footprint Calculator' represents an innovative smart solution to monitor and to evaluate the carbon footprint resulting from the collection of municipal solid waste. Due to the aim to involve all the different actors and stakeholders, the web-app is designed with two different users' profile: public decision makers and citizens. The public decision-makers can use the app to assess the carbon footprint of the 'status quo' systems and to evaluate the impact of potential changes in different technical and organizational choices for the waste collection in terms on both emissions and level of separated collection achieved. On the other hand, the use of SW-CFC can stimulate citizens’ consciousness leading their actions on right collection practice. Indeed, despite a willingness to make personal behavior changes to reduce their climate impact, individual may lack the knowledge to make effective choices (Kim et al., 2009). For this reason, by a short survey section, the app calculates and shows citizen' green attitudes and habits in terms of avoided emissions.

3. Materials and methods of the Carbon Footprint Calculator

The carbon footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, an organization, an event or a product and it is expressed in terms of CO_{2eq}.

Variables object of the service planning by a local decision makers have been identified to evaluate the carbon footprint of the municipal waste collection system. Parameters affected by peculiarities of the application area or of the collection service have to be considered too. It is referred to area’ urban fabric constraints or to regulatory and technical constraints.

An overview of the variables identified and relative influences on the carbon footprint are shown in Fig. 1.

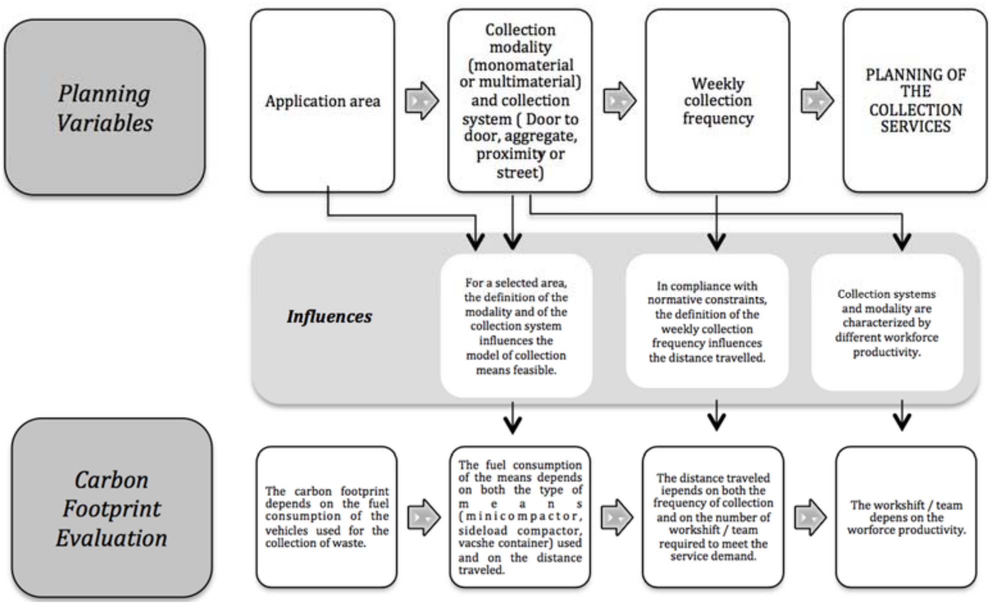

Fig. 1. Decision-making process and influences on the assessment of the Carbon Footprint

For the GHGs emissions assessment, the IPCC guidelines are followed. Basically, emissions depend on the distance travelled to ensure the collection service demand in a defined timeline. Consistently, a ‘*distance-based approach*’ (IPCC, 2006) for estimating CO_{2eq} emissions for each type of vehicle, payload and average speed is used. Going further into details, the total distance travelled to fulfill collection service demand depends on the frequency of collection as well as on the number of work-shifts for each collection route and on the average distance covered in each collection route. The number of work-shifts depends on the productivity of the collection work-team employed that is in turn influenced by the waste fraction collected and by both collection grouping and system adopted. Instead, the average distance travelled depends on the type of mean employed. For each waste fraction, emissions are calculated as in Eq. (1).

$$CF_{collection} = EF \cdot W \cdot \bar{d} \cdot f \quad (1)$$

where:
$CF_{collection}$ = Carbon Footprint for waste collection in a set timeline [t_{CO2eq}/ timeline];
EF = emission factor of the collection mean [t_{CO2eq}/ km];
W = number of work-shift for each collection routes [work-shift/ collection route];
$\bar{d}$ = average distance travelled in a work-shift [km/work-shift];
f = collection frequency [collection route/timeline].

Readers can refer to (D'Alessandro et al., 2012; Caponio et al., 2015) for collection systems and grouping systems features such as collection efficiencies, workforce productivity, and means characteristics (payload, average distance). Emissions factor adopted in the tool for mini-compactor and side/rear load compactor are provided by (Inemar, 2013).

4. Web-app "Smart Waste - Carbon Footprint Calculator"

Hereinafter, a detailed description of the app is provided exploiting actual screens of the tool. The app will be available for free to the users. As aforementioned, the app is build up in the frame of the European project 'RES NOVAE' for Bari Smart City. The tool operates at municipal level with a deeply insight at city's district level. Nevertheless it can be easily scaled up to other city or to regional level. The app' home page is shown in Fig.2. As it can be seen, Section B of Fig. 2 relates the expert user profile while the Section C of Fig.2 relates the citizen user profile. The two user profiles have been developed with different functions and purposes, but with the common goal to monitor the environmental impact and to raise awareness on sustainable development.

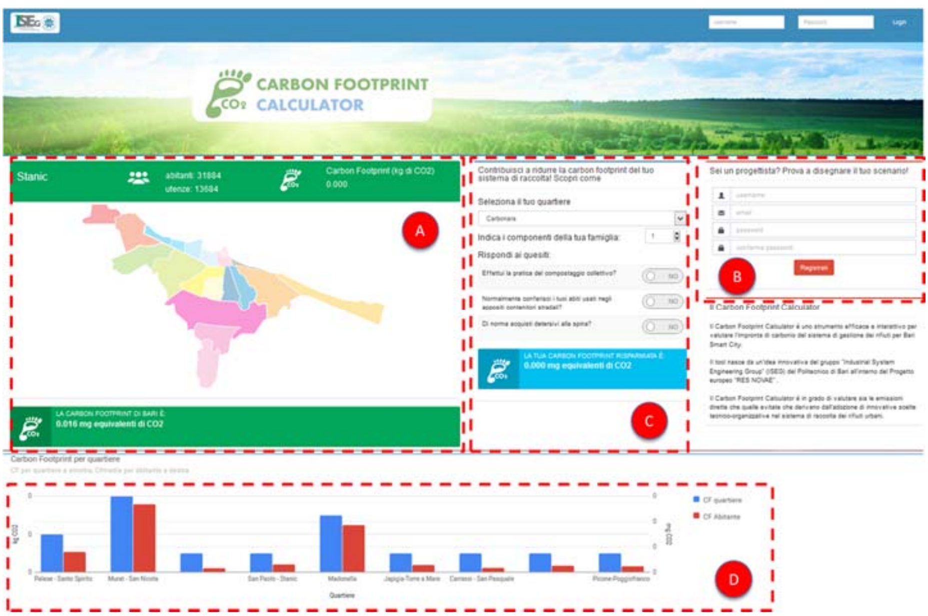

Fig. 2. Home page of 'Smart Waste - Carbon Footprint Calculator'

The Section A Fig. 2 represents the city' map with details of districts and different areas inside the district (characterized by nuances of the same color). A simple scroll on that map allows showing the annual carbon footprint for the different areas due the current collection service in place. For an easier comparison among the different districts, results in terms of (t_{CO2eq}/inhabitants) and (t_{CO2eq}/ area) are also shown in a histogram, as evident in the Section D of Fig. 2.

4.1. App Interface for public decision makers

The web-app will allow the public decision maker to assess the carbon footprint attributable to both the waste collection system already implemented and, through scenario analysis, that caused by innovative technical and organizational solutions for the recyclable and unrecyclable waste flows collection.

The steps followed by the users are shown below. They relate the characteristic elements to identify the interdependent and/or complementary operating modalities that affect the environmental impact of the collection area.

A user registration mechanism is foreseen before proceeding with the assessments (Fig. 2- Section B). The decision-making process starts with the definition of the area. The planning collection service interface is shown in Fig. 3. For each area, in the top left are listed demographic data like the number of inhabitants and the number of families (defined *'users'* from the point of view of the collection) as well as the annual waste production per capita.

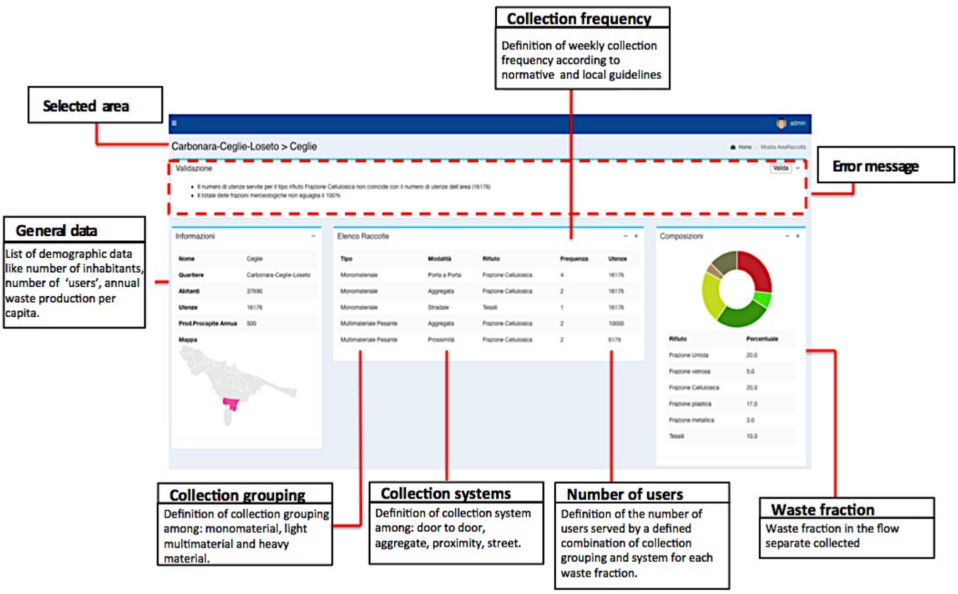

Fig.3. Planning collection service interface

The waste fractions considered in the model are the follow: organic, paper and cardboard, plastics, ferrous and aluminum cans, glass, textile, wood and others. Three types of collection grouping are foreseen in the tool: monomaterial, light multimaterial, heavy multimaterial. The monomaterial grouping system allows each fraction to be collected in a separate flow. Plastics, ferrous and aluminum cans have to be collected together in the light multimaterial. Otherwise, plastics, ferrous and aluminum cans with paper and cardboard have to be collected together in the heavy multimaterial. Four types of collection systems are foreseen in the tool: door to door, aggregate, proximity and street. The definition of the weekly collection frequency occurs in compliance with constraints set by normative regulations and guidelines.

To plan the collection service, the public decision maker is required to enter for each waste fraction the number of users served with a defined grouping system and collection system with a particular weekly collection frequency. In this phase, the planning experience plays a key role. Indeed, city' urban features have a remarkable influence on collection systems. The experience and the awareness of urban fabric restrictions allow for defining a collection service fitting with the characteristics and the needs of the interest area. To help the planning, the maximum number of users employable is added for each collection system. Regard to collection means, the choice of the type of means by the user will be bound to the type of collection system previously adopted. Downstream the definition of the collection service, it is possible to quantify the flows intercepted in the separate collection loop. Indeed it should be pointed out that for every waste fraction, each combination of grouping and collection system is characterized by a specific value of collection efficiency. Therefore, the composition of waste collected is plotted in the pie chart (Fig. 3) and the separate collection index is displayed too, as in Fig. 4.

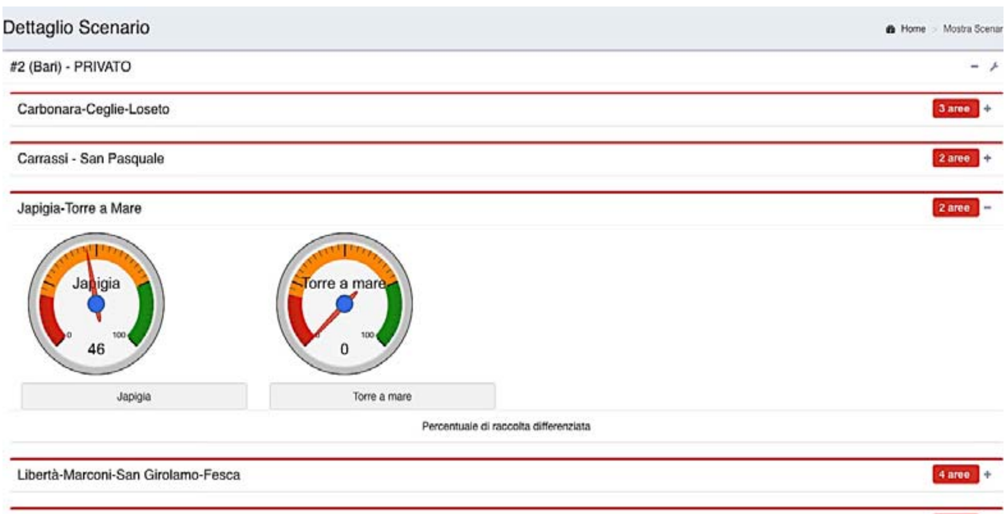

Fig. 4. Planning result: separate collection index

Proper error messages will be displayed to signal failures in fulfillment service demand or failure in the quantification of waste collected. The outcome of the decision-making process will be displayed in terms of annual CO_{2eq} emissions.

4.2. App Interface for citizens

For the citizen profile the assessment procedure is simplified. Coherently, the procedure is consistent with the training, information, and increased social participation purposes. Indeed, no registration is required.

Once the user select the area from the home page (Fig. 2 section A), the app automatically loads the collection system implemented in the district. The results displayed represent the annual GHGs emissions due to the collection in such area. Calculating the avoided individual carbon footprint due to green attitudes and habits represents the interactive section of the ‘citizen menu’ (Fig. 2-Section C). For the individual carbon footprint evaluation, the user is required to select the home area and to enter the effective number of household member. To increase the awareness of behaviors affecting waste management environmental impact, a short survey is proposed (Fig. 5).

Green attitudes and habits investigated are: home composting for the organic fraction, the use of detergents on tap to reuse the plastic bottle and inserting textiles into appropriate receptacle. Results are shown in terms of individual avoided carbon footprint (t_{CO2eq}/inh year). Increasing citizen participation as well as improving the citizen' awareness of the effects that an individual behavior has on the collective well-being and on the environment, are the main expected benefits.

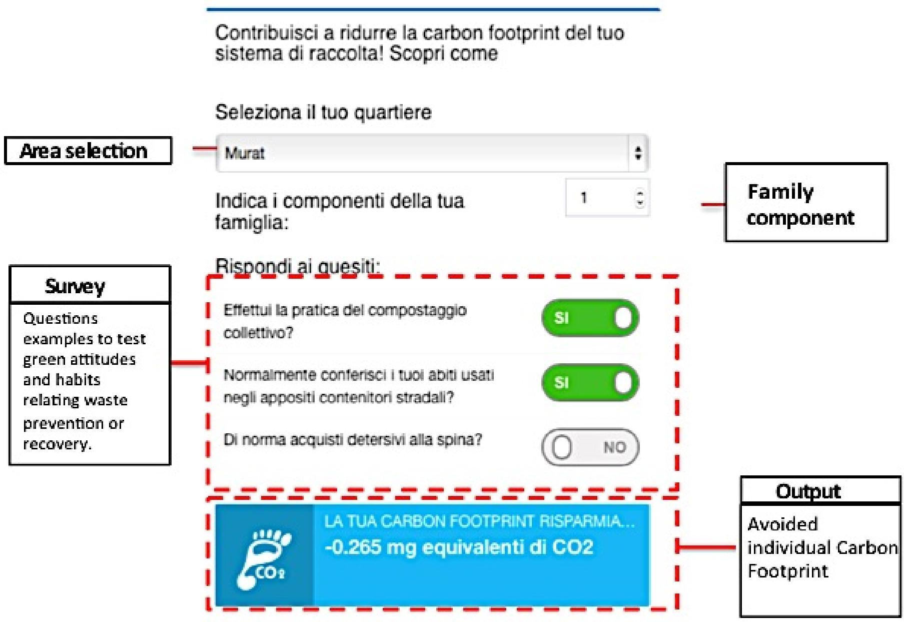

Fig.5. Citizen interface to evaluate avoided carbon footprint

5. Concluding remarks

Starting from KPI of waste production and collection, the ‘Smart Waste-Carbon Footprint Calculator’ will enable citizens and decision makers to assess the carbon footprint of the integrated system taking into account both the virtuous citizens behaviors and the technical and organizational decisions of policy makers.

Indeed, the public decision maker is able to jointly assess the carbon footprint due to the collection service already implemented and to investigate, through scenario analysis, the effects on the carbon footprint due to innovative technical and organizational collection choices.

On the other hand, the use of SW-CFC can stimulate citizens’ consciousness leading their actions on right collection practice. By a short survey section, the app calculates and shows citizen' green attitudes and habits in terms of avoided emissions. The awareness of their impact in terms of emissions will enable individuals to understand the contribution that a virtuous behavior on societal wellbeing.

Acknowledgements
The paper has been written within the framework of the project PON04a2_E "Smart Energy Master per il governo energetico del territorio - SINERGREEN - RES NOVAE". The project is supported by the Italian University and Research National Ministry research and competitiveness program that Italy is developing to promote "Smart Cities Communities and Social Innovation".

References

Batty M., Axhausen K.W., Giannotti F., Pozdnoukhov A., Bazzani A., Wachowicz M., Ouzounis G., Portugali Y., (2012), Smart cities of the future, *The European Physical Journal Special Topics*, **214**, 481-518.

Caponio G., D'alessandro G., Digiesi S., Mossa G., Mummolo G., Verriello R., (2015), *Minimizing Carbon-footprint of Municipal Waste Separate Collection Systems*, In: *Lecture Notes in Management and Industrial Engineering - Enhancing Synergies in a Collaborative Environment*, Cortés P., Maeso-González E., Escudero-Santana A. (Eds.), Springer series, 351-359.

CDP, (2013), Cassa Depositi e Prestiti Politecnico di Torino, (2013), *Smart City: progetti di sviluppo e finanziamento*, On line at: http://osservatoriosmartcity.it/wp-content/uploads/Report-monografico-Smart-City.pdf.

D'Alessandro G., Gnoni G., Mummolo G., (2012), *Sustainable Municipal Solid Waste Management and Recovery*, In: *Handbook of Sustainability Management, Imperial College*, Madu C.N. and Kuei C. (Eds.), London.

Dutta A., Jarungthammachote S., (2007), Thermodynamic equilibrium model and second law analysis of a downdraft waste gasifier, *Energy*, **32**, 1600–1669.

Gentil E.C., Damgaard A., Hauschild M., Finnveden G., Eriksson O., Thorneloe S., Kaplan P.O., Barlaz M., Muller, O., Matsui Y., Ryota I., Christensen T.H., (2010), Models for waste life cycle assessment: review of technical assumptions, *Waste Management*, **30**, 2636–2648.

Gnoni M.G., Mummolo, G., Ranieri, L.,(2008), A mixed integer linear programming model for optimisation of organics management in an integrated solid waste system, *Journal of Environmental Planning and Management*, **51**, 833-845.

Inemar, (2010), Inventario EMissioni Aria-RegioneLombardia , Fattori Emissioni medi da traffico per tipo veicolo e inquinante, On line at: http://www.inemar.eu/.

IPCC, (2006), Guidelines for National Greenhouse Gas Inventories, On line at: http://www.ipcc-nggip.iges.or.jp/public/2006gl.

Kim B., Neff R., (2009), Measurement and communication of greenhouse gas, emissions from U.S. food consumption via carbon calculators, *Ecological Economics*, **69**, 186-196.

Massaro V., Digiesi S., Mossa G., Ranieri L., (2015), The sustainability of anaerobic digestion plants: a win–win strategy for public and private bodies, *Journal of Cleaner Production*, **104**, 445-459.

Sevignè E.I, Gasol C.M, Farreny R., Rieradevall J., Gabarell X., (2013), CO2ZW: Carbon footprint tool for municipal solid waste management for policy options in Europe. Inventory of Mediterranean countries, *Energy Policy*, **56**, 623-632.