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The facility location problem in a reverse logistic network: Weeenmodels project in the city of Genoa

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Abstract— **In this paper a multi-stage multi-commodity facility location problem for a reverse logistic network is proposed. In particular, this problem is applied to the city of Genoa, Italy, which is the test case for the Weeenmodels project, co-financed by the European Commission, started in 2013 and lasting until 2016. This project aims at defining and developing innovative logistic solutions for collection, reuse and recycle of waste deriving from electric and electronic equipment, according to the recent European Directive 2012/19/EU. For this problem, a MILP formulation is proposed in the paper. Some interesting results about the development of the waste collection system in the city of Genoa are presented and discussed.**

I. INTRODUCTION

The incessant expansion of the market and the development of new technologies are making the life cycle of electrical and electronic equipment (EEE) shorter and shorter, causing a strong increase in the waste deriving from such equipment (WEEE). Therefore, the need of a proper collection and management system for this type of waste has become more and more urgent in the last years. Furthermore, the presence of hazardous materials in EEE can cause serious problems in the WEEE management process with significant risks for environment and human health. Another crucial aspect is represented by the presence of valuable materials or reusable components from which great economic benefits could be drawn. For these reasons, it can be argued that a good management of WEEE can entail both ecological and economic benefits for the system.

The European WEEE collection system was introduced with the Directive 2002/96/EC, which required Member States to develop specific initiatives in order to achieve significant collection goals. The obtained results were different from country to country and, even encouraging, they were not significant. So there is still the risk that a large portion of WEEE is not managed appropriately. This is confirmed by the fact that the recent European Directive 2012/19/EU has introduced some innovative elements with respect to the previous ones. In particular, the present Directive fixes higher goals to be reached and imposes new obligations to distributors, such as the "1 vs 0" collection system, in order to achieve greater levels of collection, to avoid illegal or improper treatment, and to facilitate the recovery of valuable materials and the release in the market of reusable components. More in detail, with the "1 vs 0" collection system, distributors are required to collect free small appliances from customers even though these latter do not buy any new equivalent product (this concept is optional for small stores). According, instead, to the already existing concept of "1 vs 1", customers are allowed to return old electronic products directly into the store, only if a new equivalent object is purchased. The new Directive, therefore, forces Member States towards the creation of a new model of WEEE collection which organizes the service in order to encourage more consumers to deliver their WEEE and facilitate them by creating appropriate structures and collection procedures.

In this context, the project named WEEENMODELS (Waste Electric and Electronic Equipment - New MODEl for Logistic Solutions) started on September 2, 2013. This project is co-financed by the European Commission and will end on December 31, 2016. The Weeenmodels project [1] is being developed in Genoa, Italy: its trial will be conducted initially in a specific municipality of Genoa as a pilot case and then the project is expected to be applied throughout the city. In the present paper, a mathematical programming model to optimally plan a logistic network for the recycling and reuse of WEEE is presented. The proposed model, characterized by a MILP (Mixed Integer Linear Programming) formulation, has been developed referring to the specific test case of the Weeenmodels project, i.e. the planning and management of the waste collection system in the city of Genoa.

This paper is organized as follows. In Section II a brief literature review regarding the management of WEEE is reported. Section III contains an introduction about Weeenmodels project, followed by the description of the problem faced in this work. The mathematical model which supports decision-making on the raised questions is formulated in Section IV. In Section V, the case study of Genoa is presented and several scenarios are analysed and discussed. Finally, some conclusions and future research directions are drawn in Section VI.

II. LITERATURE REVIEW

The scientific works present in the literature are mainly focused on generic municipal solid waste and are not specifically referred to the management of special waste types such as WEEE. The works dealing with the design and management of recovery networks for WEEE are mostly referred to long-term and medium-term time horizon planning, as it is in the present paper.

Decisions made on long-term horizons are strategic and deal with the definition of the logistic network structure and

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the acquisition of resources and infrastructure, thus requiring high investments. These include all the issues related to location of new facilities and network design problems. The main mathematical approaches used to solve these types of problems are Multi Criteria Decision Making (MCDM) techniques and mathematical programming (generally of MILP type) approaches.

The MCDM methods allow to analyze and evaluate different alternatives by monitoring the impact on different actors in the decision-making process. For instance, [2] presents a study on the location of facilities dedicated to the collection and treatment services of WEEE in Greece. In particular, a selection among a set of alternative locations is made by applying ELECTRE III, which belongs to the family of the ELECTRE methods. In [3], the authors perform a study to determine which of the Spanish municipalities are appropriate for locating and installing the recycling plants of WEEE in Spain. This problem is dealt with by applying the PROMETHEE method.

The same design and location problems can be treated by formulating and solving appropriate mathematical programming models. For instance, in [4], a MILP model for the design of a WEEE collection network in China is developed. This model is based on a capacitated warehouse location model and is applied to an example based on data from a Chinese province. In [5], the main goal is to provide an assignment which is efficient and fair for all the involved actors in the WEEE recovery network, e.g. the producers, the municipalities, and the collective schemes. To do that, an optimization-based decision support tool is developed and applied to the Danish setting. Finally, in [6], the authors adopt a warehouse location model to determine the best location to build collection and treatment services for large household appliances in Spain.

Decisions made on a long-medium time horizon are referred to tactical planning, i.e. they cover more detailed and specific issues, often classified as belonging to Service Network Design problems. In [7], a MILP model is applied to determine an optimal system of collection and recycling of computers and household appliances in Taiwan. In [8], the authors deal with the optimal design and planning of the reverse logistic network of WEEE in Portugal through the development of a MILP model based on the one proposed in an another study, [9], in which the design and planning of a generic closed-loop supply chain is considered. The proposed model is of multi-period type, where the best locations for collection and sorting centres are determined for a predefined time horizon and the return volumes vary according to the information provided by the Portuguese Association for the Management of Electric and Electronic Waste. In [10], a mathematical programming framework for multi-period reverse logistic network design problems is proposed. A case study considering large household appliances in Germany is presented and analyzed in order to illustrate the potential benefits of using a dynamic model as opposed to its static counterpart. In [11], a MILP model is formulated taking into account existing infrastructure of collection points and recycling facilities. The applicability of the developed model is demonstrated by employing a real-world case study for the Region of Central Macedonia in Greece. In [12], the authors formulate a multi-product mathematical programming model to determine the optimal location of the services for recycling, disassembling and repairing within the reverse logistic network of WEEE. In [13], a two-leveled approach is proposed to design and manage reverse logistic networks of WEEE. In a first level (internal) the network of products and materials is optimized through an LP model, then, in a second level (external), the focus is placed on the disassembling systems, where activities like sorting and storing are simulated.

In the literature, different works refer more specifically to medium-short time horizons, i.e. to transport planning decisions, mostly related to Vehicle Routing Problems (VRP) (see e.g. [14], [15], [16], [17]).

The innovative aspect of the model presented in this work, compared with the others found in the literature, is represented by its ability to optimize very detailed and complex reverse logistic networks, which can be seen as multi-stage networks. In particular, the proposed model takes into account all the changes introduced by the Weeenmodels project, which are specifically based on the new European Directive for WEEE. To the best of the authors' knowledge, none of the previous works have considered a citywide logistic network and all of them are based on the old European Directive.

III. Problem description

As aforementioned, this work has been carried out within the Weeenmodels European project. The project proposes a new model of reverse logistics, realised according to the new European Directive, with the aim of optimizing the collection and transport system of WEEE, that today is neither efficient nor effective, from both an economic and an ecological point of view.

In Italy, WEEE is classified into five categories: Category 1 - Refrigerators, air conditioners, freezers, etc.; Category 2 - Large electric appliances, such as washing machines, dishwashers, ovens, etc.; Category 3 - Televisions, LCD or plasma screens, etc.; Category 4 - Small electric equipment, as mobile phones, computers, printers, electronic games, fans, hair dryers, etc.; Category 5 - Light bulbs, neon lamps, fluorescent lamps, etc. In this work, particular attention has been given to small WEEE, i.e. to Category 4. The development of a planning procedure for this kind of equipment is particularly interesting from a practical point of view, since nowadays the quantity of collected WEEE of Category 4 is much lower compared to the other categories of WEEE. Hence, an improvement in the collection of this type of system is highly desirable.

As aforementioned, the Weeenmodels project is being developed in Genoa, starting from a specific municipality of the city as a pilot case. Note that in the present paper "municipalities" indicate the districts in which the city is divided (in the specific case of the city of Genoa, 9 municipalities are present). Due to the different characteristics of the territory of Genoa, the results of the experiment can provide useful information for further applications in other cities in Italy, as well as in Europe.

The collection system target of the Weeenmodels project is characterized by the following features:

- compliance with the European Directive 2012/19/EU and with related national regulations (Decree 49/2014);
- orientation to favor the reuse and preparation for the reuse of WEEE;
- development of a set of complementary collection services, organized to bring together all the main actors involved, in a single integrated network.

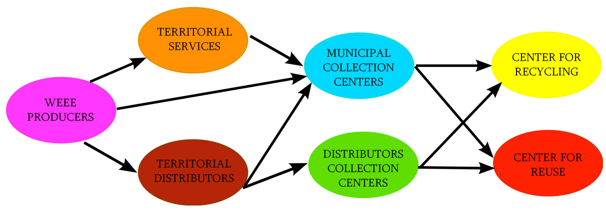

Fig. 1: The collection system target of Weeenmodels.

In Fig. 1 the Weeenmodels collection system is sketched. The *WEEE Producers* are the citizens who generate WEEE. They can deliver their waste directly to the *Territorial Distributors* (big or small stores and technical support centers) or to the collection centers called *Municipal Collection Centers*. The Municipal Collection Centers can be of two types: *Standard Municipal Collection Centers*, for both reusable and non-reusable products, and *Municipal Collection Centers for Reuse*, only for reusable ones. The WEEE Producers can also benefit from the so-called *Territorial Services*: the waste collected by these services will be taken again to the Municipal Collection Centers. The WEEE collected by the Territorial Distributors is taken either to the Municipal Collection Centers or to the *Distributors Collection Centers* (public or private) that are specifically dedicated to them and, therefore, are not open to citizens. The final destinations of WEEE are represented by either the *Center for Recycling* or the *Center for Reuse*.

In this work the logistic network for the recycling and reuse of WEEE is modeled through a graph, in which the nodes represent the actors/services involved in the logistic network, while the arcs represent all the connections between these actors. A mathematical programming model will be defined in order to optimize the location of nodes (i.e. to decide if a given facility/service has to be opened or not) and the flows of products in the network. The decisions will be taken in order to maximize the difference between the total revenue and the total cost. Note that both the revenues and the costs are to be intended as referred to the entire city system, and are computed considering one year of activity of the WEEE recycling and reuse system. Therefore, the objective of the model can be interpreted as the maximization of the yearly profit of the system.

In the optimization problem under exam two other elements are also taken into consideration, i.e. the types of products and the collection methods. The products transported along the logistic network can be distinguished (already from the initial stage) in two main typologies:

- *non-reusable* products, whose final destination is the Center for Recycling;
- *reusable* products, whose final destination is the Center for Reuse.

Instead, the WEEE collection processes can be distinguished depending on the actor involved in the intermediate stage. In particular, if WEEE are brougth to Territorial Distributors, there are three different methods:

- "1 vs 1";
- "1 vs 0" mandatory;
- "1 vs 0" optional.

As an alternative, the citizens can avail themselves of the services provided by the local public waste management company which include mobile collection services and collection points located in public areas (schools, commercial centers, public offices, and so on), i.e. the so-called Territorial Services mentioned above. Moreover, as already introduced, WEEE producers can deliver their waste to Municipal Collection Centers, also provided by the local public waste management company.

IV. Model Formulation

This section presents the general statement of a multi-stage multi-commodity location problem by means of a MILP formulation. Specifically, the location decisions are applied to a reverse logistic network in which the waste is collected in an initial stage and then brought, through a series of intermediate stages, to one or more final collection stages. It is worth noting that the formulation provided in this section has been inspired from the case studied in the Weeenmodels project and applied to the city of Genoa but is proposed in a general form, in order to be possibly applied to other reverse logistic networks.

A. The input data

The input data of the model are listed below:

- $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, graph representing the considered network described by a set of nodes $\mathcal{V}$ and a set of arcs $\mathcal{E}$;
- $\mathcal{N} = \{1, \ldots, \bar{N}\}$, set of node types (i.e. each node type represents a specific actor involved in the network); let $n = 1$ indicate the initial stage of WEEE Producers and $\mathcal{T} \subset \mathcal{N}$ denote the set of node types corresponding to the final collection stages;
- $\mathcal{V}_n \subseteq \mathcal{V}$, $n \in \mathcal{N}$, set of nodes of the generic node type n;
- $\mathcal{C} = \{1, \ldots, \bar{C}\}$, set of connections between different types of nodes (i.e. between different types of actors);
- $\mathcal{O}_c \subseteq \mathcal{V}$, $c \in \mathcal{C}$, set of source nodes of the generic connection c;
- $\mathcal{D}_c \subseteq \mathcal{V}$, $c \in \mathcal{C}$, set of destination nodes of the generic connection c;

- $\mathcal{P} = \{1, \ldots, \bar{P}\}$, set of products types;
- $\mathcal{R} = \{1, \ldots, \bar{R}\}$, set of collection methods;
- $s_{i,p,r}$, $i \in \mathcal{V}_1$, $p \in \mathcal{P}$, $r \in \mathcal{R}$, quantity of product p collected with method r and exiting from node i belonging to the initial stage (these are the waste quantities generated by WEEE Producers);
- q_i^n, $i \in \mathcal{V}_n$, $n \in \mathcal{N}/\{1\}$, maximum capacity of node i of type n (note that the capacity is defined for all types of nodes, except for the nodes of the initial stage, i.e. WEEE Producers);
- $\zeta_{i,j,p,r}^c$, $c \in \mathcal{C}$, $i \in \mathcal{O}_c$, $j \in \mathcal{D}_c$, $p \in \mathcal{P}$, $r \in \mathcal{R}$, unit yearly transportation cost for product p with collection method r on arc (i, j) belonging to connection c;
- φ_i^n, $i \in \mathcal{V}_n$, $n \in \mathcal{N}$, fixed yearly cost associated with opening the facility located in node i of type n;
- α_p, $p \in \mathcal{P}$, unit revenue for the collection of product p.

B. The decision variables

The decision variables adopted in the MILP model are:

- $x_{i,j,p,r}^c \geq 0$, $c \in \mathcal{C}$, $i \in \mathcal{O}_c$, $j \in \mathcal{D}_c$, $p \in \mathcal{P}$, $r \in \mathcal{R}$, continuous variable representing the flow of product p collected with method r on arc (i, j) belonging to connection c;
- $y_i^n \in \{0, 1\}$, $i \in \mathcal{V}_n$, $n \in \mathcal{N}$, binary variable equal to 1 if node i of type n is open (i.e. the corresponding facility/service is open), equal to 0 otherwise.

Note that, even though the location binary variables y_i^n are defined for each node $i \in \mathcal{V}_n$, $n \in \mathcal{N}$, the proposed model can be easily generalized to a case in which some nodes already exist and their location has not to be decided. In particular, if a given node i of type n is surely present in the network, the corresponding location variable y_i^n is fixed equal to 1.

C. The model

The MILP model for the location planning in a reverse logistic network is formulated as follows.

$$\max \sum_{c\in\mathcal{C}} \sum_{i\in\mathcal{O}_c} \sum_{j\in\mathcal{D}_c} \sum_{p\in\mathcal{P}} \sum_{r\in\mathcal{R}} \left(\alpha_p \cdot x_{i,j,p,r}^c - \zeta_{i,j,p,f}^c \cdot x_{i,j,p,r}^c \right) - \sum_{n\in\mathcal{N}} \sum_{i\in\mathcal{V}_n} \varphi_i^n \cdot y_i^n \quad (1)$$

s.t.

$$\sum_{c\in\mathcal{C}:\mathcal{O}_c=\mathcal{V}_1} \sum_{j\in\mathcal{D}_c} x_{i,j,p,r}^c = s_{i,p,r} \qquad \forall i \in \mathcal{V}_1,\ \forall p \in \mathcal{P},\ \forall r \in \mathcal{R} \quad (2)$$

$$\sum_{r\in\mathcal{R}} \sum_{p\in\mathcal{P}} \sum_{c\in\mathcal{C}:\mathcal{D}_c=\mathcal{V}_n} \sum_{j\in\mathcal{O}_c} x_{j,i,p,r}^c \leq q_i^n \cdot y_i^n \qquad \forall n \in \mathcal{N}/\{1\},\ \forall i \in \mathcal{V}_n \quad (3)$$

$$\sum_{c\in\mathcal{C}:\mathcal{D}_c=\mathcal{V}_n} \sum_{j\in\mathcal{O}_c} x_{j,i,p,r}^c = \sum_{c\in\mathcal{C}:\mathcal{O}_c=\mathcal{V}_n} \sum_{j\in\mathcal{D}_c} x_{i,j,p,r}^c \qquad \forall n \in \mathcal{N}/\left(\mathcal{T} \cup \{1\}\right),\ \forall i \in \mathcal{V}_n,\ \forall p \in \mathcal{P},\ \forall r \in \mathcal{R} \quad (4)$$

$$x_{i,j,p,r}^c \geq 0 \qquad \forall c \in \mathcal{C},\ \forall i \in \mathcal{O}_c,\ \forall j \in \mathcal{D}_c,\ \forall p \in \mathcal{P},\ \forall r \in \mathcal{R} \quad (5)$$

$$y_i^n \in \{0, 1\} \qquad \forall i \in \mathcal{V}_n,\ \forall n \in \mathcal{N} \quad (6)$$

The objective function (1) represents the maximization of the yearly profit of the system. Constraints (2) ensure that all the products generated by WEEE Producers are collected within the system and taken to their final destinations for recycling or reuse. Constraints (3) are used to impose that the flow of products entering each node of the network (except those of the first stage) does not exceed the maximum capacity of the node, if the node is open, and is equal to 0, if instead the node is not open. Constraints (4) are flow conservation equations, i.e. imposing that the flow of products entering a node is equal to the flow exiting it (obviously, these constraints are defined only for the intermediate stages of the considered network). Finally, (5) and (6) represent the definition of the decision variables.

V. Analysis of results

The multi-stage multi-commodity location model for a reverse logistic network described in Section IV has been applied to the case study examined in this work, i.e. to the logistic network for the recycling and reuse of small WEEE in the territory of Genoa, according to the Weeenmodels project. In particular, the MILP model has been implemented in C# and solved using Cplex 12.5 solver, by exploiting the IBM ILOG Concert library for building the model from the C# language.

Set	*Type of actor*	*# nodes*
$\mathcal{V}_1$	WEEE Producers	9
$\mathcal{V}_2$	Territorial Services	9
$\mathcal{V}_3$	Territorial Distributors	9
$\mathcal{V}_4$	Standard Municipal Collection Centers	4
$\mathcal{V}_5$	Private Distributors Collection Center	2
$\mathcal{V}_6$	Public Distributors Collection Center	1
$\mathcal{V}_7$	Center for Recycling	1

TABLE I: The actors of the current logistic network.

Set	*Type of actor*	*# nodes*
$\mathcal{V}_1$	WEEE Producers	9
$\mathcal{V}_2$	Territorial Services	9
$\mathcal{V}_3$	Territorial Distributors	9
$\mathcal{V}_4$	Standard Municipal Collection Centers	9
$\mathcal{V}_5$	Municipal Collection Center for Reuse	1
$\mathcal{V}_6$	Private Distributors Collection Center	2
$\mathcal{V}_7$	Public Distributors Collection Center	1
$\mathcal{V}_8$	Center for Reuse	1
$\mathcal{V}_9$	Center for Recycling	1

TABLE II: The actors of the target logistic network.

Referring to the case of Genoa, two different logistic networks are considered. The former is the network corresponding to the current situation (see Table I), while the latter represents the network considered as the target case in the Weeenmodels project (see Table II). In both cases the WEEE Producers, the Territorial Distributors and the

Territorial Services are represented by groups of 9 nodes, corresponding to the 9 municipalities of Genoa. The MILP model associated with the current network is composed of 348 constraints and 1391 variables, whereas the model for the target network is given by 271 constraints and 1424 variables. Both models are optimally solved with Cplex in less than 1 second. Four main scenarios have been analyzed:

1) *Current scenario* - This represents the current management system of WEEE through the reverse logistic network described in Table I. The current system collects WEEE without making a distinction between reusable and non-reusable products, so that all of them are sent to the Center for Recycling as final destination. Moreover, the only collection method between Producers and Territorial Distributors is the “1 vs 1”.
2) *Target scenario* - This scenario represents the collection system at which the Weeenmodels project aims for the future (described in Table II). In this scenario the concept of reuse is introduced, as well as the “1 vs 0” collection method, and all the Municipal Collection Centers are opened also to small shops which collect WEEE. The future network has a new Municipal Collection Center for Reuse, which collects the reusable WEEE from the Standard Municipal Collection Centers, and a new Center for Reuse as the final destination for all the reusable products collected throughout the system. Also, in order to increase the collection of WEEE, 5 new Standard Municipal Collection Centers can be introduced in order to be present in each municipality.
3) *Partial target scenario* - This scenario represents the situation that would be achieved taking into account both the Weeenmodels project and the industrial plan currently provided by the waste management company in Genoa. The difference from the previous scenario is represented by the fact that in this case no new Standard Municipal Collection Centers are planned to be introduced.
4) *Future scenario without Weeenmodels* - This represents the situation that would be achieved considering the future target amount of WEEE to be collected but without introducing the changes in the logistic network provided by Weeenmodels. Therefore, the reverse logistic network is the same as the one of the current situation, shown in Table I.

The location of the Municipal Collection Center for Reuse and the new Standard Municipal Collection Centers, for Scenario 2, has been evaluated by solving the associated MILP model. In Table III, 9 different cases are reported, corresponding to the location of the Municipal Collection Center for Reuse in the 9 municipalities of the city of Genoa, with the corresponding optimal location of the Standard Municipal Collection Centers and the unit profit value. The optimal solution corresponds to opening the Municipal Collection Center for Reuse in the first municipality and opening the Standard Municipal Collection Centers in municipalities 1, 2, 8, and 9, corresponding to a unit profit equal to 0.061 [€/kg].

Location of the Mun. Coll. Center for Reuse	*Location of St. Mun. Coll. Centers*	*Unit profit [€/kg]*
1	***1, 2, 8, 9***	**0.061**
2	*1, 2, 8, 9*	0.060
3	*1, 2, 3, 8, 9*	0.059
4	*1, 2, 8, 9*	0.054
5	*1, 2, 8, 9*	0.059
6	*1, 2, 8, 9*	0.058
7	*1, 2, 8, 9*	0.056
8	*1, 2, 8, 9*	0.060
9	*1, 2, 8, 9*	0.058

TABLE III: Scenario 2 - Location of the Municipal Collection Center for Reuse and the Standard Municipal Collection Centers.

A similar analysis has been done for Scenario 3, where only the location of the Municipal Collection Center for Reuse has to be decided. As shown in Table IV, the optimal solution corresponds to opening the Municipal Collection Center for Reuse in municipality 5, with a unit loss equal to 0.008 [€/kg].

Location of the Municipal Collection Center for Reuse	*Unit profit [€/kg]*
1	-0.017
2	-0.018
3	-0.014
4	-0.015
5	**-0.008**
6	-0.016
7	-0.009
8	-0.018
9	-0.032

TABLE IV: Scenario 3 - Location of the Municipal Collection Center for Reuse.

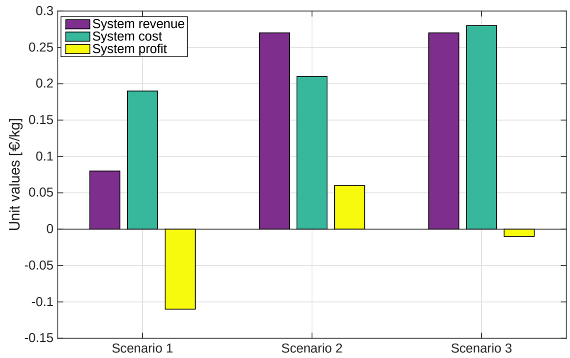

Fig. 2: Comparison among scenarios.

In Fig. 2, the first three scenarios are compared in terms of unit profit, showing also the unit revenues and costs. Scenario 4 has not been considered in the comparison since the optimization analysis has showed that this scenario is not feasible. In other words, it is not possible to collect all the WEEE expected in the future situation if the configuration and the characteristics of the current logistic network are maintained as they are in the current situation. When comparing the first three scenarios in Fig. 2, it can be observed that the best scenario is obviously Scenario 2, which introduces in the logistic network all the changes provided by Weeenmodels, entailing a unit profit for the system equal to 0.061 [€/kg]. More specifically, this is the only scenario providing a profit for the system, whereas Scenarios 1 and 3 entail losses for the system.

Finally, a sensitivity analysis has been carried out regarding Scenario 3. Specifically, it is of interest to evaluate if appropriate changes in the project parameters can lead to the same results obtained in Scenario 2 (i.e. a unit profit equal to 0.061 [€/kg]). Different parameters have been analyzed, but only two cases are here provided for space limitations.

Group	*% reusable*	*% non-reusable*	*Unit profit [€/kg]*
a	4.0	96.0	-0.008
b	4.5	95.5	0.001
c	5.0	95.0	0.010
d	5.5	94.5	0.020
e	6.0	94.0	0.029
f	6.5	93.5	0.038
g	7.0	93.0	0.047
h	7.5	92.5	0.057
i	**8.0**	**92.0**	**0.066**

TABLE V: Scenario 3 - Variation of the percentages of products types.

Group	*% Territorial Services*	*% Standard Mun. Coll. Centers*	*% Territorial Distributors*	*Unit profit [€/kg]*
a	32.1	46.1	16.1	-0.008
b	30.1	49.1	15.1	0.006
c	28.1	52.1	14.1	0.020
d	26.1	55.1	13.1	0.031
e	24.1	58.1	12.1	0.042
f	22.1	61.1	11.1	0.053
g	**20.1**	**64.1**	**10.1**	**0.063**

TABLE VI: Scenario 3 - Variation of the percentages of collection methods.

In Table V, it is shown how the results reached in Scenario 2 are obtained in Scenario 3 by varying the percentages of products types, taking into account that *Group a* corresponds to the product split of Scenario 2. Analyzing the results reported in Table V, the unit profit of 0.061 [€/kg] is reached in Scenario 3 if the percentage of reusable products is doubled with respect to Scenario 2, changing from 4.0% to 8.0%. Analogously, in Table VI, the unit profits are reported varying the percentages of the collection methods, starting from the situation of Scenario 2 represented by *Group a*.

VI. CONCLUSION

In this paper a facility location problem for a reverse logistic network has been studied, with reference to the specific case of the Weeenmodels project applied to the city of Genoa. To solve this problem, a mathematical programming model of MILP type has been formulated. Different scenarios have been discussed and compared, showing the high benefits that the introduction of an innovative waste collection system could provide to the entire city.

It is worth noting that the study described in this paper proposes an innovative approach because it is able to represent a very detailed and complex citywide reverse logistic network, considering specifically the new European WEEE collection system according to the recently developed Directive 2012/19/EU. Future research will be devoted to extend the proposed MILP formulation in order to include, besides the maximization of the yearly profit of the system, also the consideration of the costs/benefits of the system evaluated from an environmental point of view.

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