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Full Length Research Paper

Reverse logistics, solid and household waste management: The case of Tunisian territory

Harizi Riadh

Department of Business Administration, College of Business, University of Bisha, PO. Box. 1113, Bisha 61922, Saudi Arabia, Tunis University, GEF2A Laboratory.
E-mail: hariziriadh@gmail.com

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The purpose of this paper is to evaluate the current distribution of Tunisian landfill solid waste and propose a new organization of Tunisian territory. To better manage waste and establish a territorial equity, we offer a model of reverse logistics that will minimize the waste flow, reducing the overall cost of reverse logistics and create jobs. We observe quantitative data of waste management related to all operational landfills in Tunisia, and we compare it with the results of a new organization of the Tunisian territory. To minimize the total cost of landfill, we propose a deterministic model. The latter takes into account such loading capacity of the landfill, all regional requests, and the binary restriction on the location decision variables (Branch & Bound decomposition and application of fixed charge facility location problems). By using the proposed model together with the concept of rationality, we obtained the best place of every landfill. We recommend the opening of seven new landfills and the closure of six centers sites already operational. Results of our simulation can satisfy the total demand of all Tunisian regions by ensuring landfills capacities and minimizing the distances traveled to transport waste. At the same time, we can ensure territorial equity in meeting the demand regions, and we find that effective waste management involves lowering the overall cost of reverse logistics, which creates jobs.

Keywords: Cost minimization, household and solid wastes management, landfill, Tunisian landfill location, sustainable reverse logistics.

INTRODUCTION

Every day, citizens produce waste. We know that a garbage truck with its staff passes to pick up the waste. This truck can also contribute to a better management (sorting) or contribution to an elimination that meets the requirements of the environment. Sustainable waste management can be achieved in several stages: waste disposal, ecological disposal of waste and goods, more sustainable waste management through recycling, and sustainable development through waste minimization policies. To be carried out, all these policies require exchange, transport, and treatment. The problem exists in Tunisia because we believe that sustainability also requires access to public waste dumps. Some regions now have waste treatment centers while other regions pay more for transportation to the waste disposal facility. Reverse supply chain reinforces the reconciliation between all economic actors, it gives an added benefit to the balance of supply of physical flows, it provides a supplementary benefit to balance the physical flows supply. Lambert et al., (2011) have developed a reverse logistics decisions conceptual framework that offers flexibility and covers a wide variety of situations that may arise in the practical working environment. Their research considers seven elements of the reverse logistics system that is divided into strategic, tactical, and operational levels. This study shall help practitioners and academics in developing better decision-making models. Thus, it can provide a positive assessment of environmental and economic gains (De Oliveira and Borenstein, 2007; Teira-Esmatges and Flotats, 2003). Indeed, once a well reaches the end of its lifecycle, it is automatically removed (or destroyed). Therefore, if the landfill reaches its maximum capacity, it is deem necessary to create other sites (Recyc-Quebec, 2002). Consequently, the meaning of the traditional one-way chain must evolve into a new reality: The returned merchandise (ormaterials) in the network must generate added-value. This added-value can be realized through every reverse logistics activity (Der-Horng and Meng, 2009; Jiuh-Biing et al., 2005). The integration of these activities in the planning tools, control of production or distribution procedures becomes necessary (Melo et al., 2009; Jiuh-Biing et al., 2005).

In addition to the organizational aspect, this problem has a legal aspect, especially when it comes to minimizing the negative effects of waste on the environment (flora and fauna). Recently, in order to organize this problem and reduce waste weight, many laws have been promulgated. For example, several industrial countries in Europe have enforced environmental legislation charging manufactures with the responsibility for reverse logistics flows, including used products and manufacturing-induced wastes (Fleischmann et al., 2000). Several countries have sought to develop a reverse logistics system to direct states and firms at the waste management or to arrange the transport of waste.

Wastes vary drastically between developed and developing countries and between urban areas and rural areas (Chalak et al., 2016). Various estimation methods have been developed by researchers to collect data on household waste. Some studies are based on waste statistics published by the public authorities (Brautigam et al., 2014; Deutsche Gesellschaft Für Internationale Zusammenarbeit, 2014; Beretta et al., 2013;Monier et al., 2010). Other studies have used questionnaires surveys (Parizeau et al., 2015; Abeliotis et al., 2014). Generally, results of studies show that household waste mass was influenced significantly by the household size (number of occupants per household), the housing type and the nature of the environment (urban or rural).

Our ambition is to find the best location of waste sites by minimizing traveled distance, transport times or more generally by minimizing the total operating costs of landfills. Most real-world planning problems called combinatorial optimization problems share three properties: They are optimization problems, are easy to state and have a finite but usually very large number of feasible solutions. While some of these are e.g. the Minimum Spanning Tree problem (MSTP) and the Shortest Path problem (SPP) have polynomial algorithms, the majority of the problems in addition share the property that no polynomial method for their solution is known.

Branch and Bound (B&B) is by far the most widely used tool for solving large scale NP-hard combinatorial optimization problems. B&B is, however, an algorithm paradigm, which has to be filled out for each specific problem type, and numerous choices for each of the components exist. Even then, principles for the design of efficient B&B algorithms have emerged over the years.

More specifically, our primary goal is to contribute to improving environmental practice in Tunisia, this paper aims to evaluate the current distribution of Tunisian landfill solid waste and proposes a new organization of Tunisian territory. The remainder of the paper is structured as follows. In the next section, we review the issues of waste collection in Tunisia. In section three, we describe the research setting and methodology for solving problems of Tunisian landfill location. Our results are presented and discussed in section four. Section five concludes the paper and reports limitations of the research and additional research needs.

ISSUES OF WASTE COLLECTION IN TUNISIA

Article 2 of Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal defines waste as “substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law” (Basel Convention on the Control of Transboundary, 2005). Therefore, the solution is to eliminate waste in order to protect the environment and reduce pollution. The European Union defines waste in its directive of March 18, 1999 as “a substance or object which the holder discards or intends or is required to discard”. Thus, every waste producer in Europe is responsible for the total elimination and preservation of a clean environment. For example, in France the Environmental Code states that a waste is “any residue of a process of production, processing or use, any substance, material, product or more generally any personal property abandoned or that the holder intends to retire”. It requires all producers of waste to comply with all existing players in the environment.

Thus, most countries have begun to dump these wastes in order to get rid of. Landfills have been defined in many ways, but these definitions all lead to the same direction. It is a convenient device for collecting bulky waste (occasional or dangerous) or site clean and lay. The site allows recovering the waste either by recycling, composting or recovery of large quantities of waste (Heimlich et al., 2005). Then, landfills are places in which it traditionally includes all types of waste and household refuse. They include micro-organisms that contribute to the production of methane, carbon, water, etc.

For the Tunisian case, several studies have looked at the nature of the soil to find the discharges, the chemical composition of the waste, the speed of infiltration of wastewater, the concentrations of fluoride, the hydraulic conductivity at long-term using wastewater, and phosphate in the end of the hydraulic conductivity. Zraï et al., 2004 show that cities in Tunisia face serious problems of environmental pollution caused mainly by the inadequate and inefficient final disposal of their generated solid wastes. Hamdi and Srasra, 2013 studied three natural clayey soils for various degrees of compaction from Tunisia to assess their suitability for use as a liner for an acid waste disposal site.Another study conducted by Abichou et al., 2011 is interested in developing scaling and correlation factors for methane oxidation parameters measured in laboratory incubation experiments performed on homogenized soil specimens and the actual methane oxidation rates to be expected under field conditions. Zayen et al., 2016have developed a combined process of anaerobic digestion (AD), lime precipitation (P), a microfiltration (MF), and reverse osmosis (RO) for the treatment of landfill leachate. Their results show that the reduction of the optimum lime quantity by 50% and, thus avoiding additional costs related to reagents and excess sludge treatment and an increase in flux by 35% and 40% during MF and RO respectively was recorded. The overall treatment process achieved high removal efficiencies leading to the generation of an effluent in agreement with the Tunisian Standards for effluent discharge into the sewage system.

However, little research has been interested in the location of discharges based on benefit-cost and distances between the Tunisian regions. For this reason, we propose to evaluate the real spatial distribution of Tunisian discharges, through several criteria such as collection costs, distances traveled and the current location of these waste centers on Tunisian territory.

Organization and legislative framework of the Tunisian system

In Tunisia, the urban population, representing two thirds of the total population, generates a significant amount of solid household waste (HW) in urban areas (Labidi, 2010). For example, the volume generated of waste generated is of 2.423 million tons per year, the annual growth rate is almost 2.5% per year, the HW are characterized by a strong presence of biodegradable organic matter (68%), however, the share of packaging is 24% (see figure 1).

DSM humidity levels exceeding 65%, in urban areas, the specific production is 0.815 kg-capita-day, while in rural areas it is 0.150 kg-capita-day.

The collection of HW is 80% covered in communal areas and 10% in rural areas. 66% of the Tunisian population lives in 264 municipalities, the municipal budget participating in waste management costs up to 40%, a ton of waste generates fees from 60 to 80 TND in the phase of collection and transportation and 20 TND in the phase of transfer and burial in the landfill (Deutsche Gesellschaft FürInternationale Zusammenarbeit, 2014-; Banque Mondiale, 2004). In rural areas, during the 2000-2014 periods, the HW production is between 0.1 and 0.25 kg-citizen-day, but, it was between 0.65 and 0.85 kg-citizen-day in urban areas (see Figure 2).

The evolution of this quantity is proportional to the development of urban areas. To save its environment (air, water and ecosystem), Tunisia has implemented several systems and various programs to collect and eliminate waste. There are three operational systems have been used in 2011: Eco-Lef; Eco-Zit and Eco-Battery, (Republic Of Tunisia, Ministry Of Environment And Sustainable Development, 2006).

System recovery and re-valorization of used packaging (Eco-Lef)

The packaging waste collected annually is estimated at 55,000 tons of Contents plastics, 44,000 tons of paper-cardboard and 100 tons of food packaging (food cartons), however, Eco-Lef only collects 12,000 tons per year.

The plastics waste is ranked second among HW in Tunisia (11% in 2015). The country imports 250 million tons of plastic grains that generate 40 tons of waste among which only 15 tons are recycled (Agence Nationale de Gestion des déchets en Tunisie [ANGED], 2010; EURONET Consortium, 2006). In addition, the presence of bottles and plastic bags has an impact on the aesthetics of the cities, which can negatively influence the touristic activity in the country (main sector contributing to the creation of the added value of the Tunisian economy). This system is managed by the National Agency for the Protection of the Environment [NAPE], which since its creation in 1997 seeks to reduce the national waste production and its destructive nature.

Eco-Lef carries out its activities in partnership with one hundred and ten enterprises of recycling plastic waste, municipalities and associations. Consequently, the collected waste quantities have been increased (13.5 tons/day in 2001 to 43.84 tons/day in 2007).

The wasted lubricating oils sector (Eco - zit)

25.000 tons/year of waste lubricating oils approximately are passed in the environment, requiring the Tunisian legislature to enact the Act on waste and control of their management and disposal (Act n° 96-41 June 10, 1996). This Act is to establish the appropriate framework in the field of waste and their management modes to achieve the following objectives: prevention and reduction of the production of waste and its harmfulness including acting at the manufacturing and distribution products; the recovery of waste by reuse, recycling and all other actions for the recovery of reusable materials and their use as an energy source.

This Act subsequently allowed to create the public system of recovery and regeneration called “Eco-zit”.

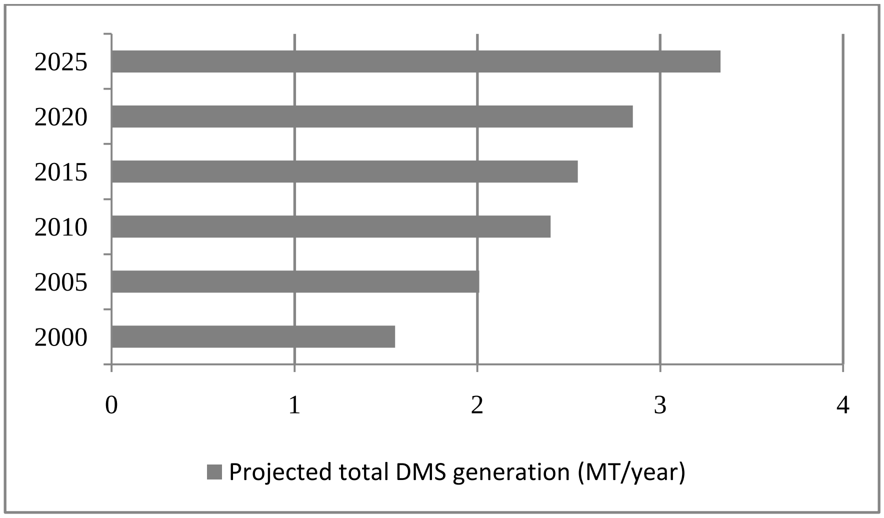

Figure 1. Projection of the generation of the DMS in the 2000-2025 period.
Source Labidi, R., 2010 and author's calculation.

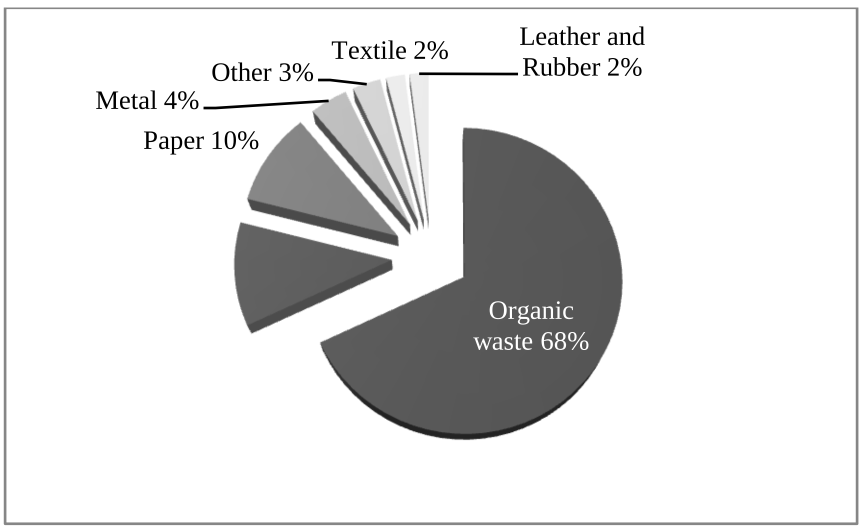

Figure 2. Composition of household and similar waste.
Source. Deutsche Gesellschaftfür Internationale Zusammenarbeit, 2014 and author's calculations.

Thus, the ANGED became responsible for the development of the sector of lubricating oils, it studied and set up management plans of waste collected.
Subsequently, ANGED enter into partnership with Tunisian lubricants, named SOTULUB, which is responsible for collecting, storage andreuse ofused lubricating oils (10,000 collection centers in Tunisia).

Eco- batteries system

To rationalize the management of lead, Tunisia has established the Eco-battery system. Indeed, the management of this type of waste leads to heavy investments, the Government encouraged the private sector to invest in this area (collection, recycling and recovery of waste). This system has proved to be efficient and effective since it has recovered 84% of batteries marketed on the Tunisian market.

CURRENT DISTRIBUTION OF TUNISIAN LANDFILLS AND PROBLEM DESCRIPTION

To managewaste, the Tunisianauthoritiesprovidecontrol, rehabilitation and closure of landfills (if necessary, espec-

Table 1. Currentlandfillsin Tunisia.

Landfills	Annual capacity	Investment cost	Transfer center	Current manager
Jebel Chakir	700.000 T	10.000 MD	3	PIZZRONO/AMSE groups
Bizerte	100.000 T	8.250 MD	5	SITA DICTRA SEGOR group
Gabes	65.000 T	6.750 MD	5	SITA DICTRA SEGOR group
Djerba	45.000 T	5.750 MD	3	SITA DICTRA SEGOR group
Sfax	180.000 T	9.000 MD	7	SITA DICTRA SEGOR group
Médenine	55.000 T	5.000 MD	2	DECO ECOTI group
Sousse	230.000 T	8.500 MD	2	DECO ECOTI group
Kairouan	60.000 T	4.500 MD	4	DECO ECOTI group
Mounastir	180.000 T	7.000 MD	6	DECO ECOTI group
Nabeul	150.000 T	12.000 MD	7	DECO ECOTI group
Total	1.700.000T	76.750 MD		PIZZRONO/AMSE groups

ially the anarchic dumps). In addition, these authorities organize and perform the new landfill. However, to locate and build a new landfill, it must reallocate existing waste stream. At the same time, the policy maker must ensure all regions needs.

In 2010, ten landfills are operational, but they cover thirteen regions out of 24 and their total capacity does not exceed 1.700.000 tons/year (see Table 1). However, the total amount emitted by Tunisian population is approximately 2,500,000 tons (in 2010). Therefore, we should reflect on the absorption of this difference (800000 tons): public authorities must build new landfills and reorganize the waste flows. Therefore, the current situation requires intensive interest and research.

MODEL DEVELOPMENT

Problem definition, Parameters, Decision variables, and Objective Function

The “location-allocation” problem is due to two decision-making policies: strategic level (location decisions) and tactical level (allocation decision). When the waste flow is known, the implementation and operating costs of a site depends on where it is located (Tung-Lai et al., 2002). Thus, the problem is to find the best location of the sites by minimizing a linear total cost function. It is assumed that demand is known. In addition to minimizing the distance between two zones (zone of waste generation and collection area), the objective is to find the best location of the sites while satisfying the total demand.

Our model is of MCFLP-type (Multi-product capacited fixed charge facility location), it is an extension of the model UCFLP (Uncapacited fixed charge facility location problems). In this research work, we study the geographical allocation (Gomes et al., 2007).

To assign regions i to landfill j ($i \in I$ / $I = \{1,...24\}$ and $j \in J$ / $J = \{1,...,24\}$) and determining if the assignment is optimal or not, we build a deterministic and multi-criteria model (F). In this model, the objective function (F) seeks to minimize the total cost of landfill, including the cost of opening of the discharge and the cost of transport of waste from the region until discharge.

The objective function is formulated in the following equation:

$$\text{(F)} \quad \min \sum_{j \in J} F_j . X_j + \alpha \sum_{j \in J} \sum_{i \in I} V_i . D_{ij}$$

Subject to

$$\sum_{j \in J} \sum_{i \in I} V_{ij} \leq X_j C_j \qquad (1)$$

$$\sum_{j \in J} A_{ij} . X_j \geq 1, \quad i \in I, \qquad (2)$$

$$X_j \in [0,1], \quad j \in J, \qquad (3)$$

$$A_{ij} \in [0,1], \quad j \in J \text{ and } i \in I. \qquad (4)$$

$$X_j = \begin{cases} 1, & \text{if the discharge } j \text{ is open and functional;} \\ 0, & \text{otherwise;} \end{cases} \qquad (5)$$

$$A_{ij} = \begin{cases} 1, & \text{if the region } i \text{ is covered by the discharge } j; \\ 0 & \text{otherwise;} \end{cases} \qquad (6)$$

Where F_j is the total cost of opening a landfill. α is the transportation cost per unit distance, D_{ij} is the distance between the region i and landfill j, C_j is the capacity of the landfill j, V_i is the volume of waste produced by the region i. Two decision variables (X_j and A_{ij}) are required, they are defined as follows: X_j shows if the region i is covered by the discharge j or not and shows if the region i is covered by the discharge j or not.

Constraint (1) ensures that we must respect the capacity of each landfills, the mass transported to each landfills must be lower to its capacity. Constraint (2) guarantees

Table 2. The detected positions of Tunisian landfills (X_j)

Landfills	Decision (X_j)	Landfills	Decision (X_j)
Jebel Chakir	1	Nabeul	0
Bizerte	0	Mahdia	0
Sousse	1	Bouselem	0
Monastir	1	Gafsa	0
Sfax	0	Ben Arous	1
Kairouan	1	Zaghouane	0
Gabes	0	ElKrib	0
Djerba	0	SidiBouzid	1
Médenine	0		

that each region is affected to at least one discharge. Constraints (3 and 4) ensures that two decision variables are equal to 0 or 1.

Simulation modeling of the reverse logistics network

There are two kinds of outcome expected: First, we determine the landfill to be opened or to be closed (step 1). Then we assign the waste stream emitted by the regions to these landfills (step 2). Finally, we check whether the results are optimal or not (step 3). To determine the number of landfill that "will be opened or to be closed" (including the one currently operational), we use the decomposition method of B&B.

To solve the problem of allocating waste stream emitted by Tunisian regions to landfills, we use the results previously obtained and other necessary data: Distances matrix between regions and landfills, matrix of quantities produced by each region, costs matrix of opening of landfills and the landfills capacity matrix. These data were used as inputs for the model to be executed on Matlab program.

Once the landfill opening is found, we treat these data on Matlab to assign each to a Tunisian region of these landfills to dispose of their waste there. To choose the pair assignment “region –landfill” (origin-destination), we calculated the cost of landfill to be borne by each region for landfills implemented in order to choose the lowest cost. In addition, we compared the quantities of waste issued by Tunisian regions with the capacity of landfills in order to obtain an optimal allocation.

RESULTS AND DISCUSSION

First, the B&B method gave the results summarized in Tables 2 and 3. Six landfills are open with a total cost of 51.5 million dinars: 2 landfills already open (Djebel Chékir and Sousse) and four new landfills detected (Monastir, Kairouan, Ben Arous, Sidi Bouzid). Second, considering only six landfills already detected (positioned), and using the Matlab programming of the proposed model, we get assignments (see Table 4).

Third, these results are not optimal because the region of Kebéli was not affected in any landfill (unsatisfied demand). In addition, landfills detected are not fully exploited (residual capacity always positive). For example, a capacity of 9113 tons in the discharge Djbel-Chekir is still free, with a capacity of 5947 tons untapped in Sousse (same for 6898 tons in Monastir, Kairouan 4538, BenArous 1102, Sidi Bouzid 462 tons).

We must refine the result by searching an optimal solution (which takes into account the unsatisfied demand). Indeed, two options are available and the best is the one that minimizes the cost: (1) divide the amount of waste produced in the region of Kebéli already proposed landfill or (2) propose the opening of an additional landfill. Technically, we repeated the model run on Matlab to decide on the most cost effective solution ("1" or "2"): To search for the optimal solution, we must take into account the following data: The total cost of landfills, the cost allocation of kebéli waste quantities on six other landfills (detected in Table 3) and matrix distances between the region of Kebéli and operated landfills. First, we calculated the total cost of reverse logistics in two cases:(1) if we open a landfill in the region of Kebéli. (2) If we assign the kebéli waste to other landfills.

Finally, the optimal solution is the one that minimizes the total cost of reverse logistics. The results show that the solution (2) is more efficient since the cost of discharge opening is lower than where it divides the amount of waste emitted by this region:

- Cost solution (1): 5.0861 million DNT.
- Cost solution (2): 6.547928 million DNT.

The current solution is incomplete because it poses a new problem: what is the landfill to be kept among those eliminated in the previous solution? At this level, two selection criteria are retained: The first criterion is the total cost of landfill and the second is the constraint of full coverage of Tunisian territory. So we must seek the solution with the lowest cost and ensures that each

Table 3. The assignments of the governorates (origins-destinations allocation).

Governorates (Regions)	1	2	3	4	5	6	Costs (million DNT)
Tunis	0	0	0	0	1	0	21.0389
Sfax	0	0	1	0	0	0	7.0183
Nabeul	0	0	0	0	1	0	21.1609
Sousse	0	1	0	0	0	0	8.4
Kairouan	1	0	0	0	0	0	10.0728
Ben Arous	0	0	0	0	1	0	21
Bizerte	0	0	0	0	1	0	21.1571
Monastir	0	1	0	0	0	0	8.4411
Ariana	0	0	0	0	1	0	21.0304
Medenine	1	0	0	0	0	0	10.5264
Kasserine	1	0	0	0	0	0	10.2500
Jendouba	1	0	0	0	0	0	10.2609
Mahdia	1	0	0	0	0	0	10.2066
SidiBouzid	1	0	0	0	0	0	10.2035
Gabes	1	0	0	0	0	0	10.3265
Mannouba	1	0	0	0	0	0	10.1905
Gafsa	1	0	0	0	0	0	10.2682
Beja	0	0	0	1	0	0	4.4063
Djerba	0	0	0	0	0	1	1.5335
Kef	1	0	0	0	0	0	10.0533
Tozeur	0	1	0	0	0	0	8.5278
Siliana	0	0	1	0	0	0	6.6568
Zaghouan	0	0	0	0	1	0	21.0112
Tatatouine	0	1	0	0	0	0	8.5043
Kebeli	0	0	0	0	0	0	-
Residual capacity	**9113**	**5947**	**6898**	**4538**	**1102**	**462**	**282.2453****

*is the Total cost; Jebel Chakir = 1; Sousse = 2, Monastir = 3; Kairouan =4; Ben-Arous = 5; SidiBouzid = 6.

region will be assigned at least one discharge.

The implementation of the modified model shows that it is profitable to open the landfill of Gafsa. Thus, the final results presented in Table 4 can give an idea of the strategic design of the “Tunisian waste reverse logistics”.

The total cost of the final solution proposed is 287.7207 million dinars. It is 10% higher than the previous solution (282.2453 million dinars). Essentially, this solution can meet the total demand.

In addition to the costs involved, the Tunisian regions spend additional logistics costs, especially areas that do not have controlled landfills. The additional logistics cost is 20.654 million dinars (Direction Generale Des Collectivites Publiques, 2010). These costs are more important when it comes to areas that do not have landfills (see Figure 3). Areas not covered are spending 84% of this cost (17.384 million dinars).

Thus, our solution will reduce or eliminate the additional cost because the satisfaction of the total regional demand will limit the occurrence of anarchic discharges, especially in not covered regions. So we can assume that this solution will reduce the total logistics cost, it will be 267.0667 million dinars (287.7207-20.654).

Finally, our aim is to improve the country’s network, we propose the closure of six landfills because they are not profitable: Bizerte, Sfax, Gabes, Djerba, Medenine, Nabeul.

CONCLUSIONS

We tried to investigate whether the waste reverse logistics in Tunisia is efficient or not. We proceeded by taking into account two essential criteria: the satisfaction of the total demand of the regions while considering the landfills capacities (optimal restructuring of the waste stream and minimization of distances). At present ten landfills are functional: Bizerte, Sfax, Gabes, Djerba, Medenine, Nabeul, JebelChekir, Sousse, Monastir, Kairouan. But after modeling and simulations, the results show:

Elimination of six operational landfills: Bizerte, Sfax, Gabes, Djerba, Medenine, Nabeul.

Construction of three new landfills: Ben Arous, SidiBouZid and Gafsa.

Total cost is 287.7207 million dinars.

Table 4. The final results of the “Tunisian waste Reverse Logistics” (origin-destination and costs).

Governorates (Regions)	1	2	3	4	5	6	7	Costs (million DNT)
Tunis	0	0	0	0	1	0	0	21.0389
Sfax	0	0	1	0	0	0	0	7.0183
Nabeul	0	0	0	0	1	0	0	21.1609
Sousse	0	1	0	0	0	0	0	8.4
Kairouan	1	0	0	0	0	0	0	10.0728
Ben Arous	0	0	0	0	1	0	0	21
Bizerte	0	0	0	0	1	0	0	21.1571
Monastir	0	1	0	0	0	0	0	8.4411
Ariana	0	0	0	0	1	0	0	21.0304
Medenine	1	0	0	0	0	0	0	10.5264
Kasserine	1	0	0	0	0	0	0	10.2500
Jendouba	1	0	0	0	0	0	0	10.2609
Mahdia	1	0	0	0	0	0	0	10.2066
SidiBouzid	1	0	0	0	0	0	0	10.2035
Gabes	1	0	0	0	0	0	0	10.3265
Mannouba	1	0	0	0	0	0	0	10.1905
Gafsa	1	0	0	0	0	0	0	10.2682
Beja	0	0	0	1	0	0	0	4.4063
Djerba	0	0	0	0	0	1	0	1.5335
Kef	1	0	0	0	0	0	0	10.0533
Tozeur	0	0	0	0	0	0	1	5.5339
Siliana	0	1	0	0	0	0	0	8.4517
Zaghouan	0	0	0	0	1	0	0	21.0112
Tatatouine	0	1	0	0	0	0	0	8.5043
Kebeli	0	0	1	0	0	0	0	6.6744
Residual capacity	**9113**	**5947**	**6898**	**4538**	**1102**	**462**		**287.7207***

*is the Total Cost; Jebel Chakir = 1; Sousse = 2, Monastir = 3; Kairouan =4; Ben-Arous = 5; SidiBouzid = 6; Gafsa = 7.

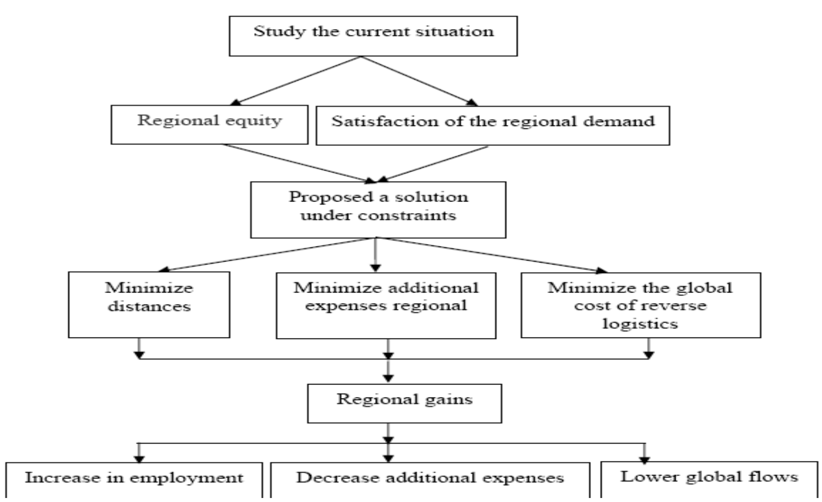

Figure 3. Study process

With this restructuring plan, the Tunisian territory can accumulate two types of gains: (*i*) Territorial restructuring and reorganization of the optimal waste (gain in terms of distance). This gain appears in the new matrix "origin-

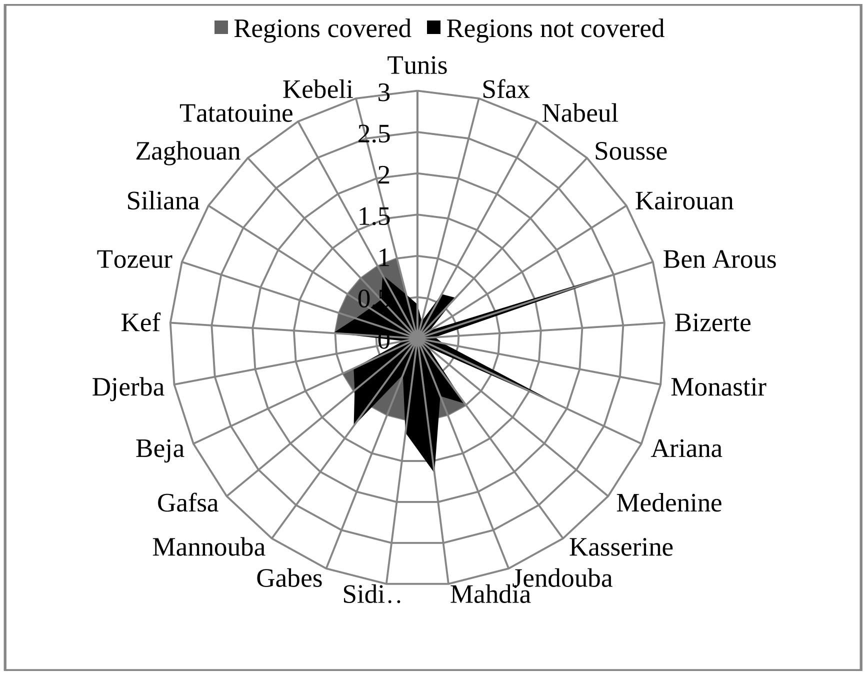

Figure 4. Additionallogistics costsin theTunisian regions

destination", which can ensure the optimal management of flows between the landfill and the regions and complete coverage of the Tunisian territory. (*ii*) Elimination of additional logistics costs supported largely by the regions not covered. The proposed reallocation of the waste stream is as follows:

Kairouan, Medenine, Mannouba, Kasserine, Jendouba, Mahdia, SidiBouzid, Gabes, Gafsa and Kef will be assigned to the landfill of DjbelChékir.

Tunis, BenArous, Bizerte, Zaghouan and Arianna will be assigned to the landfill of BenArous.

Sousse, Monastir, Siliana and Tataouine will be assigned to the landfill of Sousse.

Bejawill be assigned to Kairouan, Tozeurto Gafsa, and finally Djerbawill be assigned to Sidi Bouzid.

Finally, in this paper we suggest a solution which aims to rearrange the Tunisian landfills by minimizing the cost of reverse logistics. But in reality, this solution is still insufficient because wastes produce external effects on the environment. Thus, it is necessary to think about recycling waste, using a different technique to benefit from reuse. It would be interesting in future research to understand the extent to which the tools currently used in solid waste management are effective.

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