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Benefits from GIS Based Modelling for Municipal Solid Waste Management

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1. Introduction

Waste management issues are coming to the forefront of the global environmental agenda at an increasing frequency, as population and consumption growth result in increasing quantities of waste. Moreover, technological development often results in consumer products of complex composition, including hazardous compounds, which pose extra challenges to the waste management systems and environmental protection at the end of their useful life, which may often be fairly short (e.g. cell-phones and electronic gadgets). These end-of-pipe challenges are coupled with the deepening understanding that the Earth's natural resources are finite by nature and their current exploitation rate unsustainable, even within a midterm perspective. The self-cleaning capacity of the Earth systems is often also viewed as a «natural resource» under stress, with climate change being the most pronounced expression of this risk.
In the context of the above mentioned challenge a New Paradigm for waste management has emerged, shifting attention to resources efficiency and minimisation of environmental impacts throughout the life cycle of waste management, from waste prevention to safe disposal. This is best expressed, but not confined, in the relevant EU policy and legislation (e.g. the Thematic Strategy on the prevention and recycling of waste, the Thematic Strategy on the Sustainable Use of Natural Resources and the revised Waste Framework Directive, WFD-2008/98/EC). Especially the latter is of particular interest as it has a legally binding nature for all EU member states and sets a benchmark which is often also taken into consideration by the waste management systems of non-EU countries. The WFD reaffirms the need to move waste management higher in the so called "waste hierarchy", preferring, in this order, prevention, reuse, recycling and energy recovery over disposal. Separate collection for dry recyclables in municipal solid waste (MSW) should be implemented while separate collection of biowaste should be promoted (although no specific legislative requirements are set) (Nash, 2009).
Overall, EU and national waste management policies and legislation in many parts of the world are becoming increasingly demanding for the providers of these services, namely municipalities and their associations, demanding high recovery and recycling rates for a wide range of materials and goods, high diversion targets for the biodegradable fraction of the waste, advanced treatment processes, long after-care periods for existing and future landfills etc (COM, 2005; Lasaridi, 2009). Moreover, this increased level of service will need to be provided at the minimum possible cost, as the public will not be able to bear large

increases in its waste charges and municipalities are increasingly being required to benchmark their performance, to ensure they offer their waste management services at the most efficient manner (Eunomia, 2002; Karadimas et al., 2007). The current economic crisis inevitably intensifies this need.

The need for improved performance at low costs is not restricted to developed countries seeking to apply increasingly complex separate waste collection, treatment and recovery systems. Under a different context, it also exerts its pressure to the municipal services of the developing countries, which strive to ensure waste collection and public health protection for the large populations of highly urbanised areas with severe infrastructure and economic limitations (Gautam & Kumar, 2005; Ghose et al., 2006; Kanchanabhan et al., 2010; Vijay et al., 2005).

Local authorities (LAs) constitute worldwide the main providers of municipal solid waste (MSW) management services, either directly or indirectly through subcontracting part or all of these services. Especially waste collection and transport (WC&T) are typically provided at the local municipality level and constitute the main interface between the waste generator and the waste management system. Assessing the different components of the solid waste management costs is a complex, poly-parametric issue, governed by a multitude of geographic, economic, organisational and technology selection factors (Eunomia, 2002; Lasaridi et al., 2006). However, in all cases WC&T costs constitute a significant component of the overall waste management costs, which may approach 100% in cases where waste is simply dumped. For modern waste management systems WC&T costs vary in the range of 50-75% of the total, which overall is significantly higher, as advanced treatment and safe disposal take their own, large share of the total costs (Sonesson, 2000).

Therefore, the sector of WC&T attracts particular interest regarding its potential for service optimisation as (a) waste management systems with more recyclables' streams usually require more transport (Sonesson, 2000) and (b) this sector, even for commingled waste services only, already absorbs a large fraction of the municipal budget available to waste management (Lasaridi et al., 2006). Optimisation of WC&T making use of the novel tools offered by spatial modelling techniques and geographic information systems (GIS) may offer large savings, as it is analysed further in this chapter. In spite of their proved utility and a significant development of the relevant research in the last decades in many parts of the world, including most Greek local authorities, WC&T is typically organised empirically and in some cases irrationally, under public pressures.

The aim of this chapter is to present a methodology for the optimisation of the waste collection and transport system based on GIS technology. The methodology is applied to the Municipality of Nikea (MoN), Athens, Greece based on real field data. The strategy consists of replacing and reallocating the waste collection bins as well as rescheduling the waste collection via GIS routing optimisation. The benefits of the proposed strategy are assessed in terms of minimising collection time, distance travelled and man-effort, and consequently financial and environmental costs of the proposed collection system.

2. The role of GIS for sustainable waste management

Geographic Information Systems (GIS) are one of the most sophisticated modern technologies to capture, store, manipulate, analyse and display spatial data. These data are usually organised into thematic layers in the form of digital maps. The combined use of GIS with advanced related technologies (e.g., Global Positioning System – GPS and Remote

Sensing - RS) assists in the recording of spatial data and the direct use of these data for analysis and cartographic representation. GIS have been successfully used in a wide variety of applications, such as urban utilities planning, transportation, natural resources protection and management, health sciences, forestry, geology, natural disasters prevention and relief, and various aspects of environmental modelling and engineering (among others: Brimicombe, 2003). Among these applications, the study of complex waste management systems, in particular siting waste management and disposal facilities and optimising WC&T, have been a preferential field of GIS applications, from the early onset of the technology (Esmaili, 1972; Ghose et al., 2006; Golden et al., 1983; Karadimas et al., 2007; Sonesson, 2000). Nowadays, integrated GIS technology has been recognised as one of the most promising approaches to automate the process of waste planning and management (Karadimas & Loumos, 2008).

As mentioned above, the most widespread application of GIS supported modelling on waste management lies in the areas of landfill siting and optimisation of waste collection and transport, which are discussed in detail in the following section. Additionally, GIS technology has been successfully used for siting of recycling drop-off centres (Chang & Wei, 2000), optimising waste management in coastal areas (Sarptas et al., 2005), estimating of solid waste generation using local demographic and socioeconomic data (Vijay et al., 2005), and waste generation forecasting at the local level (Dyson & Chang 2005; Katsamaki et al., 1998).

2.1 GIS-based modelling for landfill selection

The primary idea of superimposition of various thematic maps in order to define the most suitable location according to the properties of the complex spatial units derived after the map overlay, was first introduced in the late 60's (McHarg, 1969). This idea was applied next within the context of early GIS in many optimal siting applications (Dobson, 1979; Kieferand & Robins, 1973). The allocation of a landfill is a difficult task as it requires the integration of various environmental and socioeconomic data and evolves complicated technical and legal parameters. During this process the challenge is to make an environmentally friendly and financially sound selection. For this purpose, in the last few decades, many studies for landfill site evaluation have been carried out using GIS and multicriteria decision analysis (Geneletti, 2010; Higgs, 2006; Nas et al., 2010; Sener et al., 2006), GIS in combination with analytic hierarchy process (Saaty, 1980) – AHP (Vuppala et al., 2006; Wang et al., 2009), GIS and fuzzy systems (Chang et al., 2008; Gemitzi et al., 2007; Lofti et al., 2007), GIS and factor spatial analysis (Biotto et al., 2009; Kao & Lin, 1996), as well as GIS-based integrated methods (Hatzichristos & Giaoutzi 2006; Gómez-Delgado & Tarantola 2006; Kontos et al., 2003, 2005; Zamorano et al., 2008).

A large fraction of these applications produce binary outputs while most recent ones aim at evaluating a "suitability index" as a tool for ranking of the most suitable areas (Kontos et al., 2005). The main steps of a typical GIS – based landfill allocation model (fig.1) are as following.

a. Conceptualisation of the evaluation criteria and the hierarchy of the landfill allocation problem. This step is dedicated to the selection of the criteria related to the problem under investigation.
b. Creation of the spatial database. Here, the development of GIS layers for the modelling is implemented. These layers correspond to the primary variables.

c. Construction of the criteria – layers within the GIS environment. Criteria maps are primary or secondary variables.
d. Standardisation of the criteria – layers. This step includes reclassification of the layers in order to use a common scale of measurement. Most often, the ordinal scale is used.
e. Estimation of the relative importance for the criteria. This estimation is implemented by weighting, e.g. with the use of Analytic Hierarchy Process (AHP) and pair wise comparison between variables.
f. Calculation of the suitability index. A standard procedure for this step is the weighted overlay of the standardised criteria/layers.
g. Zoning of the area under investigation is the next phase of the modelling. This classification action is based on the suitability index and reveals the most suitable areas for the application.
h. Sensitivity analysis and validation of the model.
i. Final selection – land evaluation.

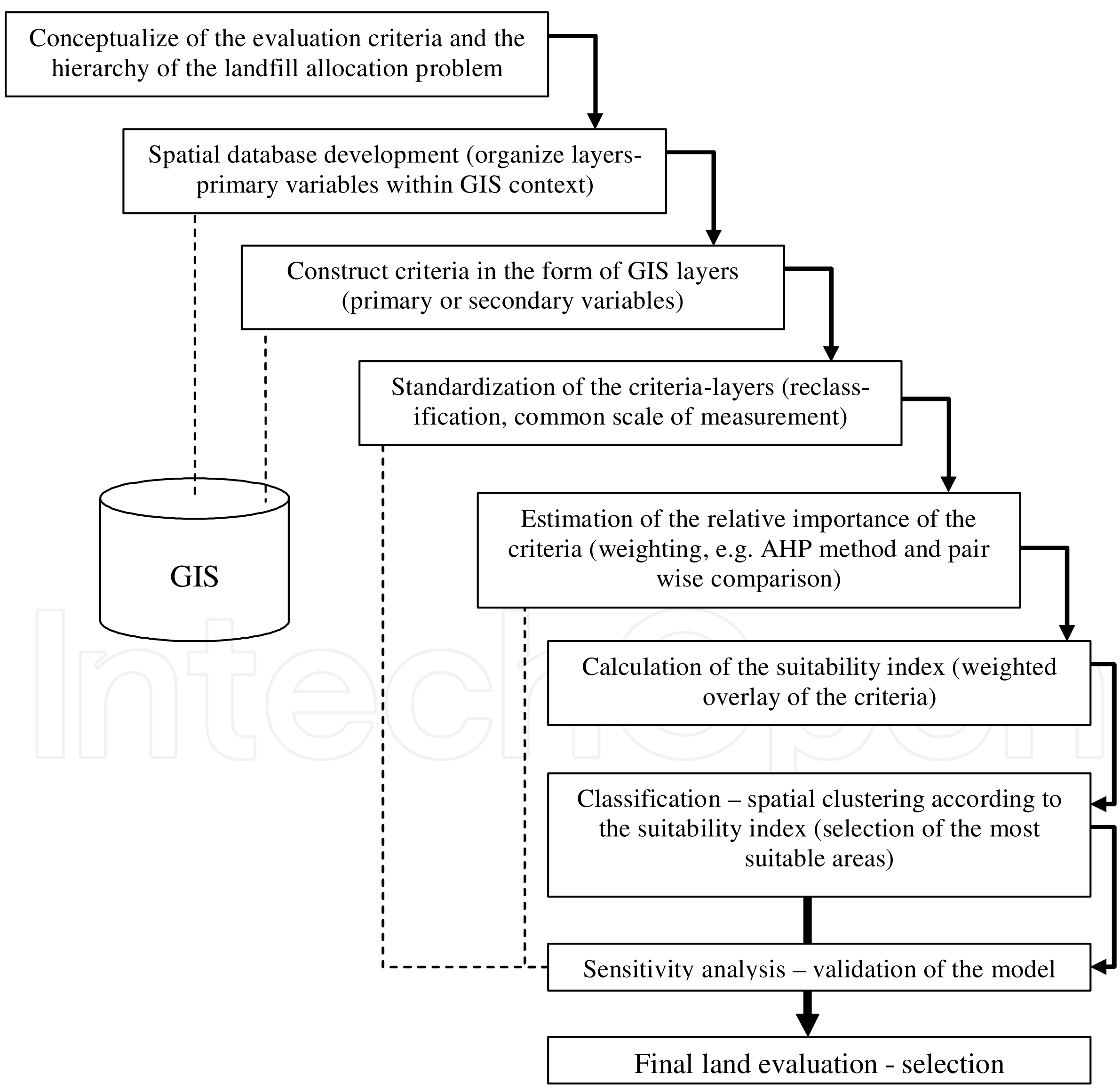

Fig. 1. Landfill site selection. A GIS approach.

It should be noticed that for most of the aforementioned functions the geographic background (in digital format) of the area under investigation is required. Figure 1 demonstrates the data flow of the adopted procedure. Sumanthi et al. (2008) underline that the main advantages of applying GIS technology in the landfill siting process are: "*the selection of objective zone exclusion process according to the set of provided screening criteria, the zoning and buffering function, the potential implementation of 'what if' data analysis and investigating different potential scenarios related to population growth and area development, as well as checking the importance of the various influencing factors etc., the handling and correlating large amounts of complex geographical data, and the advanced visualization of the output results through graphical representation*."

Additionally, the incorporation of various spatial analysis methods, such as geostatistics, analytical hierarchy process, fuzzy logic modelling and many others, constitutes a major advantage of a GIS-based modelling approach. Finally, a particularly useful option of a GIS-based decision making model is the combination of experts knowledge with the opinions of citizens and stakeholders (Geneletti, 2010).

3. GIS modelling for the optimisation of waste collection and transport

The optimisation of the routing system for collection and transport of municipal solid waste is a crucial factor of an environmentally friendly and cost effective solid waste management system. The development of optimal routing scenarios is a very complex task, based on various selection criteria, most of which are spatial in nature. The problem of vehicle routing is a common one: each vehicle must travel in the study area and visit all the waste bins, in a way that minimises the total travel cost: most often defined on the basis of distance or time but also fuel consumption, CO_2 emissions etc. This is very similar to the classic Travelling Salesman Problem (TSP) (Dantzig et al., 1954). However, the problem of optimising routing of solid waste collection networks is an asymmetric TSP (ATSP) due to road network restrictions; therefore adaptations to the classic TSP algorithm are required, making the problem more complex.

As the success of the decision making process depends largely on the quantity and quality of information that is made available to the decision makers, the use of GIS modelling as a support tool has grown in recent years, due to both technology maturation and increase of the quantity and complexity of spatial information handled (Santos et al., 2008). In this context, several authors have investigated route optimisation, regarding both waste collection in urban and rural environments and transport minimisation, through improved siting of transfer stations (Esmaili, 1972), landfills (Despotakis & Economopoulos, 2007) and treatment installations for integrated regional waste management (Adamides et al., 2009; Zsigraiova et al., 2009).

Optimisation of WC&T making use of the novel tools offered by spatial modelling techniques and GIS may provide significant economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions (Johansson, 2006; Kim et al., 2006; Sahoo et al., 2005; Tavares et al., 2008). These systems are particularly rare in Greek local authorities, where WC&T is typically organised empirically and in some cases irrationally, under public pressures.

According to Tavares et al. (2008) "*effective decision making in the field of management systems requires the implementation of vehicle routing techniques capable of taking advantage of new technologies such as the geographic information systems*". Using GIS 3D modelling in the island of Santo Antao, Republic of Cape Verde, an area with complex topography, they achieved up to 52% fuel savings compared to the shortest distance, even travelling a 34% longer distance. Nevertheless, most of the previous work relating to optimal routing for solid waste collection is based on the minimisation of the travelled distance and/or time (Apaydin & Gonullu, 2007; Lopez et al., 2008), which is considered a sufficient calculator parameter for fuel consumption and emissions minimisation in flat relief (Brodrick et al., 2002).

Sahoo et al. (2005) presented a comprehensive route-management system, the WasteRoute for the optimal management of nearly 26000 collection and transfer vehicles that collect over 80 million tons of garbage every year for more than 48 states of USA. The Implementation of WasteRoute across the USA from March 2003 to the end of 2003 yielded 984 fewer routes, saving $18 million.

Alvarez et al. (2008) presented a methodology for the design of routes for the "bin to bin" collection of paper and cardboard waste in five shopping areas of the city of Leganés (Community of Madrid, Spain). Their proposed system was based on GIS technology and optimised urban routes according to different restrictions. From the comparison of their system with the previous situation they concluded that the proposed "bin to bin" system improved the quality of the paper and cardboard in the containers, avoiding overflow and reducing the percentage of rejected material.

Teixeira et al. (2004) applied heuristic techniques to solve a collection model in order to define the geographic zones served by the vehicles, as well as the collection routes for recyclable waste collection of the centre-littoral region of Portugal. The study indicated that proper modelling of the collection procedure can provide cost effective solutions.

Nuortio el al. (2006) developed a GIS-based method for the optimisation of waste collection routes in Eastern Finland. They estimated an average route improvement in comparison with the existing practice of about 12%. Moreover they proposed a combination of routing and rescheduling optimisation. This combination in some cases introduced extremely significant savings (~40%). They concluded that by allowing rescheduling it is possible to significantly increase the improvement rate.

Karadimas & Loumos (2008) proposed a method for the estimation of municipal solid waste generation, optimal waste collection and calculation of the optimal number of waste bins and their allocation. This method uses a spatial Geodatabase, integrated in a GIS environment and was tested in a part of the municipality of Athens, Greece. After the reallocation of the waste bins, their total number was reduced by more than 30%. This reduction had a direct positive impact on collection time and distance.

Chalkias & Lasaridi (2009) developed a model in ArcGIS Network Analyst in order to improve the efficiency of waste collection and transport in the Municipality of Nikea, Athens, Greece, via the reallocation of waste collection bins and the optimisation of vehicle routing in terms of distance and time travelled. First results demonstrated that all the examined scenarios provided savings compared to the existing empirical collection organisation, in terms of both collection time (savings of 3.0% -17.0%) and travel distance (savings of 5.5% - 12.5%).

Apaydin & Gonullu (2006) developed an integrated system with the combination of GIS and GPS technology in order to optimise the routing of MSW collection in Trabzon city, northeast Turkey. The comparison of the proposed optimised routes with the existing ones revealed savings of 4–59% in terms of distance and 14-65% in terms of time, with a benefit of 24% in total cost.

Finally, Kanchanabhan et al. (2008) attempted to design and develop an appropriate storage, collection and routing system for Tambaram Municipality in South Chennai, India using GIS. The optimal routing was investigated, based on population density, waste generation capacity, road network, storage bins and collection vehicles. They roughly estimated 30% cost-savings with this approach.

4. The Nikea case study, in Greece

The total cost for waste collection and transport (WC&T) in Greece frequently accounts for more than 70% of the total municipal solid waste (MSW) management costs. Thus, it is crucial to improve the WC&T system through routing optimisation.

Here we present a general methodology for the optimisation of the waste collection and transport system, based on GIS, technology for the municipality of Nikea (MoN), Athens, Greece. This methodology was developed using standard GIS and network analysis procedures in order to improve the efficiency of WC&T in the study area via: (a) the reallocation of waste collection bins; and (b) the optimisation of vehicle routing in terms of distance and time travelled, via GIS routing. The outputs of various different scenarios examined are finally compared with the empirical routing, which is the current vehicle routing practice. Benefits are assessed in terms of minimising collection time, distance travelled and man-effort, and, consequently, financial and environmental costs of the collection system.

In Greece Local Authorities (LAs) are by law responsible for waste management (Decrees 25/1975 and 429/1976). Waste collection and transport are provided at the individual municipality level, usually directly through their Waste Management Department. Currently, WC&T of commingled MSW in the country is responsible for a large portion of the total waste management cost (70% - 100%), which is considerably higher than the typical values, of between 50 and 75%, reported for modern waste management systems (Sonesson, 2000). This is observed because the largest fraction of the waste stream is currently landfilled at very low cost, without pre-treatment for materials and/or energy recovery, while in some cases illegal dumping may be still practiced (Lasaridi, 2009).

4.1 The study area and the existing collection system

The MoN (Fig. 2) is one of the largest in the Attica Region, lying in the SW part of Athens metropolitan area. It has a permanent population of 95,798 habitants according to the 2001 Census (National Statistical Service of Greece - NSSG, 2001) and a total area of 6.65 km^2. Nikea is a typical Greek urban municipality, characterised by multi-storey apartment buildings, combined by lower multiple dwellings (2-4 apartments) and mixed residential and commercial land uses in many neighbourhoods. The annual MSW production in MoN is estimated at 45,625 tn, or 1.30 kg/ca/d.

Waste collection is carried out mechanically, using 12,107 wheelie bins and 17 rear-end loaded compaction trucks with 9 tn average capacity. Most of the bins are small, of 120 and 240 L capacity, but a few larger ones exist in some central points. The total storage capacity of the bin system is 3.4 million litres. The crew size on the collection vehicle is three persons, a driver who never leaves the truck (as required by safety regulations) and two workers who move and align the bins with the hydraulic lifting mechanism of the truck.

Nevertheless, due to traffic restrictions and narrow roads, it is estimated that only 70% of the bins are really mechanically collected, with the content of the rest being manually transferred in other bins, by an extra worker walking ahead of the collection vehicle. The Municipality is empirically divided into 15 sectors (collection zones), each of which is further divided into two sub-sectors. Waste is collected in each sub-sector four times per week.

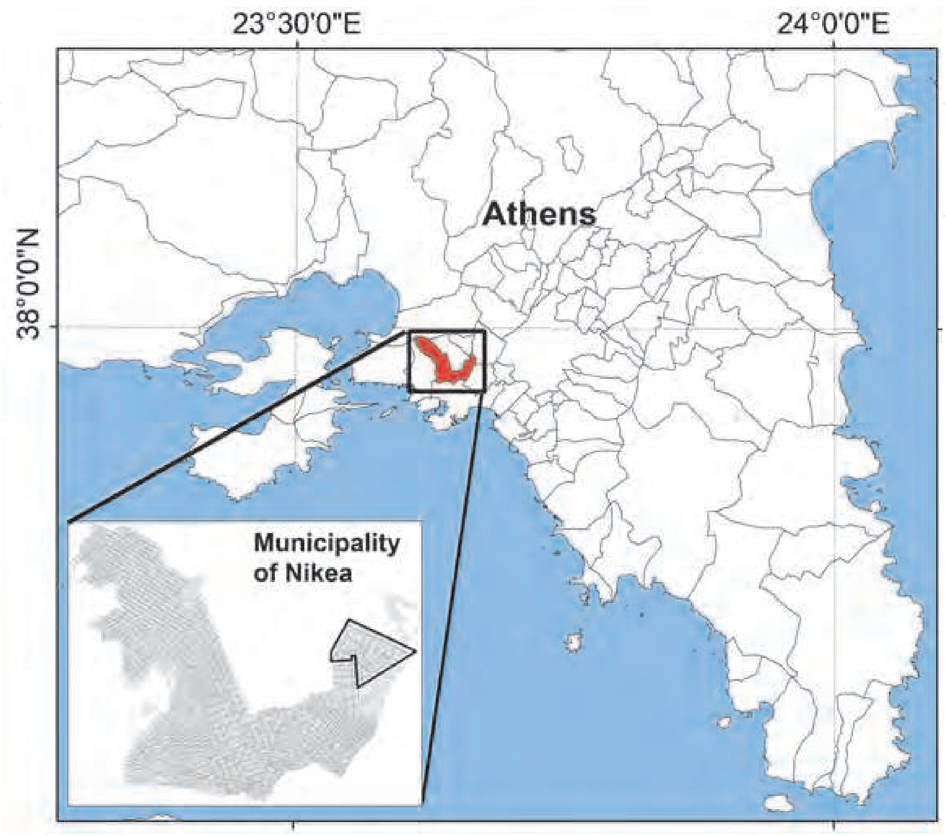

Fig. 2. The study area: Municipality of Nikea, Athens, Greece.

This work applies the developed waste collection and transport optimisation methodology in a typical sector (Sector 1) of the municipality with mainly residential land uses. However, some commercial establishments, schools, stadiums and parks are also found in the area. The served equivalent population in Sector 1 (i.e. taking into account the MSW load created by non-residential land uses) is 6,790 people, divided in 63 parcels (building blocks). The total average waste production is 2,610 ton/yr, according to the weighing sheets of the collection vehicles in the period 2005-2007. This corresponds to an average daily commingled waste production of 1.053 kg/ca eq. This is not in contrast with the municipality average reported above, as the former is calculated on the basis of the 2001 census population, while the latter also takes into account the equivalent population corresponding to the non-residential land uses.

In the current waste collection system, 714 bins are located in Sector 1 (Fig.3), of which 501 are mechanically collected, with total capacity of 157,000 L. The content of the rest is manually transferred to the mechanically collected ones by the extra worker mentioned above. Since Sector 1 is rather flat (mean elevation ~ 50 m) it is assumed that fuel consumption and emissions are linearly related to collection time (Brodrick et al., 2002).

For waste collection purposes Sector 1 is divided into two sub-sectors both served by one waste collection vehicle. Waste in each sub-sector is collected four times per week, in alternate week days, resulting into eight collection trips per week. Collected waste is disposed of at the Fyli landfill site, about 25 km north-west from Sector 1. The key points to the proposed optimisation approach are: a) the replacement of the existing large number of small bins (120 and 240 L) with a reduced number of larger bins (1100 L); b) the resectorisation; and finally, c) the optimal routing. Using the collected data and the analytical tools of the GIS software, specific proposals are developed regarding the optimisation of the existing WC&T system of commingled MSW. For results assessment both the vehicle trip within the sector and travel to and from the landfill are considered.

Fig. 3. Waste bins in the study area.

4.2 Data collection and spatial database description

To efficiently manage the municipal solid waste system, detailed spatial information is required. This information is related to the geographical background of the area under investigation, as well as to spatial data related to the waste collection procedure. A large amount of waste management data for the period 1998-2007 has been collected and statistically analysed regarding the static and dynamic data of each existing collection program: population density; waste generation rate for mixed waste and for specific waste streams; number, type and positions of waste bins; the road network and the related traffic; the current routing system of the collection vehicles; truck capacities and their characteristics; and the geographic boarders and characteristics of the waste collection sectors. The range of data acquired and utilised is illustrated in Table1.

For the optimisation of the collection process a spatial geodatabase was constructed, in a standard commercial GIS environment (ArcGIS, ESRI). This choice ensures compatibility with the available data from the municipality and access to many network analysis routines available from the software. The content of the spatial database is summarised in Table 2.

Background spatial data for road network, existing routes, bins and building parcels were obtained from MoN. These data were updated with field work and other non spatial data such as road name, road type, vehicle average speed, travel time, road slope, bin number, bin type/capacity, bin collection time were added. Furthermore, special attributes of road network were registered. These attributes include traffic rules, traffic marks, topological conditions and special restrictions (e.g. turn restrictions) in order to efficiently model the real world road network conditions.

Data	*Source*
Study area boundary	(MoN Corporation)
Detailed urban plan of the municipality	(official toposheet plan)
Population density distribution	(National Statistical Service of Greece: NSSG)
Land use of the study area	(NSSG)
Satellite image of the municipality	(Google Earth)
Road network of the study area	(official toposheet plan, , field work)
Road class information: restrictions and traffic volume details	(official toposheet plan, MoN Corporation, field work)
Location of waste bins	(MoN Corporation, field work)
Capacities of bins	(MoN Corporation, field work)
Time schedule for the collection process	(MoN Corporation, field work)
Existing collection routes	(MoN Corporation, field work)
Vehicle speed, fuel consumption, CO_2 and other gas emissions of the compactors	(MoN Corporation, field work, literature).

Table 1. Data collected and their source.

Spatial Data	*Type*	*Geometry*
Road network	vector	Line
Waste bins	vector	Point
Urban plan / parcels	vector	Polygon
Existing run routes	vector	Line
Street address	tabular	-
Road network attributes / restrictions	tabular	-
Waste bins' attributes	tabular	-
Population data	tabular	(join with parcels)
Land use data	tabular	-
Satellite image of the MoN	Raster	-

Table 2. The spatial database - type of data and corresponding geometry.

4.3 Methodology

The key point of the proposed analysis is GIS technology. GIS provides a powerful context to import, manage and analyse spatially based data. The methodology implemented in this study comprised of three general steps (Fig. 4). Step 1 establishes the spatial database of the study area as described previously. Step 2 is dedicated on the reallocation of waste collection bins with the use of GIS spatial analysis functions. Finally, Step 3 consists of the

waste collection routing optimisation for minimum time, distance, fuel consumption and gas emissions. The waste collection optimisation model was developed with the use of ArcGIS 9.2 Network Analyst (NA) GIS software.
To analyse the spatial data for the optimisation of the waste collection scheme in MoN, a spatial database (SDB), within a GIS framework, was constructed, as previously described, using: (a) analogue maps from MoN; (b) digital data from various official providers (e.g. National Statistical Service); (c) data derived from field work /on-site data capture with the use of GPS technology.

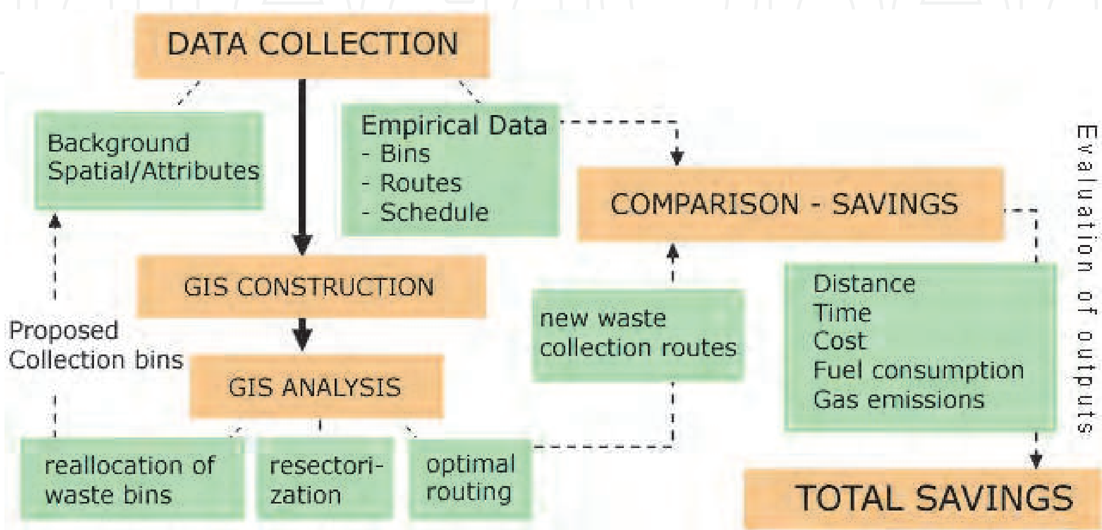

Fig. 4. Data flow of the proposed methodology

4.3.1 Reallocation of waste collection bins and resectorisation

The next phase of the proposed methodology is related to the reallocation of waste collection bins. This analysis was implemented in a GIS environment with the use of the proper spatial analysis functions. The allocation of waste collection bins in their newly proposed locations was based on the following criteria /restrictions:

i. On the basis of the population density and the type of buildings in the study area, bins of 1100L capacity were considered preferable, in order to minimise the number of required bins and vehicle stops. This is the typical bin type used in most Municipalities in the wider Athens area.
ii. The required number of bins (N) was calculated to cover the waste production of the sector for a five trips per week schedule (D=7/5), assuming a waste density in the bin of ρ=110 kg.m^{-3}, and a coefficient of filling the bin, ε = 0.80 of its capacity, according to the equation (1):

$$N = W_D x D / (V x \rho x \varepsilon) \quad (1)$$

where WD (kg) is the daily waste quantity and V (m^3) is the bin capacity. A 10% safety margin was added to this number (Panagiotakopoulos, 2002).
Thus, instead of the existing 501 bins of various sizes (§2.2) Sector 1 is covered by 142 large bins (1100L).
iii. Next, these bins are allocated in the study area according to the following rules: a) allocate bins on the road network (intersections are preferable); b) install proposed bins

near an existing bin location (in a buffer zone of 60 m radius); and, c) allow the placement of more than one bin in the same intersection. The number of bins sharing the same intersection point is related to the land use and population of the covered area.

Figure 5 illustrates the proposed reallocation of waste bins in the sector under investigation.

Fig. 5. Reallocation of waste collection bins in the new sector

The definition of the new sectors is restricted by the capacity of the available waste collection vehicles. Thus, the size (in terms of the number of bins) of a new sector was estimated at the 2/3 of the existing sector. Therefore, instead of 4 routes per week for each of the two subsectors (total: 8 routes per week) we designed smaller sectors and schedule 5 routes per week in these new sectors.

As a result of the above mentioned approach, each new sector should contain 95 bins, which can be collected in one vehicle trip. The reallocation of bins was based on travel distance from each residence to the nearest bin and the general intention to decrease the total number of bins. A maximum travel distance of 60 meters from each resident to the proposed new site of the bin was allowed. Moreover, the introduction of new bins with larger capacity, to accommodate for the same waste quantity, ensures the decrease in the total number of bins and collection stops. A higher priority for the allocation of the new bins was given to locations of bins in the existing system and to crossroads in order to facilitate social acceptance and collection vehicle travel.

Summarising, we assume a new waste collection planning: the MoN is divided into 22 new sectors and each collection vehicle should make 5 collections per week in each of these sectors. Thus we propose an improved collection schedule for the study area, as the vehicle collects each bin 5 times per week instead of 4, according to the existing situation. For this study we did not proceed to the full re-sectorisation for the total area of the municipality, but limited our approach within Sector1. Thus, we assumed a new sector (Sector_N1) within Sector1, with the properties described above (2/3 of the size of Sector 1, 5 collections per week). The evaluation of the results of the proposed modelling approach was based on the comparison between Sector_N1 and corresponding part of Sector1.

4.3.2 Routing – Network Analysis

After the reallocation of the waste collection bins and the definition of Sector_N1 the optimisation of waste collection vehicle routing was performed, using the ArcGIS Network Analyst modelling package. The optimal path finding algorithm of NA is an alteration of the classic Dijkstra's algorithm (Dijkstra, 1959) which solves the problem of optimal route selection on an undirected, nonnegative weighted graph in a reasonable computational time.

Fig. 6. Optimal waste collection route.

In the literature, many modifications and new algorithms have been used for the incorporation of the aforementioned restrictions. In the context of ArcGIS Network Analyst commercial GIS software, this algorithm is improved further, using effective data structures such as d-heaps (ESRI, 2006). To use it within the context of real transportation data, this algorithm must be modified in order to respect real problem restrictions, such as one-way roads, prohibited turns (e.g. U-turns), demand at intersections (nodes) and along the roads, and side-of-street constraints while minimising a user-specified cost attribute. The key point is to build a cost matrix containing the costs between origins and destinations. These points correspond to pairs of vehicle stops (waste bins).

The total vehicle travel time is the sum of the travel time for each road segment plus the collection time for emptying of the bins. The user can define all the relevant traffic restrictions described above, the time delay for each stop for bin collection, as well as the first and last collection stop within the sector. The final output is the optimal solution in terms of distance or time criteria (fig. 6).

4.4 Results and discussion

The method described above was applied to simulate the waste collection procedure of the study area. Based on the methodology presented in the previous sections and the criteria and restrictions introduced in ArcGIS Network Analyst, different routing solutions were created for the collection of the new bins (95 bins of 1100 L) in their new location within Sector_N1. Evaluation of the results of the developed methodology is based on the comparison of the proposed waste collection scenario (Sp) with the existing one (Se). The time needed during waste collection has three distinct components: 1) time for hauling; (assumed as 25+25 km with average speed 50 km/h); 2) time for driving during collection; and, 3) time for emptying the bins.

The parameters input to the model were based on real data provided by the MoN and verified by field studies. More specifically, the time for emptying of the bins (bin loading, emptying and unloading – component 3) is 30 sec for bins with capacity up to 330 L and 60sec for bins with capacity equal to or larger than 660 L. The time for driving during collection (component 2) is determined by the average speed of the collection vehicle in the travel between stops and the total distance travelled in the collection segment of the route. For MoN the average speed is 5, 10 and 15 km/hr for 1-way, 2-way and central roads, respectively.

Both parameters are not readily available and default literature values are scarce. Sonesson (2000) reports values for the time required for bin emptying from empirical data for the wider Uppsala area in Sweden, as follows: 68.4 sec for inner city, 43.2 sec for suburbia and 57.4 sec for rural areas. Although the bin size is not defined, these values are in good agreement with the observed figures in the MoN. The author also reports an average collection speed of 20, 30 and 50 km/h for inner city, suburbs and rural areas, respectively. This is higher than the values achieved in MoN (conditions comparable with the inner city in Uppsala). Possible explanation is twofold: 1) different conditions of the road network and traffic in the two cities; and, 2) a denser matrix of collection points, due to a higher population density, allowing for shorter distances travelled between collection points and therefore lower speed. Nevertheless, the vehicle speed used for central roads in Nikea (15 km/h) compares well with the inner city collection speed in Uppsala (20 km/h).

The comparison of results, on a weekly basis, between the existing collection scenario (Se) and the proposed one (Sp) is illustrated in Table 3. The optimal solution expressed in Scenario Sp (Fig. 6) corresponds to 287 km of distance travelled by the waste collection vehicle on a weekly basis. This provides a 3% improvement when compared to the existing equivalent empirical route (Se). The improvement is more significant if assessed in terms of the total travel time in the optimal route, defined as the runtime of the collection vehicle

plus collection time for the waste bins. The total travel time, on a weekly basis, for the optimal route (Sp) is estimated to be 1225 minutes (18% reduction compared to the empirical route (Se). For the calculations the hauling time to the Fyli landfill (~25 km from Sector 1) should be added. Assuming an average speed of 50 km/h, the travel time to and from Fyli is about one hour.
Restricting the discussion to the collection phase only of the WC&T cycle, it is expected that fuel consumption relates more to time of operation and number of stops than distance travelled, as most of the collection time is spent for bin loading and emptying. Fuel consumption and corresponding gas emissions are functions of work performed for stopping and accelerating, actual driving, traffic related stops and lifting and compacting the waste (Sonesson 2000).

	Se	*Sp*	*Savings*
Distance (km)	296.5	287.5	9 (3.1%)
Time (h)	24.9	20.4	4.5 (18.1%)
V_{mean} (km/h)	11.9	14.1	2.2 (18.5%)
Fuel consumption (L)	266.9	230.0	36.9 (13.8%)
Cost (in €, 1L=1.4 E)	373.6	322.0	51.6 (13.8%)*
CO_2 (kg)	274.9	240.1	34.9 (12.7%)

Table 3. Comparison between the existing *(Se)* and the proposed *(Sp)* waste collection scenarios. (*) Cost savings are restricted to fuel costs and would be higher if maintenance and personnel costs were considered.

Therefore, even for the same distance travelled, changes in the number of stops, i.e. the number of the collected bins, can considerably affect fuel consumption and respectively, CO_2 emissions. In this study fuel consumption values and CO_2 emissions were calculated for heavy vehicles (8 – 16 tones) using the following formula (Hickman, 1999):

$$\varepsilon = \mathrm{K} + a \cdot v + b \cdot v^2 + c \cdot v^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3} \quad (2)$$

where: ε is the emission value (gr/Km); K: constant value; a-f: coefficients; and, v: mean velocity of the vehicle (km/h).
The heavy dependence of collection time on the number of stops in combination with the new time schedule constitutes the main explanatory factor for the significant differences in the percentage savings in distance and time. Routing using the GIS modelling resulted to a 3.1% improvement of the distance travelled, although larger new sectors were proposed in comparison with the existing subsectors. In all the other values (fuel consumption, collection cost and CO_2 emissions, the percentage savings are estimated to exceed 10%. Finally, according to rough calculations, (extrapolation of the percentage savings to the total area of the municipality), the total savings for the municipality in one year, only from the reduction in fuel consumption, could approximate €68,000 and 46 tons CO_2 emissions, compared with the existing collection procedure.

5. Conclusions

GIS technology supports the optimisation of municipal solid waste management as it provides an efficient context for data capture, analysis and presentation. Two main categories of GIS-based waste management applications can be identified in the international literature. In the first, GIS is used for the selection of waste disposal landfills, and to a smaller extent, other waste treatment facilities. Most of these applications benefit from map overlay GIS functions and spatial allocation modelling methods. The final output of an application of that type is the suitability map of the area under investigation. This map could be the core of a spatial decision support system for a landfill site / waste treatment facility selection problem.

The second, more complex category of GIS supported waste management applications is related to waste collection. There are several applications for route optimisation, reallocation of waste bins and complete redesign of the collection sectors. The main aim of these applications is to reduce the collection distance and/or time of the collection vehicle fleet. The implementation of GIS-based modelling for waste collection optimisation in many countries with different socioeconomic conditions and technological background shows that significant savings could be achieved in most setups. The optimisation of routing has a direct positive impact on cost savings (reduction of fuel consumption and maintenance costs) as well as significant environmental impacts due to the lower levels of sound pollution within the urban environment and the reduction of greenhouse gases emissions. The application of GIS-based waste collection modelling should consider the following aspects, in order to provide reliable results:

a. Accurate and up to date information about the road network of the area under investigation.
b. Detailed capture of the spatial properties of the existing collection system (collection routes, location and attributes of waste bins, existing time schedule). Most often, especially in developing countries, the research team has to acquire this information with field work.
c. Installation of a modern GIS facility within the municipality enriched with network analysis functions. Advanced training of the staff is a very important factor for the efficient operation of this system.
d. Validation of the outputs from GIS-based modelling in order to ensure the applicability of the proposed routes in real life conditions.

Nowadays, although GIS-supported waste collection modelling is a mature scientific field the general diffusion of this technology is hampered by factors such as the absence and the poor quality of digital spatial data, the high cost of spatial data capture and the lack of personnel with the proper technological background to operate such modelling.

The methodology developed in this study and its application to the Municipality of Nikea, Athens, resulted in significant savings, especially in terms of time (18%), fuel consumption (13.8%) and CO_2 emissions (12.7%). The study demonstrated the value of GIS technology as a waste collection optimisation tool, capable of supporting decision making, in the context of a Mediterranean, densely populated city. The adoption of this technology could provide significant financial and environmental benefits for local communities.

6. References

Adamides, E.D.; Mitropoulos, P.; Giannikos, I. & Mitropoulos, I. (2009). A multi-methodological approach to the development of a regional solid waste management system. *Journal of the Operational Research Society*, Vol. 60, pp. 758-770, ISSN 0160-5682

Alvarez, J.V.L.; Larrucea, M.A.; Quero, S.F-C. & Del Valle, A.J. (2008). Optimizing the collection of used paper from small businesses through GIS techniques: The Leganés case (Madrid, Spain). *Waste Management*, Vol. 28, pp. 282-293, ISSN 0956-053X

Apaydin, O. & Gonullu, M.T. (2007). Route optimization for solid waste collection: Trabzon (Turkey) case study. *Global NEST Journal*, Vol. 9, No.1, pp. 6-11, ISSN 1790-7632

Biotto, G.; Silvestri, S.; Gobbo, L.; Furlan, E.; Valenti, S. & Rosselli, R. (2009). GIS, multi-criteria and multi-factor spatial analysis for the probability assessment of the existence of illegal landfills. *International Journal of Geographical Information Science*, Vol. 23, No.10, pp. 1233-1244, ISSN 1365-8824

Brimicombe, A. J. (2003). A variable resolution approach to cluster discovery in spatial data mining. *Lecture Notes in Computer Science*, Vol. 2669, pp. 1-11, ISSN 0302-9743

Brodrick, C.J.; Dwyer, H.A.; Farshchi, M.; Harris, D.B. & King, F.G.J. (2002). Effects of Engine Speed and Accessory Load on Idling Emissions from Heavy-Duty Diesel Truck Engines. *Journal of the Air & Waste Management Association*, Vol. 52, pp. 1026-1031, ISSN 1047-3289

Chalkias, C. & Lasaridi, K. (2009). A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece. *WSEAS Transactions on Environment and Development*, Vol. 5, No. 10, pp. 640-650, ISSN 1790-5079

Chang, N. & Wei, Y.L. (2000). Siting recycling drop-off stations in urban area by genetic algorithm-based fuzzy multi objective nonlinear integer programming modelling. *Fuzzy Sets and Systems*, Vol. 14, pp. 133–149, ISSN 0165-0114

Chang, N.B.; Parvathinathan, G. & Breeden, J.B. (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. *Journal of Environmental Management*, Vol. 87, pp. 139-153, ISSN 0301-4797

COM (2005). 'Report from the Commission to the Council and the European Parliament on the national strategies for the reduction of biodegradable waste going to landfills ', COM(2005) 105 final: Brussels, 30-3-2005.

Dantzig, G.B; Fulkerson, D.R. & Johnson, S.M. (1954). Solution of a large-scale travelling salesman problem. *Operations Research*, Vol.2, pp. 393-410, ISSN 0030-364X

Despotakis, V.K. & Economopoulos, A.P. (2007). A GIS model for landfill siting. *Global NEST Journal*, Vol. 9, No.1, pp. 29-34, ISSN 1790-7632

Dijkstra, E.W. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik*, Vol.1, pp. 269-271, ISSN 0029-599X

Dyson, B. & Chang, N. (2005). Forecasting municipal solid waste generation in a fast-growing urban region with system dynamics modelling, *Waste Management,* Vol. 25, pp. 669–679, ISSN 0956-053X

Esmaili, H. (1972). Facility selection and haul optimization model. *Journal of the Sanitary Engineering Division*, ASCE, Vol. 98, pp. 1005-1021, ISSN 0044-7986

ESRI, (2006). *ArcGIS Network Analyst Tutorial*, ESRI press, 36 pages.

EUNOMIA, (2002). Costs for Municipal Waste Management in the EU. Final Report to Directorate General Environment, European Commission.

Gautam, A.K. & Kumar, S. (2005). Strategic planning of recycling options by multi-objective programming in a GIS environment. *Clean Technologies and Environmental Policy*, Vol. 7, pp. 306-316, ISSN 1618-9558

Gemitzi, A.; Tsihrintzis, V.A.; Voudrias, E.; Petalas, C. & Stravodimos, G. (2007). Combining geographic information system, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills. *Environmental Geology*, Vol. 51, pp. 797-811, ISSN 1432-0495

Geneletti, D. (2010). Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. *Waste Management*, Vol. 30,, pp. 328-337, ISSN 0956-053X

Ghose, M.K.; Dikshit, A.K. & Sharma S.K. (2006). A GIS based transportation model for solid waste disposal - a case study of Asansol Municipality. *Waste Management*, Vol.26, pp. 1287-93, ISSN 0956-053X

Golden, B.L.; DeArmon, J. & Baker, E.K. (1983). Computational Experiments with algorithms for a class of routing problems. *Computers and Operation Research*, Vol.10, No.1, pp. 47-59, ISSN 0305-0548

Gómez-Delgado, M. & Tarantola, S. (2006). GLOBAL sensitivity analysis, GIS and multi-criteria evaluation for a sustainable planning of a hazardous waste disposal site in Spain, *International Journal of Geographical Information Science*, Vol. 20, pp. 449-466, ISSN 1365-8824

Hatzichristos, T. & Giaoutzi, M. (2006). Landfill siting using GIS, fuzzy logic and th*e* Delphi method, *International Journal of Environmental Technology and Management*, Vol. 6, No. 1-2, pp. 218-231, ISSN 1741-511X

Hickman, A. J. (1999). *Methodology for Calculating Transport Emissions and Energy Consumption*, Project Report SE/491/98, UK: Transport Research Laboratory.

Higgs, G. (2006). Integrating multi-criteria techniques with geographical information systems in waste facility location to enhance public participation. *Waste Management & Research*, Vol. 24, pp. 105-11, ISSN 1096-3669

Johansson, O.M. (2006). The effect of dynamic scheduling and routing in a solid waste management system. *Waste Management*, Vol. 26, pp. 875-885, ISSN 0956-053X

Kanchanabhan, T.E.; Abbas Mohaideen, J.; Srinivasan, S. & Lenin Kalyana Sundaram, V. (2011). Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality. *Waste Management & Research*, Vol. 29, pp. 323-339, ISSN 1096-3669

Kao, J.-J. & Lin, H.-Y. (1996). Multifactor spatial analysis for landfill siting. *Journal of Environmental Engineering*, Vol. 122, pp. 902-908, ISSN 1943-7870

Karadimas, N.V.& Loumos, V.G. (2008). GIS-based modeling for the estimation of municipal solid waste generation and collection. *Waste Managenent & Research*, Vol. 26, pp. 337-346, ISSN 1096-3669

Karadimas, N.V.; Papatzelou, K. & Loumos, V.G. (2007). Optimal solid waste collection routes identified by the ant colony system algorithm. *Waste Management & Research*, Vol. 25, pp. 139-147, ISSN 1096-3669

Katsamaki, A.; Willems, S. & Diamantopoulos, E. (1998). Time series analysis of municipal solid waste generation rates. *Journal of Environmental Engineering*, 124: 178–183, ISSN 1943-7870

Kim, B.I.; Kim, S. & Sahoo, S. (2006). Waste collection vehicle routing problem with time windows. Computers and Operations Research, Vol. 33, pp. 3624-3642, ISSN 0305-0548

Kontos, T.D.; Komilis, D.P. & Halvadakis, C.P. (2005). Siting MSW landfills with a spatial multiple criteria analysis methodology. *Waste Management*, Vol. 25, pp. 818– 832, ISSN 0956-053X

Kontos, T.D.; Komillis, D.P. & Halvadakis, C.P. (2003). Siting MSW landfills in Lesvos Island with a GIS based methodology. *Waste Management & Research*, Vol. 21, pp. 262–277, ISSN 1096-3669

Lasaridi, K., Rovolis, A., Abeliotis, K. (2006). Waste management costs in Greece: spatial patterns and causal factors. *WIT Transactions on Ecology & the Environment*, Vol. 98, pp. 55-64, ISSN: 1743-3541

Lasaridi, K. (2009). Implementing the landfill directive in Greece: problems, perspectives and lessons to be learned. *Geographical Journal*, Vol. 175, No.4, December 2009, pp. 261-273, ISSN 1475-4959

Lopez Alvarez, J.V., Aguilar Larrucea, M., Fernandez-Carrion Quero, S., Jimenez del Valle, A. (2008). Optimizing the collection of used paper from small businesses through GIS techniques: The Legane's case (Madrid, Spain). *Waste Management*, Vol.28, No. 2, 2008, pp. 282–293, ISSN: 0956-053X

Lotfi, S., Habibi, K., Koohsari, M.J. (2007). Integrating GIS and fuzzy logic for urban solid waste management (A case study of Sanandaj City, Iran). *Pakistan Journal of Biological Sciences*, Vol. 10, No. 22, November 2007, pp. 4000-4007, ISSN: 1028-8880

McHarg, I.L., (1969). *Design with nature*. The Natural History Press, ISBN: ISBN 0-471-11460-X, Garden City, NY.

Nas, B., Cay, T., Iscan, F., Berktay, A. (2010). Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. *Environmental Monitoring and Assessment*. Vol. 160, No. 1-4, January 2010, pp. 491-500, ISSN: 0167-6369

Nash, H.A. (2009). The revised Directive on Waste: resolving legislative tensions in waste management. *Journal of Environmental Law*, Vol. 21, No. 1, pp. 139-149, ISSN 1464-374X

Nuortio T., Kytöjokib J., Niska H., Bräysy O. (2006). Improved route planning and scheduling of waste collection and transport. *Expert Systems with Applications*, Vol. 30, No. 2, February 2006, pp. 223-232, ISSN: 0957-4174

Panagiotakopoulos, D. (2002). *Sustainable Management of Municipal Solid Waste*. ZYGOS publishers, ISBN: 978-960-8065-31-4, Thessaloniki (in Greek).

Saaty, T. L. (1980). *The analytic hierarchy process,* (p. 287), ISBN: ISBN 0-07-054371-2, New York: McGraw-Hill

Sahoo, S., Kim, S., Kim, B-I., Kraas, B., Popov, A. (2005). Routing Optimization for Waste Management. *Interfaces*, Vol. 35, No. 1, January 2005, pp. 24-36, ISSN: 0092-2102

Santos, L., Coutinho-Rodrigues, J., Current, J. (2008). Implementing a Multi-vehicle Multi-route Spatial Decision Support System for Efficient trash Collection in Portugal. *Transportation Research, Part A: Policy and Practice*, Vol.42, No. 6, July 2008, pp. 922-934, ISSN: 0965-8564

Sarptas, H., Alpaslan, M. N., Dolgen, D. (2005). GIS supported solid waste management in coastal areas. *Water Science and Technology*, Vol. 51, No. 11, 2005, pp. 213–220, ISSN:0273-1223

Sener, B., Süzen, M.L. Doyuran, V. (2006). Landfill site selection by using geographic information systems. *Environmental Geology*, Vol. 49, No.3, January 2006, pp. 376-388, ISSN: 0943-0105

Sonesson, U. (2000). Modeling of waste collection - a general approach to calculate fuel consumption and time. *Waste Management and Research*, Vol.18, No. 2, April 2000, pp. 115-123, ISSN: 1096-3669

Sumathi, V.R, Natesan, U., Sarkar, C. (2008). GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Management*, Vol. 28, No. 11, November 2008, pp. 2146-2160, ISSN: 0956-053X

Tavares, G., Zsigraiova, Z., Semiao, V., Carvalho, M. (2008). A case study of fuel savings through optimization of MSW transportation routes. *Management of Environmental Quality*, Vol.19, No.4, 2008, pp. 444-454, ISSN: 1477-7835

Teixeira, J., Antunes, A., P., de Sousa, J., P. (2004). Recyclable waste collection planning–a case study. *European Journal of Operational Research*, Vol. 158, No. 3, November 2004, pp. 543-554, ISSN: 0377-2217

Vijay, R., Gupta, A., Kalamdhad, A.S., Devotta, S. (2005). Estimation and allocation of solid waste to bin through geographical information systems. *Waste Management & Research*, Vol. 23, No. 5, October 2005, pp. 479–484, ISSN: 0734-242X

Vuppala, P., Asadi, S.S., Reddy, M.A. (2006). Solid waste disposal site selection using analytical hierarchy process and geographical information system. *Pollution Research,* Vol. 25, No. 1, 2006, pp. 73-76, ISSN:0257-8050

Wang, G., Qin L., Li G., Chen L. (2009). Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. *Journal of Environmental Management*, Vol. 90, No.8, June2009, pp. 2414-2421, ISSN: 0301-4797

Zamorano, M., Molero E., Hurtado A., Grindlay A., Ramos, A. (2008). Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology. *Journal of Hazardous Materials*, Vol. 160, No. 30, December 2008, pp. 473-481. ISSN: 0304-3894

Zsigraiova, Z., Tavares, G., Semiao, V., Carvalho, M.G. (2009). Integrated waste-to-energy conversion and waste transportation within island communities. *Energy*, Vol. 34, No. 1, January 2011, pp. 623-635, ISSN: 0360-5442

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This book reports research on policy and legal issues, anaerobic digestion of solid waste under processing aspects, industrial waste, application of GIS and LCA in waste management, and a couple of research papers relating to leachate and odour management.