Designing waste management systems towards resilient cities

C. Karkanias[1], D. Tsiftelidis[1], G. Perkoulidis[2], E. Feleki[2], T. Hagipanagiotou[3], E. Zevgara[3], E. Kladouri[4], H. Vassiliadis[1], A. Malamakis[2], I. Sarigiannis[1], N. Moussiopoulos[2]

[1]ANATOLIKI SA, Development Agency of Eastern Thessaloniki's Local Authorities, Thermi, Region of Central Macedonia, 57001, BOX: 60497, Greece
[2]Laboratory of Heat Transfer and Environmental Engineering, Aristotle University of Thessaloniki, Thessaloniki, Region of Central Macedonia, 54124, Greece
[3]Municipality of Kalamaria, Region of Central Macedonia, 55132, Greece
[4]Municipality of Thermi, Region of Central Macedonia, 57001, Greece

Keywords: municipal solid waste, circular economy, resilient city, waste collection, qualitative analysis, waste management plan.
Corresponding author email: ckarkanias@anatoliki.gr

Abstract
One of the main issues that recently came to the fore in the Greek public sector is urban resiliency which is considered as a mean to the transition to circular economy. Circular economy aims at tackling waste as a resource, while at the same time, it is inextricably linked to the policy of waste sorting at source and used also as a tool for its implementation.
Based on this concept, the Municipalities of Thermi and Kalamaria in Northern Greece are redesigning their waste management systems in terms of waste temporary storage, collection and transfer. They both aim at reducing waste management cost and achieving resiliency that will help the local authorities to confront with future sharp changes in everyday life.
This paper presents an integrated scheme for optimising the waste management system applied to the two aforementioned municipalities. Initially, the current status of the temporary waste disposal networks was recorded, while a qualitative analysis regarding the three identified conventional waste streams (mixed, packaging and packaging residues) took place. The required number and type of the waste bins were also estimated, whereas new spots for installing them were indicated. Finally, new collection routes for the waste vehicles were designed. The study contributes in waste management research and its novelty is the design of a new system based on real data derived from on the spot waste analysis. This analysis revealed an unexpected rate of organic waste in the mix waste in these areas indicating a rather unusual recycling level.

Introduction
The development of an integrated Municipal Solid Waste (MSW) management system in local level is prerequisite for the righteous operation of the respective mechanism, as well as for meeting the targets set by the EU and national waste frameworks. The revised National Waste Management Plan adopted in Greece in 2015 follows the principles and orientations of the 2008/98/EC Waste Framework Directive. The country needs to reduce the amount of waste that ends up in landfills, increase recycling and recycling rates to achieve the Plan's goals by 2020, and reduce greenhouse gas emissions from waste management. According to National Waste Management Plan (Law 4042/2012), by 2020, the rate of reuse and recycling must be at least 50% of the total weight of waste. Despite the progress made by Law 4496/2017 on recycling and the adoption of the National Action Plan for Circular Economy, most of Greece's municipal solid waste is disposed of in landfills [1].
In this context, a complete reflection of the current situation concerning both the quality and the quantity of all waste streams is the basis for developing the new waste management strategy. In terms of the waste composition, the national waste management plan published the average values of waste components' weights based though on studies that took place in areas other than the aforementioned municipalities.

The current study took into account a qualitative analysis carried out in the selected areas, thus using data actually related to the study areas. The new waste management plan will introduce an organic waste management scheme and will support the update of the existing waste recycling and sorting schemes.
Despite all the efforts made in local, regional or national level as well as the targets set by the EU directives the balk amount of all types of the generated municipal waste still ends up in landfills. The new era of circular economy brought a wind of change to the long-suffering issue of waste management, but soon multiple obstacles occurred. One of the major problems in Greece is the lack of accurate data concerning waste generation and composition in the vast majority of municipalities except for the large cities. The qualitative analysis solves this problem and provides the necessary waste characteristics for a thorough study.
The main objective of this study is to record, analyse and update the existing outdated municipal solid waste disposal and collection networks in the municipalities of Thermi and Kalamaria located in the Region of Central Macedonia, Greece.

Materials and methods

This study was carried out by the Development Agency of Eastern Thessaloniki's Local Authorities, ANATOLIKI SA in cooperation with the Laboratory of Heat Transfer and Environmental Engineering of the Aristotle University of Thessaloniki and the Municipalities of Thermi and Kalamaria.
At first, the current situation regarding the waste temporary storage network was recorded. In particular, the exact number of the bins for all waste streams placed in the municipalities' areas as well as the specific spots (recesses) within the pavement was recorded. This action was implemented using Geographic Information System (GIS), but also cartographic software developed as an application for devices running Android for the needs of this study. The application receives the exact geographical position of the installed waste bins, the recesses as well as the market areas showing high rates of waste generation including super markets and restaurants.
The aim of the routing stage was the minimisation of both the total distance traveled by waste vehicles (and travel time) and the required number of vehicles, the reduction of the vehicles pollutants, the equal distribution of workload among vehicles and the efficient waste management and collection. The methodology used for the routing was divided into five sub-stages: 1) analysis of the existing collection and transport system, 2) identification of existing problems, 3) creation of new service zones for the different types of waste, 4) routing of the new service areas and 5) creation of the new weekly waste management program.
During the second phase of the study, three waste streams including mixed waste, packaging waste and the residues of the later were identified. Two separate analyses carried out for this reason during winter (February) and summer (July) time in 2019 respectively taking into account the factor of seasonal variation. The selected methodology was based on the analysis of representative samples of waste derived from waste bins located in the study areas. The following measures were taken ensuring the analysis process and the quality of the results. Appropriate vehicles and experienced staff involved in the process, while the sorting area was fully equipped and authorised.
The whole operation was also supervised and all weighing instruments were properly calibrated. In order the statistical standards to be accepted, the results were expressed at confidence level of 95% (EU standards) and the accuracy level of the results was below 10% which is considered the maximum limit for random sampling errors.
The samples were selected from waste bins taking into account local characteristics such as community activities (urban, rural and market), the local population's living standards and the current waste collection routes.
Given that the population of the Municipality of Thermi was 53.201 inhabitants (2011) and taking into account the national production rate of 1 kg per inhabitant and day, the daily quantity of municipal solid waste produced was considered 53 t [2, 3]. The diversion rate from landfill and

the utilization of packaging waste of Thermi Municipality of the produced waste was estimated at 8.1%, and this meant that in all green bins there would be an average daily amount of waste of 49 t. The sample used in the study was 6 t, corresponding to 11% w/w for green bins MSW, which was a statistically accepted value.
In Kalamaria Municipality the population was 91,518 inhabitants (2011) and following the same procedure with Thermi Municipality, the daily average production was 92 t. The diversion rate from landfill and the recycling utilization on municipal solid waste generated was estimated at 9% w/w, which meant that the average daily amount of waste in green bins would be 83 t. The total sample that was collected from the six samples (7,986 kg) to be utilized in the analysis, corresponded to 10% w/w of the municipal solid waste in the green bins of the Municipality, and therefore it was an acceptable value for the whole population.
In terms of municipalities of Kalamaria and Thermi the analysed waste samples were 7,5 t and 5,7 t respectively which represent statistically accepted samples. On the other hand, the samples of the recyclable waste residues from the recycling unit were based on the annual utilized material for the years 2017 and 2018. The analysed samples for the recyclable waste were 211 kg and 317 kg respectively. The results of these analyses helped in estimating the number of the required waste bins in each municipality area. The new spots for waste bins were also mapped using the GIS. Finally, new routes for the waste collection vehicles were proposed in order to minimise the environmental and social burden as well as the collection cost.
The total duration of the study was 22 months including fieldwork. In particular, the winter samplings for the Municipality of Thermi were four (4) in total and took place from 13/02/2019 to 20/02/2019, while the sample quantities ranged from 400 to 2,360 kg derived from bins (underground bins included) for mixed waste. In addition, the summer sampling for Thermi Municipality took place from 26/06/2019 to 28/06/2019 and the related quantities of sample derived also from bins (underground bins included) for mixed waste ranged from 400 to 2,360 kg. In terms of Kalamaria Municipality, the winter sampling from mixed waste bins (770 L and 1,100 L) started on 06/02/2019 ending up on 15/02/2019, while the summer sampling took place from 25/06/2019 to 03/07/2019.

Results and discussion

Current situation

Municipality of Thermi

The Municipality of Thermi uses 17 vehicles in total for collecting the generated waste including 9 for mixed waste, 4 for packaging waste, 1 for mixed waste in underground bins and 3 for bulky waste. The above vehicles collect waste on a daily and weekly basis depending on the type of waste. In particular, there exist 11,5 routes for mixed waste and 4,5 routes for packaging waste daily, as well as 5 routes for mixed waste (underground bins) and 3 routes for bulky waste on a weekly basis. Furthermore, there exist routes for collecting glass when needed.
The recording of the waste bins showed that there are 4.418 bins in total installed in the municipality of Thermi as well as 631 recesses for bins (532 for one bin, 88 for two bins and 11 for three bins) within the pavement. Particularly, 2.530 bins for mixed waste (capacity of 1.100 l, 660 l και 240 l), 1.073 bins for recyclable waste (1.100 l, 360 l and 240 l), 582 bins for paper waste (1.100 l), 61 bins for glass (2.500 l and 1.300 l), 144 underground bins for mixed waste and 36 bins for clothes are installed in the municipality area.
The total capacity of the bins for mixed waste is 3.082 m^3, for recyclable ones 1.167 m^3, for glass 78,5 m^3 and for paper waste 640 m^3. Furthermore, 35 shops (13 restaurants and 22 supermarkets) having waste bins in a close distance and being considered as important organic waste sources were recorded. The total amount of the generated waste in 2018 in the Municipality of Thermi was 23.946 t.

Municipality of Kalamaria

On the other hand, the Municipality of Kalamaria uses 25 vehicles, including 19 vehicles for mixed waste, 5 for packaging waste and 1 for mixed waste in underground bins. These vehicles collect waste on a daily and weekly basis depending on the type of waste. Particularly, there

exist 12 routes for mixed waste and 5 routes for packaging waste daily, as well as 5 routes for mixed waste (underground bins) on a weekly basis and routes for bulky and glass waste when needed. The total amount of waste bins installed in the Municipality of Kalamaria is 3.965, while there exist 519 recesses for bins within the pavement.

The recording of the waste bins showed that there are 3.965 bins in total installed in the municipality of Kalamaria and 519 recesses for bins (377 for one bin, 121 for two bins and 21 for three bins) within the pavement. In details, 2.386 bins for mixed waste (capacity of 1.100 l, 660 l and 240 l), 1.299 bins for recyclable waste (1.100 l, 360 l and 240 l), 68 bins for paper waste (1.100 l), 82 bins for glass (2.500 l and 1.300 l), 40 underground bins for mixed waste and 90 bins for clothes are installed in the municipality area.

The total capacity of the bins for mixed waste is 2.236 m^3, for recyclable ones 1.403 m^3, for glass 121 m^3 and for paper waste 75 m^3. In addition, 92 shops (47 restaurants and 45 supermarkets) having waste bins in a close distance and being considered as important organic waste sources were recorded. Finally, 31.276 t of waste were generated in the Municipality of Kalamaria in 2018.

After analysing the current waste management program of the two Municipalities, the problems identified were that the number of waste bins recorded within the service areas were not equally distributed in the whole waste collection route system. This caused an additional problem, leaving uncollected waste according to the schedule.

Qualitative analysis

The results occurred after the analysis of the mixed waste fraction was processed with statistical analysis t-Student. This method was chosen because the sample was small and in this case the distribution differs from the normal distribution. No significant difference was observed concerning the composition of the sample between the urban areas of the two municipalities in relation to the other areas (semi-urban, rural) and the areas where numerous enterprises operate.

Moreover, the results of the analysis showed no difference taking into account the living standards of citizens. In conclusion, the results analysis revealed the high level of public awareness in terms of recycling in both municipalities. The results of the qualitative analysis in the municipalities of Kalamaria and Thermi are presented in Table 1.

Table 1. Qualitative analysis of waste streams in the Municipalities of Thermi and Kalamaria.

Waste	Average % (summer period) -Thermi Municipality	Average % (winter period) - Thermi Municipality	Average % - Thermi Municipality	Average % (summer period) - Kalamaria Municipality	Average % (summer period) - Kalamaria Municipality	Average % - Kalamaria Municipality	Average – Thermi/Kalamaria Municipalities	Average %Region Central Macedonia (2016)	Average % (Regional Waste Management Plan
Organic	90,25%	80,42%	85,33%	88,38%	80,23%	84,31%	82,36%	45,5%	44,3%
Paper/carton	1,63%	4,07%	2,85%	1,34%	4,41%	2,88%	3,47%	20,0%	22,2%
Plastic	2,16%	8,19%	5,18%	2,32%	7,13%	4,73%	6,46%	12,2%	13,9%
Metals	0,23%	1,68%	0,95%	0,56%	1,42%	0,99%	1,33%	3,8%	3,9%
Glass	0,00%	2,30%	1,15%	0,19%	1,91%	1,05%	1,68%	3,6%	4,3%
Other	5,73%	3,34%	4,53%	7,44%	4,89%	6,17%	4,75%	14,9%	11,4%

The average percentage of waste types in recyclable and residues of recyclable waste are shown in Tables 2 and 3.

Table 2. Composition of recyclable waste and recyclable waste residues

Recyclable waste streams	Average %	Recyclable waste streams in residues	Average %
		Organics	22,69
		Paper/cardboard	2,64
Paper/cardboard	69,91	Plastic	4,14
Plastic	20,00	Glass	0,14
Glass	4,41	Aluminum	0,30
Aluminum	0,51	Metals	0,07
Metals	5,17	Other	70,02
TOTAL	**100,00**	**TOTAL**	**100,00**

Redesign of waste storage systems

Critical factors were taken into account when re-designing waste temporary storage systems in the municipalities of Thermi and Kalamaria including the Waste Generation Rate (WGR), type, volume, capacity and the average fullness of the waste bins, the method and the waste collection frequency as well as the local characteristics of the selected area. The WGR was estimated based on the population and growth rate having as a basis the waste amount generated in 2018. For future population estimation the exponential model developed in the context of Malthus theory (Eq. 1) was used.

$$P_k = P_0(1+r/100)^k \quad (1)$$

Where P_0 the population at started year, r the population increase per period, k the number of the selected periods and Pk the population after k periods. When testing this model, the population changes between the censuses of 2001 και 2011 at the aforementioned municipalities were used.

For the growth rate estimation for the period 2019-2023 the Financial Forecast Report of the Hellenic Statistical Authority was taken into account (HSA, 2019) according to which the growth rate for 2019 is projected at 2,1% of GDP, at 2,3% of GDP in 2020, at 2,21% in 2021, at 1,8% in 2022 and at 1,8% in 2023. The corresponding Eurostat report (2011) “Generation and treatment of municipal waste in the EU-27 from 1995 to 2009” was also taken into account. According to this report, the average increase of EU 27 GDP is correlated to the waste generation increase in between 1995 and 2009.

The daily WGR was estimated based on the waste generation per capita (kg/cap/d) and the municipality population according to the following function Eq. 2 [4].

$$W_{\mu i} = p_k \times WGRc \quad (2)$$

Where $W_{\mu i}$ the WGR. In addition, the volume of the generated waste (m^3) for each waste stream was estimated using their specific weight when uncompressed [5], the required capacity of the selected waste storage systems and the waste collection frequency. Another critical factor was the average fullness of the waste bins (σ) calculated using the following function, Eq. 3 [6].

$$\sigma = \frac{[Volume/(Number\ of\ Bins\ /\ waste\ collection\ route\ )]}{Bin\ capacity} \quad (3)$$

The calculation of the required number of waste bins for each waste collection route was based on the following function, Eq. 4 (Panagiotakopoulos 2002).

$$\Sigma XK = n \times V_K \times \sigma \Rightarrow n = \frac{\Sigma XK}{V_K \times \sigma} \quad (4)$$

Where, n: number of required waste bins, ΣΧΚ: total volume of waste bins, Vκ: volume of a bin, σ: bin’s fullness rate.

Municipality of Thermi

The total waste generation in the municipality of Thermi is estimated to reach 32.610 t in 2020 and 33.393 t in 2023. The required number of waste bins (1.100 l and 360 l for organic waste) for each waste stream is shown in Table 4. Particularly, for glass collection it has been estimated that no additional waste bins are needed due to the sufficient current storage system taking into account the targets set by the Nation waste framework.

Table 3. Required number of waste bins for each waste stream in the municipality of Thermi for the years 2020 and 2023.

Waste stream	Number of bins 2020	Number of bins 2023
Mixed waste	2.230	2.142
Organics	250*	576(660 l.)/1.152(360 l.)
Paper/cardboard	402	790
Plastics/metals	400	615
Mixed recyclables	600	-
TOTAL	3.899	4.247/4.823

* Currently Thermi municipality is not operating an extended organic waste collections system.

Municipality of Kalamaria

Waste generation in Kalamaria municipality is estimated at 33.534 t in 2020 and 34.548 t in 2023. The required waste bins (1.100 l and 360 l for organics) for each waste stream is shown in Table 5. Particularly, for glass collection it has been estimated that no additional waste bins are needed due to the sufficient current storage system taking into account the targets set by the Nation waste framework.

Table 4. Required number of waste bins for each waste stream in the municipality of Kalamaria for the years 2020 and 2023.

Waste stream	Number of bins 2020	Number of bins 2023
Mixed waste	2.280	2.046
Organics	300*	600
Paper/cardboard	200	642
Plastics/metals	-	618
Mixed recyclables	1.200	-
TOTAL	3.980	3.906

* Currently Kalamaria municipality is not operating an extended organic and paper waste collections system.

Redesign of waste collection and transfer system

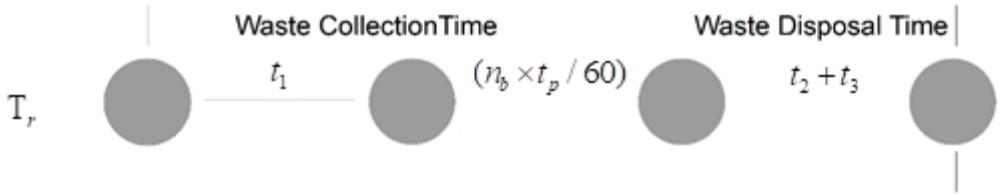
During the 2st Phase of developing the waste management plan of the two aforementioned municipalities the collection zones were initially rescheduled. In particular, the following were estimated: a) the volume of waste that can be transferred within each waste collection route and

b) the required time for the execution of each waste collection route. The calculation of the above factors was made based on the following Eq. 5 and 6 [6].

$$\Sigma_{\Delta} = \left(\frac{V_w}{y_c \times V_t}\right) \times f \qquad (5)$$

$$T_r = t_1 + (n_b \times t_p / 60) + t_2 + t_3 \qquad (6)$$

Where Σ_{Δ}: the total number of waste collection routes for each waste stream, V_w: volume of waste in bins, y_c: compression factor, V_t: waste vehicle capacity, T_r: time period of waste collection route, n_b:number of bins, t_1: required time for waste collection vehicle to reach the first waste bin, t_2: required time for waste collection vehicle to reach the final disposal unit and back to the parking site, t_3: time needed for waste unloading from vehicle, t_p: waste collection time.



The weekly waste collection schedule for each waste stream in the municipalities of Thermi and Kalamaria is shown in Table 6.

Table 5. Weekly waste collection routes in the municipalities of Thermi and Kalamaria.

Waste stream	Compression factor	Collection frequency		Municipality of Thermi		Municipality of Kalamaria	
		2020	2023	2020	2023	2020	2023
Mixed waste	4	5	5	45	45	40	40
Organics	5	6	6	12	42	12	45
Paper/cardboard	3	3	4	15	15	6	20
Plastics/metals	3	2	3	8	8	-	15
Mixed recyclables	3	4	-	16	-	20	-
TOTAL				96	110	78	120

After zone number determination, the waste bins were equally distributed in each zone. Taking into account that the work duration of typical waste management staff is 6:30 hours, the break time is 15 minutes, time needed to collect one bin is 1 minute and the average speed of waste collection trucks in urban areas, indicated by the vehicle drivers is 15 km/h, the possibility of on schedule bins collection, per sub-zone, was checked.

Finally, after the volume and time control of the different zones, through consultations with the competent bodies, there were a distribution of the different zones of waste types per vehicle and day, forming the new weekly waste management program. The results of the analysis and the proposal for the year 2020 waste management program were the reduction of the zones, saving of vehicles, recording of the routes of the fleet and their service areas, identifying the optimal routes and saving of human resources for the two Municipalities. The vehicles and the human resources saved was planned to be used for the collection of the new types of waste, after the separation of the recyclable materials into different type of bins (Fig. 1).

Figure 1. Mapping of waste bins in Kalamaria municipality.

Conclusions

Organic waste represent almost 80% of the total generated waste, while the rest are packaging waste in the Municipalities of Thermi and Kalamaria. The discrepancy between the results of this study and the previous corresponding region waste management plan can be attributed to the long period passed after the last study. Furthermore, municipalities of Thermi and Kalamaria are considered pioneers among Greek municipalities in this issue.

This study revealed the need for organic waste separate collection. In addition, the waste bins are proposed to be installed in groups including all the waste streams (mixed, packaging, paper, organic, plastic/metals and glass).

In terms of resiliency, the results of the analysis showed that in the case the local authorities follow the suggested actions listed in this study can reduce waste management cost and indirectly reduce CO2 emissions because of the less waste collection routes.

References

[1] GIZ: Waste management and the Circular Economy in Greece. Available at https://www.giz.de/en/worldwide/75350.html (2019) (accessed 8 June 2020).

[2] Moussiopoulos, N.: Solid Waste Treatment and Management: Solid waste production – Quantitative and Qualitative analysis. Issue: 1.0. Thessaloniki. Available at http://eclass.auth.gr/courses/OCRS392/ (2014) (accessed 10 May 2020).

[3] PESDA PKM: Region of Central Macedonia Waste Management Plan, 2nd Revision (2016)

[4] Panagiotakopoulos, D.: Sustainable management of liquid waste. *Zigos* (2002)

[5] Tsobanoglous, G., Theisen, H. and Vigil, S.: Integrated solid waste management. Engineering principles and management issues, *Mc Graw Hill* (1993)

[6] Famelos, S. and Tsiftelidis, D.: Design of sustainable management of packaging waste in Thessaloniki, *Anatoliki* (2012)