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Article

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Energy Reports

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Elsevier

Suggested Citation: Sözer, Hatice; Sözen, Hüseyin (2020) : Waste capacity and its environmental impact of a residential district during its life cycle, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 6, pp. 286-296,
<https://doi.org/10.1016/j.egy.2020.01.008>

This Version is available at:

<https://hdl.handle.net/10419/244031>

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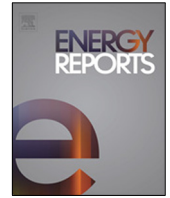
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Research paper

Waste capacity and its environmental impact of a residential district during its life cycle

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ARTICLE INFO

Article history:

Received 13 September 2019

Received in revised form 21 January 2020

Accepted 21 January 2020

Available online xxxx

Keywords:

Life cycle assessment

District-scale waste management

Waste capacity

Municipal solid waste

Liquid waste

Demolition waste

ABSTRACT

Buildings generate a significant amount of waste that has considerable impacts on environment and energy flow. This study aims to investigate the waste capacity of the selected district and its effect on the environment within the current waste management policy via Life Cycle Assessment (LCA) methodology based on the two indicators; global warming potential and energy flow. The district has 82 buildings with 64,971m² total gross area and 2,000 populations. Accordingly, the district's waste capacity was evaluated within the classification of Municipal Solid Wastes (MSW), liquid wastes, and demolition wastes.

The system boundaries of the LCA were set based on the gate-to-grave approach, which includes generated wastes during the lifespan of the buildings, including their end-of-life stage. Consequently, energy recovery potentials from waste processes were investigated and compared with the primary energy demand of the operational energy consumption of the buildings to perceive the amount of energy compensation range.

Additionally, buildings' physical conditions, which obtained from their Building Information Models (BIM), energy performances, derived from their energy models and local specifications, obtained from standards were utilized to identify the current conditions and waste management systems. Critically, the outcomes of all those were used as input data for the LCA model.

The results showed that there had been energy recovery potentials from MSW's treatments, while liquid wastes and demolishing wastes treatments have consumed energy. Energy recovery potential from MSW has compensated only 5.8% of operational energy annually, which came from recycling processes. Also, all waste management systems release greenhouse gases to the atmosphere that cause global warming.

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1. Introduction

Waste leads to significant environmental and health problems, though it has considerable recovery potential due to the recycling process if appropriately treated. The amount of total household waste that was generated in EU countries was 214,240,000 tons/year in 2016, which 18% was recyclable (Anon, 2018). Correspondingly, the amount of wastes generated by households in Turkey was 27,985,092 tons in 2016 (Anon, 2018) which is almost 8% higher than in EU countries. Because of that, authorities have to manage the wastes carefully to avoid their harmful effect and take advantage of their waste recovery potential.

Wastes that are generated in the buildings could be categorized into three groups as Municipal solid waste (MSW), liquid waste, and demolition waste. MSWs and liquid wastes are generated during the building-in-use period, while demolition wastes

occur after the building is demolished. There are different treatment processes for each waste type; therefore, their management plan, impacts on the environment, and human health have to be defined and assessed individually. LCA methodology is commonly used to investigate waste management policies and their impact on the environment, energy flow, and health from material production to the disposal process. There are different system boundary approaches to define the scope of the LCA. The most detailed one is the cradle-to-grave approach, which evaluation process starts from the raw material extraction and finishes in the disposal phase. However, waste management is mostly utilized in the gate-to-grave approach, where the material production phase of waste is not considered. Blengini et al. (2012) also suggest applying the cradle-to-grave approach to waste management. Correspondingly, Di Maria and Micale (2014) analyzed a waste management system within the gate-to-grave approach in Italy.

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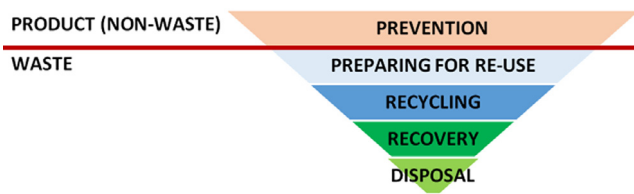


Fig. 1. The waste policy defined in the Directive 2008/98/EC (E.P. and of the Council, 2018).

1.1. National and international legislation on waste management

In the EU, the waste management policy is defined in Directive 2008/98/EC within the waste framework directive (E.P. and of the Council, 2018), which primarily aims to prevent waste generation. Then the sequence of framework continues with preparing the waste for reuse, recycling, recovery, and finally for disposal, which is represented in Fig. 1. EU also has separate legislation to handle the special wastes such as batteries, mining, and packaging in their individual waste streams.

In Turkey, Turkish Environmental Law is in force since 1983, and improvements on the regulation on waste and waste management are still progressing. Some regulations are also regulated based on EU directives. For solid wastes, there is one general regulation that is called Solid Waste Management Regulation, which the first version was published at 14.03.1991 and the last revision on 02.04.2015. The regulation does not involve gas emission, wastewater, radioactive waste, and dangerous waste (Ministry of Environment and Urbanization, 2015). Additionally, there are specific regulations related to waste of package, waste of electrical and electronic equipment, and waste of landfill. Furthermore, for liquid waste, there is one regulation that is called Urban Wastewater Treatment Regulation, which the last revision was published on 08.01.2006. It regulates the standard of domestic wastewater treatment plants, besides the standard for realizing the industrial wastewater to the urban sewage system (Ministry of Environment and Urbanization, 2006). Besides, there is a regulation for storm water management, which mostly focus on the technical aspects. As in solid waste regulations, regulators regulate waste oil and cooking oil individually. Furthermore, there is one regulation, called Excavation Soil, Construction and Demolition Waste Management Regulation, which regulates waste's collection and transportation, recycling, and reuse as well as responsibilities of municipalities and facilities (Ministry of Environment and Urbanization, 2004).

2. Literature review

As mentioned before, wastes are categorized into three different groups as MSW, liquid waste, and demolition waste in this study. In the literature, each category was examined separately. Also, while MSW and liquid waste were analyzed in a district or city level, demolished wastes were evaluated only at the building level. Selected of those studies that have a valuable impact are summarized below.

2.1. Municipal solid wastes

Municipal solid wastes are also called as household wastes. They can be defined as wastes that are generated from residential, office, or service buildings in daily activities. Due to their characteristics, they have to be managed separately. LCA has utilized as a tool to assess MSW management plans and their effects on environment and energy flow. MSW includes different sub-wastes such as organic, glass. The waste management plan for

MSW and the capacity of the treatment plant are planned based on the characteristic of MSW. Sezer et al. investigated waste characteristics of the Istanbul–Kemerburgaz Region for 12 months to examine the amount of organic wastes to compost processes. Their results showed that organic has the highest percentage, with 49.5%. They listed other waste types as: paper 16.4%, plastic bag 8.3%, diaper 5.1%, textile 4.6%, glass 3.5%, plastic 2.7% and others 9.9% (Kadir Sezer and Arıkan, 2009). Özcan et al. examined the fraction of MSW in a district. Fraction of MSW was organic 57.69%, 8.41% plastic, 8.01% combustibles, 6.13% glass and 19.76% the others (Ozcan et al., 2016). Yıldız et al. assessed a fraction of MSW in the city scale; besides, organic waste also had the highest percentage in their results. Based on the fraction of MSW, different management plans were assessed with LCA methodology to show their impact (Yildiz et al., 2013). Özeler et al. analyzed the MSW management system in Ankara by defining various scenarios. Their results showed that the most environmental and feasible scenario was the source reduction scenario. On the other hand, if the global warming potential (GWP) is taken into account, the scenario that contained the anaerobic digestion process was the most environmental one (Özeler et al., 2006). Yay analyzed the Sakarya MSW management plan. According to their report, the MSW system only has landfill and incineration area that has a negative influence on the environment. As a result, they suggested an integrated system that includes material recovery facilities (MRF), composting, incineration, and landfill to achieve a sustainable system (Erses Yay, 2015).

2.2. Liquid wastes

The most important liquid waste type that is generated in the buildings is domestic wastewater. Due to that, only domestic wastewater was taken into account as liquid waste in this paper. Wastewater has various pollutant inside of it; besides, the most effective ones for the environment are biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen types, phosphorus and suspended solids (Orhon et al., 1997; Aziz and Ali, 2017; Sari et al., 2014). If the pollutants do not treat properly, they can cause serious environmental or health problems, especially in the district or city scale. The other liquid waste type from the building is rainwater. There are different survey to show usage area of rainwater; also, rainwater can be used for irrigation, toilet flushing, clothes washing and drinking and cooking for some specific conditions (Heyworth et al., 2006; and et al., 1996); however, rainwater was not involved to the system boundaries of this survey because the district does not have rainwater collecting system.

2.3. Demolition wastes

Instead of daily wastes, demolition wastes are also generated from buildings after the building's lifetime ends. While MSW and liquid wastes show similarities for all buildings, demolition waste changes based on building materials. Some survey-examined fraction of demolition waste and concrete was the most effective sub-waste based on the amount (Zakar, 2009; Blengini, 2009). Ding and Xiao evaluated demolition waste based on building type and construction period (Ding and Xiao, 2014). Brière et al. assessed a fraction of demolition waste, besides, their results showed that the most effective wastes were listed as masonry 52.8%, reinforced concrete 26.4%, mixed inert waste 9.3% and the other 11.5% (Raphaël Brière et al., 2014).

As represented, the total waste capacity of a building during its lifetime has not been investigated yet. In Turkey, on the other hand, most research was done and published about the waste management and current waste management policies of the city

or district. Usually, the selected types of wastes were examined separately in building, district, or city scale, as that is also the case in existing global literature. In fact, MSW and wastewater were assessed in the district or city level, while demolition wastes were examined in the building scale.

In this research paper, a selected district was examined based on its waste streams during the building's lifespan to develop a waste management strategy in the scope of environmental perspective. Firstly, waste streams of the district's buildings were categorized according to their waste types, which include MSW, wastewater, and demolishing waste that were analyzed based on their effect on two indicators; energy flow and carbon emission. Regarding local and national legislation, a waste management strategy was suggested by utilizing LCA methodology. System boundaries of the study were selected as the gate-to-grave approach, which contained the building-in-use and end-of-life stages. Thus, generated waste during the building lifetime and demolition waste after the end-of-life stage were examined. As it is defined in waste management policies, waste management had begun from a building level as a waste generating resource. Therefore, the aim of this paper is examining waste management systems from the building-scale to district-scale with LCA methodology, not been represented in the literature yet.

3. The method through a case study

The method of the research was developed based on ISO 14040, ISO 14044 (I. 14040, 2006; ISO 14044, 2006), and EN EN 15978 standards (European Committee for Standardization, 2011). Therefore, the study was developed by following four main steps as goal and scope definition, inventory analysis, life cycle impact assessment, and interpretation. These steps are related to each other, and they have to be managed together during LCA.

On the other hand, EN 15978 divides the LCA methodology into four main stages with sub-steps that are: **Product Stage**, is also called cradle, which is classified as A and contains three sub-steps; A1: Raw Material Extraction, A2: Transport and A3: Manufacturing; **Construction Stage** is also classified under A and contains two sub-steps; A4: Transport, A5: Construction & Installation; **Use Stage**, is also called gate, which is classified as B and contains three sub-steps; B2: Maintenance, B4: Replacement, B6: Operational Energy construction, **End of Life Stages**, is also called grave which is classified as C and contains four sub-steps; C1: Demolition, C2: Transport, C3: Waste Processing, C4: Disposal (European Committee for Standardization, 2011).

The primary purpose of the study is to investigate the environmental impact of building wastes on a district scale. Hence, the boundaries of the LCA of the buildings were considered from gate to grave, which the production process of waste materials is not considered in the framework. The study was started from the building-in-use stage, which is considered as the gate that contains operational energy flow, maintenance, replacement during the span of buildings, and completed with the building-end-of-life stage, which is considered as the grave that contains demolition and transportation to the treatment site of the wastes.

The most critical stage of the work is to collect reliable data to get accurate results. Therefore, two different analysis methods also were utilized to produce data for LCA. Those were the development of BIM© and energy performance models. Developed BIM of each building type in the district provides information about the amount of building materials and wastes with their categorization, waste management strategies (Autodesk Inc., 2018) as well as geographical information about the locations and the distances; those are provided from Geographical Information Systems (GIS, 2018). On the other hand, the energy performance models of each building type include information about buildings

energy consumption during their operational usage, which was developed with e-QUEST© software (Hirsch, 2010). Hence, all data needed for LCA are provided from the BIM and the buildings' energy models. Therefore, a methodology was developed and represented in Fig. 2.

3.1. The case study district

The district is located in Soma, Manisa. It has 82 building blocks that 79 of them are residential, two of them are guest-houses, and one of them is the convention center with a total of 64,971 m² total gross area and 2000 inhabitants. Wastes that are generated in those were examined based on their current waste management systems. The site plan and location of buildings are given in Fig. 3.

3.2. Goal and scope definition

The definition of the goal and scope of the study is the most critical stage of the research. Final expected outcomes and research boundaries based on defined approaches were clarified in this step. Relatedly, functional unit, and assumptions were determined. EN 15978 and its calculation method was used.

The goal of the study is to investigate the waste capacity of the selected district with the LCA methodology based on the selected two indicators; global warming potential and energy flow.

The system boundaries of the LCA were set based on the gate-to-grave approach. The district has 82 buildings with 2000 populations. Buildings' lifetime was defined as 50 years. Generated wastes during the lifespan of the buildings and their end of life scenario according to current waste management system were assessed which includes building in use (B) and end of life (C) stages of the EN 15978 standard. Consequently, the energy recovery from the waste process was investigated and compared with the primary energy demand of the operational energy consumption of the buildings to perceive the amount of compensation range. Likewise, demolition wastes that occur through the buildings' lifespan from replacement and maintenance processes were added into the model. The system boundaries of the study are shown in Fig. 4 in detail.

3.2.1. Current waste management in the case study district

There is one sanitary landfill area in Manisa Province where is close to the center of Manisa. After MSW is collected by Soma municipality, they are transferred to the sanitary landfill that is called *Uzunburun Katı Atık Bertaraf Tesisi*. The distance between the district and the landfill is approximately 65 km. The plant is branded as the second group sanitary landfill area by related regulation (Ministry of Environment and Urbanization, 2010). Based on regulation, only MSW and non-hazardous waste might be treated in the second group plant. There are three main processes in the plant as sanitary landfill, composting, and mechanical separation.

Domestic wastewater is collected by the sewerage system by Manisa Water and Sewerage Administration (MASKI). There is a wastewater treatment plant, 5.3 km away from the district. The biological treatment system is applied to treat domestic wastewater.

The responsibility of demolition wastes belongs to the building owners. There is a treatment plant for demolition waste in the Soma district. The distance between the plant and district area is about 5.5 km.

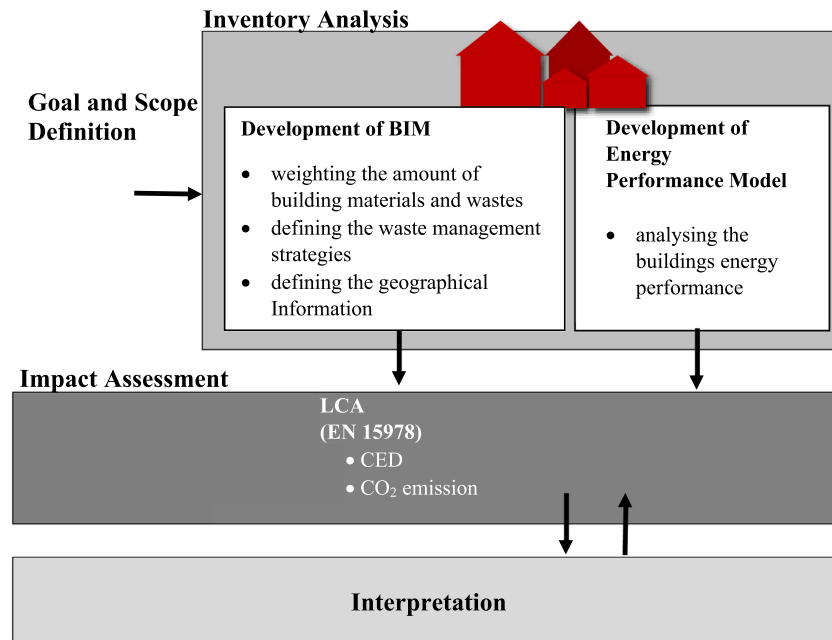


Fig. 2. LCA methodology.

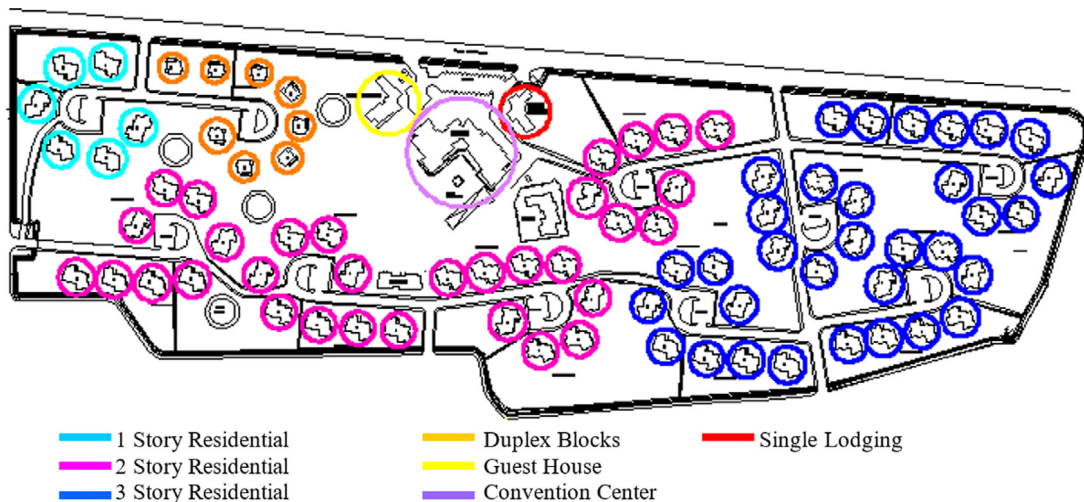


Fig. 3. Site plan of the district.

3.3. Inventory analysis

Based on defined scope and system boundaries, all input-output and their amount were determined to be utilized in the LCA model. The specific software was used; to identify the amount of materials, and their waste capacities is Building Information Modelling (BIM)© (Autodesk Inc., 2018) and to analyze the building energy performance is e-QUEST© (Hirsch, 2010).

A detailed explanation of the inventory analysis phase, which requires the application of EN 15978, is developed and represented in Fig. 5.

Three different waste types were defined in the study as municipal solid waste, domestic wastewater, and demolition waste. The capacities of waste types were calculated one by one.

The amount of MSW and domestic wastewater were calculated by taking advantage of the TUIK database (Turkish Statistical Institute (TUIK), 2016). Besides, the fraction of MSW was obtained from the literature. The amount of demolition wastes, on the

other hand, was defined by developing a BIM for each building. Different types of building materials were identified in the model layer by layer; besides, the material file was created to evaluate the volume of each building's material. In addition, the operational energy consumption of the building was included in the model by developing the energy performance model of each building type. Details of analyses and their results were represented below.

3.3.1. The capacity of MSW of the district

Based on the Turkish Statistical Institute (TUIK), the MSW generation rate for Manisa was 1.34 kg/cap./day in 2016; besides, this rate was used in this survey for calculation. The calculation for the capacity of MSW was given in Eq. (1). The total amount of generated MSW during one year is 978.2 tons for the district.

$$\text{Capacity of the MSW} = 2000 \times 1.34 = 2680 \text{ kg/day} = 978.2 \text{ ton/year} \quad (1)$$

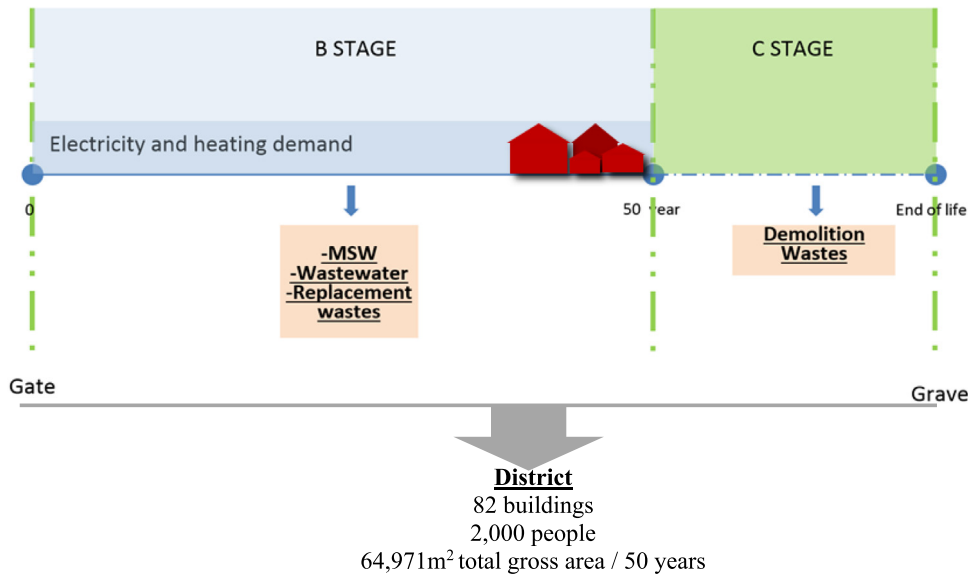


Fig. 4. System boundaries based on the gate-to-grave approach.

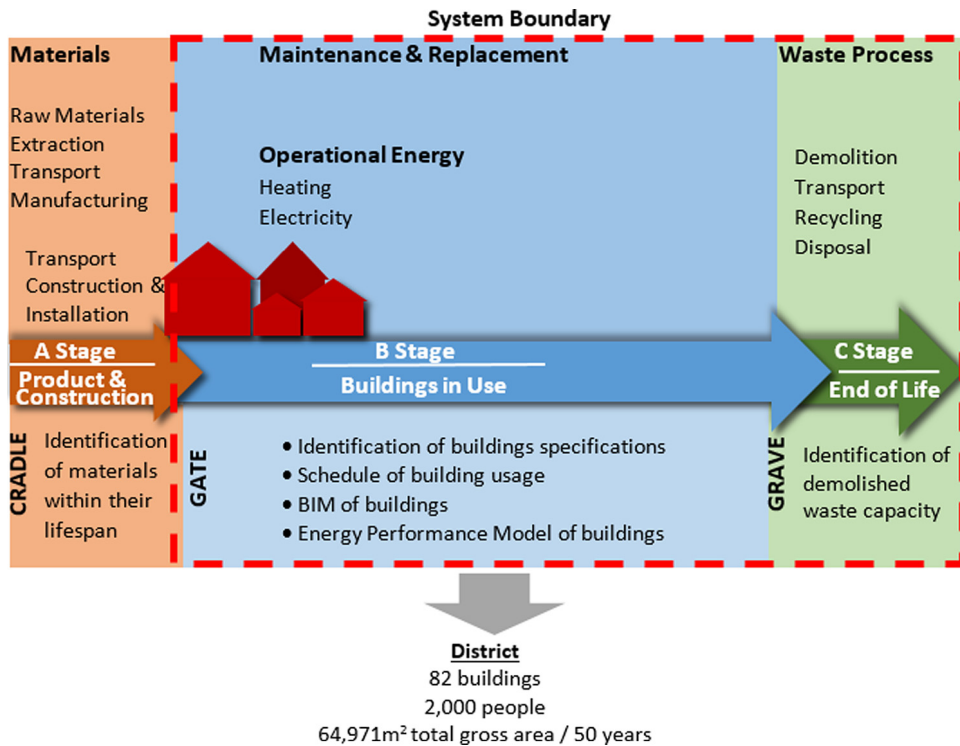


Fig. 5. The inventory analysis phase of the methodology.

As mentioned before, the fraction of MSW is also important for the waste management plan. For this purpose, the survey results that were made by Ozcan et al. (2016) were used. Based on their calculated fraction, the capacity of sub-wastes for the district were given in Table 1.

3.3.2. The capacity of domestic wastewater

Domestic wastewater generation rate per person in Soma is 153 L/cap./day (Orhon et al., 1997). Based on this rate, the capacity of domestic wastewater was calculated in Eq. (2). The district generates 111,690 m³ domestic wastewater annually; besides, it

was treated at the closest wastewater treatment plant.

$$\begin{aligned} \text{Capacity of the waste waster} &= 2000 \times 153 = 306000 \text{ L/day} \\ &= 111690 \text{ m}^3/\text{year} \end{aligned} \quad (2)$$

3.3.3. The capacity of demolition wastes

It envisaged that after building's lifetime finish, all buildings in the district would be demolished. The demolition waste capacity of the district was obtained from the developed BIM of each building type. In the models, selected material types were defined layer by layer to get their amounts. Examples of building

Table 1
MSW fraction in the district.

Building solid waste fraction	Fraction (%)	The amount of sub-wastes (tons/year)
Organics	60.62	593
Paper and Cardboard	10.98	107
Plastic	8.41	82
Glass	6.13	60
Metal	1.01	10
Electrical and electronic equipment	1.23	12
Others	11.62	114
TOTAL	100	978

Table 3
The amount of demolition waste.

Material type	Ton	Percentage (%)
Brick	40.560	39
Concrete	48.156	46
Cement	6.368	6
Wood	2.433	2
Plastic	363	0,3
Glass	225	0,2
Metal	479	0,5
Other	1	0,001
Plaster	6.230	6
Wool	35	0,03
TOTAL	104.850	100

envelope characteristics based on a building type are represented in Table 2.

The materials were categorized; moreover, their amount and percentage of the total were given in Table 3. As seen, concrete and brick produced the highest amount of wastes, which would be expected.

3.3.4. Operational energy demand

The operational energy demand of the buildings was obtained from detailed energy performance models. The results of the analyses for each building type are represented in Table 4. The buildings' energy consumption was calculated as final-energy,

Table 2
Building envelope and its specifications with thermal characteristic for a selected building.


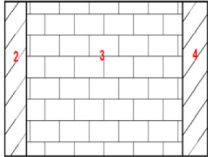
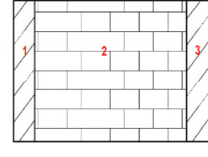
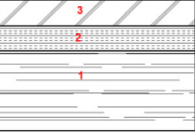
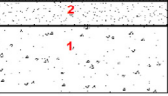
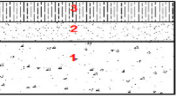
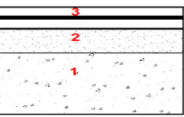

Envelope	Detail	
		
External wall	1. Internal paint 2. Internal plaster (2 cm) 3. Brick wall (25 cm) 4. External plaster (2 cm) 5. External paint U-value = 1.786 W/m ² K	
Internal wall	1. Internal plaster (2 cm) 2. Brick wall (15 cm) 3. External plaster (25 cm) 4. Paint (2 cm) U-value = 0.45 W/m ² K	
Roof	1. Pitched roof 2. Membrane (Waterproofing-3mm) 3. Tile U-value = 0.732 W/m ² K	
Ground floor	1. Concrete 2. Cement finish U-value = 2.839 W/m ² K	
Internal floor (Type 1)	1. Concrete 2. Cement finish 3. Tile finish U-value = 1.83 W/m ² K	
Internal floor (Type 2)	1. Concrete 2. Cement finish 3. PVC finish U-value = 1.83 W/m ² K	
Window	Single glazed U-value = 2.34 W/m ² K	

Table 4
Detail information of building types in the district.

Building Type	Gross area [m ²]	Number of building	Façade Area [m ²]	Energy Consumption (kWh/m ² .year)	BIM of the buildings	The image of the building
One-Story	421	6	241	107		
Two-story	703	32	436	103		
Three-story	986	33	632	81		
Duplex	217	8	237	95		
Single Lodging	1.350	1	645	139		
Guest House	1.678	1	942	106		
Convention Center	2.646	1	736	193		
Total	64.971	82				

Table 5
CED and GWP results of MSW.

Waste type	Unit	Transport	Recycle	Compost	Landfill	TOTAL
Glass	MJ/year	5971	-240,000	-	18,500	-215,529
	kgCO ₂ eq/year	339	-16,800	-	29,500	13,039
Metal	MJ/year	2180	-76,200	-	6780	-67,240
	kgCO ₂ eq/year	124	-8080	-	10,800	2844
Organic	MJ/year	59,040	-	34,356	195,208	288,604
	kgCO ₂ eq/year	3356	-	20,338	310,450	334,143
Other	MJ/year	11,317	-	-	44,943	56,259
	kgCO ₂ eq/year	643	-	-	71,500	72,143
Paper	MJ/year	10,700	-1,160,000	-	33,000	-1,116,300
	kgCO ₂ eq/year	608	-13,600	-	52,600	39,608
Plastic	MJ/year	8190	-1,240,000	-	25,400	-1,206,410
	kgCO ₂ eq/year	446	-32,300	-	40,400	8546
TOTAL	MJ/year	97,397	-2,716,200	34,356	323,831	-2,260,616
	kgCO ₂ eq/year	5516.583	-70,780	20,337.66	515,249.8	470,323

and results are provided as heating and electricity demand. Lignite is used as a heating energy source, and electricity is supplied from the current electricity grid in the district. They further investigated by LCA methodology to make a comparison between operational energy demand and waste management systems. Thus, the capacity for energy recovery potential from wastes compared with the energy consumption of buildings during their lifetime.

3.4. Life cycle impact assessment

SimaPro software was used to develop the LCA model, which operates with the Ecoinvent database (SimaPro V.8.5.0.0, 2018).

After the inventory lists were created for each waste type, all provided data were used as input data for the LCA model. Results were represented within two defined indicators; cumulative energy demand (CED), and the other was global warming potential (GWP). Thus, the primary energy demand of the current waste management system and emitted greenhouse gases were calculated.

CED: It represents the primary energy consumption of a system instead of final-energy consumption. Hence, a product, process, or system are investigated based on its primary energy demand. The unit of CED was defined as kWh in this study. Besides, the cumulative Energy Demand method was used for the calculation.

GWP: It is an indicator to show emitted greenhouse gases emission from a system. The most effective greenhouse gases are carbon dioxide (CO₂) and methane (CH₄) in the atmosphere. The unit of GWP is defined as kgCO₂ equivalent. It means that the greenhouse gas impact is converted to the kgCO₂eq. according to the defined constant. Thus, a comparison is made with literature in the same unit. Also, GWP was calculated by the IPCC 2013 GWP 100a method.

Results were also included CED and GWP from processes such as transportation, recycling, sanitary landfill, composting, and wastewater treatment. Also, MSW was investigated according to sub-categories of wastes such as organic, metal, while wastewater and demolition wastes were given in total.

3.4.1. Result of MSW potential

The capacity of MSW and its fraction were calculated as represented in the above section. As a result, the CED and GWP were evaluated. Based on CED results, there is an energy recovery potential from recyclable wastes, which comes from the glass as 215,529 MJ/year, from the metal as 67,240 MJ/year, from the paper as 1,116,300 MJ/year, and from the plastic 1,206,410 MJ/year. Nevertheless, the potential of paper and plastic is higher than glass and metal because of two reasons: the amount of sub-wastes and processes during treatment. While organic waste causes energy consumption with compost and landfill processes, the overall MSW results have an energy recovery potential of 2,260,616 MJ/year.

GWP results showed that the waste management system of entire sub-wastes release total 470,323 kgCO₂eq/year to the atmosphere. There are reduction potentials from recycling processes; nonetheless, these potentials are comparatively low when results of landfill processes were taken into account. The details of CED and GWP for each material are given in Table 5.

Table 6
CED and GWP results of wastewater.

Waste type	Unit	Wastewater treatment
Wastewater	MJ/year	23,630
	kgCO ₂ eq/year	1828

Table 7
CED and GWP results of demolition waste.

Waste type	Unit	Transport	Recycle	Landfill	TOTAL
Brick	MJ/year	4021	6257	130,269	140,547
	kgCO ₂ eq/year	236	408	231.817	232,461
Cement	MJ/year	728	1132	23,592	25,453
	kgCO ₂ eq/year	43	74	41,850	41,967
Concrete	MJ/year	6975	18504	225 662	251,142
	kgCO ₂ eq/year	408	1204	402.089	403,702
Glass	MJ/year	457	-18,422	519	-17,446
	kgCO ₂ eq/year	27	-15 18	15	-1476
Metal	MJ/year	1219	-48,210	3303	-43,688
	kgCO ₂ eq/year	72	-5313	5867	625
Other	MJ/year	2	-	67	69
	kgCO ₂ eq/year	0	-	26	26
Plaster	MJ/year	724	-17,109	23,387	7002
	kgCO ₂ eq/year	42	-2134	41,440	39,348
Plastic	MJ/year	373	-62,570	1007	-61,189
	kgCO ₂ eq/year	22	-1744	1791	69
Wood	MJ/year	175	1432	5662	7269
	kgCO ₂ eq/year	10	402	10,073	10,485
Wool	MJ/year	21	-	689	711
	kgCO ₂ eq/year	1	-	1225	1226
TOTAL	MJ/year	14,696	-118,986	414,158	309,868
	kgCO ₂ eq/year	861	-8620	736,193	728,434

3.4.2. Result of wastewater potential

After domestic wastewater is collected by the sewage system, it treats in a wastewater treatment plant that has biological treatment. The cumulative energy demand of treatment processes is 23,630 MJ/year. Released greenhouse gases to the atmosphere during the treatment processes is 1828 kgCO₂eq./year as they are seen in Table 6. The results showed that treatment of wastewater consumed energy and released greenhouse gases into the atmosphere. Nevertheless, untreated wastewater causes more environmental and health problems.

3.4.3. Result of demolition waste potential

Demolition waste results were obtained based on sub-waste types; besides, their results are given in Table 7 for CED and GWP.

While there are energy recovery potentials from different wastes, overall results showed that the waste management system for demolition waste consumes a considerable amount of energy. Recyclable materials (glass, metal, and plastic) have energy recovery potential. Similarly, when GWP results were considered, there is a global warming reduction potential from some recycling processes. However, overall results showed that the demolition waste management system released greenhouse gases to the atmosphere.

For both indicators, concrete and brick are the most negatively effective sub-wastes. In addition, cement has a substantial impact on both indicators. Additionally, metal and plastic have a remarkable impact on CED, and plaster impact is higher than others except for brick, cement, and concrete in GWP.

3.4.4. Result of operational energy consumption

Operational primary energy demand and global warming potential were calculated for the whole district, as represented in Table 8. Primary energy demand for the entire district for

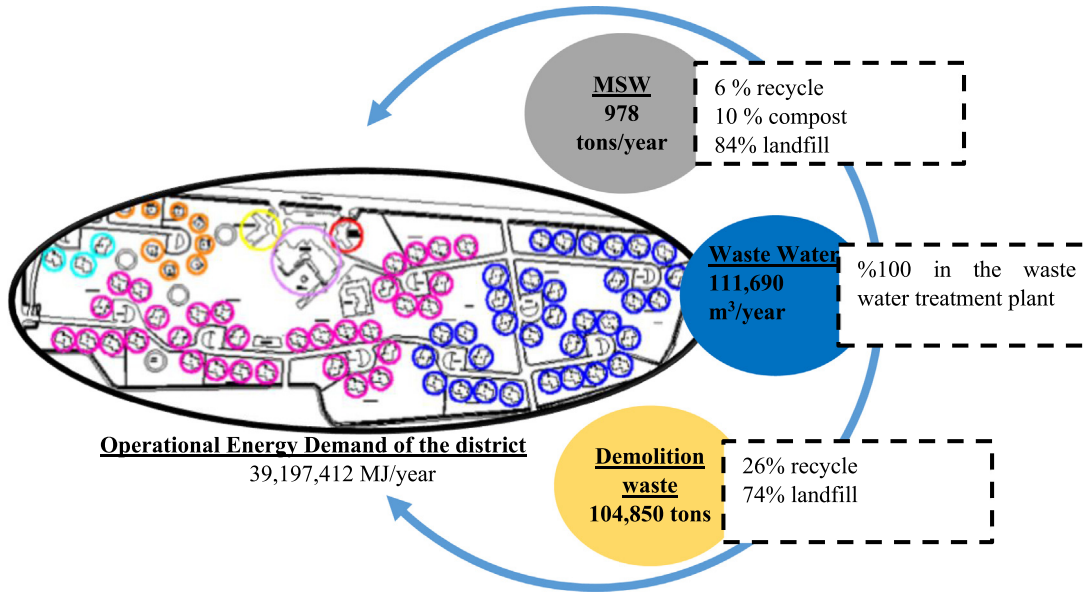


Fig. 6. Defined processes and amounts for waste types.

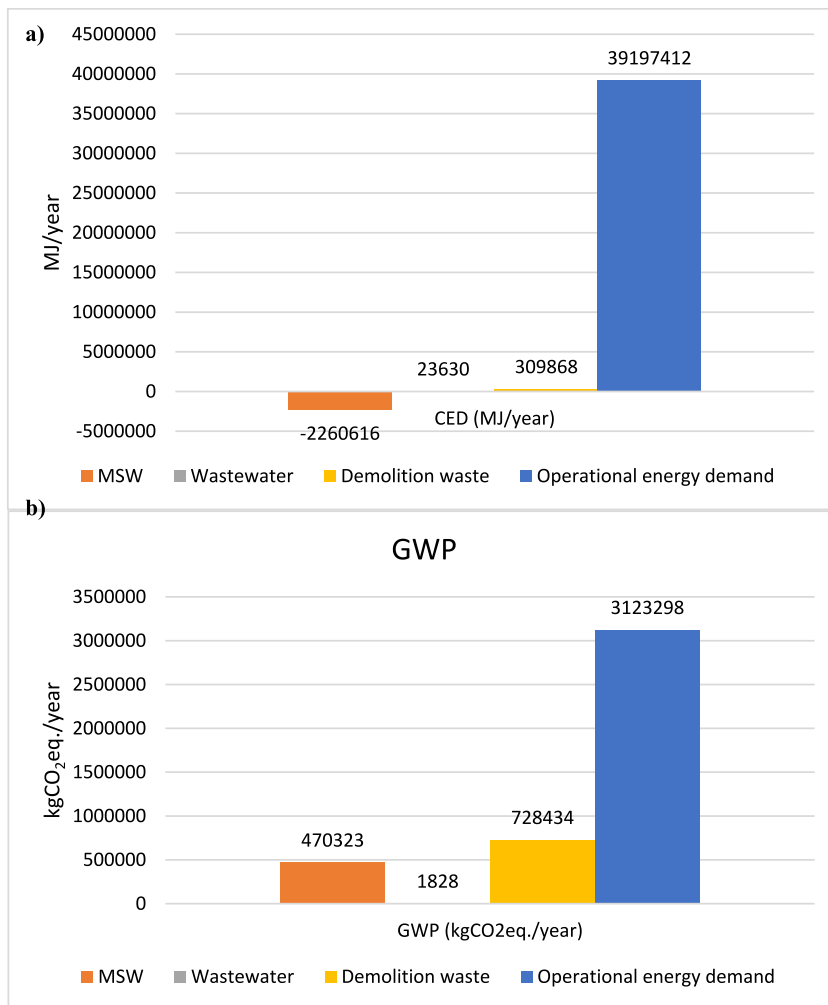


Fig. 7. (a) Comparison of CED results (b) Comparison of GWP results.

Table 8

CED and GWP results of operation energy demand.

Buildings	CED (MJ/year)	39,197,412
	GWP (kgCO ₂ eq./year)	3,123,298

operational energy demand is 39,197,412 MJ/year; besides, released greenhouse gases due to operational energy consumption is 3,123,298 kgCO₂eq./year.

3.5. Interpretation

After the results were obtained, they were investigated and interpreted. Contributions from different waste management processes on energy consumption and global warming potential were examined. The most impacted processes were mentioned. Also, comparisons were made between the current waste management system and operational energy consumption of the buildings to answer the question that is there any energy recovery potential from the waste management system to compensate for the operational energy demand of the building. In addition, processes in different waste types were compared based on defined indicators. Wastes capacities and their treatment processes were represented in Fig. 6. MSW has recycled and composting potential while almost 75% of demolition waste was proposed to send to landfill. The detailed results of the evaluation were represented in the results section.

Results were obtained based on defined wastes as MSW, wastewater, and demolition and their sub-wastes. Therefore, all processes and outcomes were represented separately.

3.5.1. Comparison of a waste management system and operational energy demand

After all, results were obtained, operational energy demand results and waste management system results were compared with each other to show energy recovery or greenhouse gas reduction potentials. The comparisons were given in Fig. 7.

Only MSW has energy recovery potential on the whole process. This potential could be compensated by only 5.8% of total operational primary energy demand annually. All other management systems consume energy in overall. Also, all waste management systems and operational energy consumption release greenhouse gases to the atmosphere; besides, there is not a reduction potential from the waste management system.

4. Conclusions

As represented, the selected district's wastes were grouped into three groups as MSW; wastewater and demolition waste; and each of them were investigated with the LCA methodology based on their energy flow and global warming potential by considering their current waste management procedures. In addition, operational energy demand was also examined to compare with them.

In Fig. 8a, CED results of all three waste management systems and operational energy demand were given based for buildings 50 years' lifespan. As seen, only MSW has energy recovery potential of 113,030,800 MJ/50 years. The other two waste management systems consume energy corresponding to 1,181,500 MJ/50 years for the wastewater and 15,493,400 MJ/50 years for the demolishing waste. Likewise operational energy consumption is 1,959,870,600 MJ/50 years. Therefore, energy recovery potential only comes from recycling processes. Moreover, this potential can compensate 5.8% of yearly operational energy consumption.

Fig. 8b, GWP results also were given for buildings 50 years' lifespan. The MSW process releases gases of 23,516,150

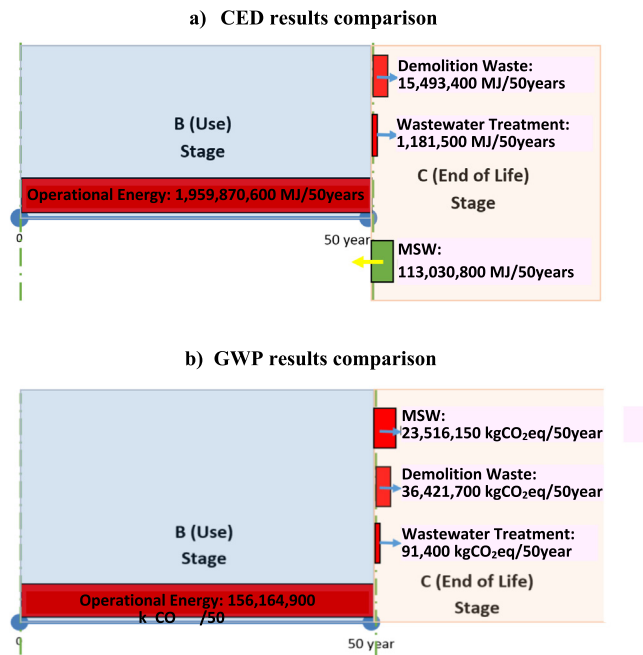


Fig. 8. Comparison of CED and GWP.

kgCO₂eq/50year, the wastewater process releases gases of 91,400 kgCO₂eq/50year, and the demolishing waste releases gases of 36,421,700 kgCO₂eq/50year. Likewise, for the operational energy demand of lifespan releases gases of 156,164,900 kgCO₂eq/50year.

Treatment processes were taken into account separately for whole management systems. Consumption and emission from transport processes are related to the amount of wastes. In addition, landfill processes release more greenhouse gases to the atmosphere than the other processes. Finally, the energy recovery rate and greenhouse reduction rate are low due to the recycling percentage. If the recycling percentage is increased in MSW and demolition waste management systems, recovery potential can increase directly.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Hatice Sözer: Conceptualization, Validation, Resources, Data curation, Writing - review & editing, Supervision. **Hüseyin Sözen:** Validation, Formal analysis, Investigation, Data curation, Writing - original draft.

Acknowledgment

The information of the selected district was taken from the European Union project that was called as "Replicable and innovative future efficient districts and cities (CITYFIED)" with the Project No: 609129 (CITYFIED, 2014).

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