Perspectives of energy recovery from food waste generated from hotels

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Abstract
The Food and Agriculture Organization defines food waste as food which was originally produced for human consumption but was not consumed by humans, instead it was directed into a non-food use as feed for animals or it was treated to anaerobic digestion plants or it was disposed at landfills. Aim of this manuscript was to present a system for evaluating the perspectives of energy recovery from food waste from hotels in the Region of Central Macedonia, Greece. 1,195 hotels with 88,196 beds were included in the capacity of tourist facilities of the Region. A daily average of 1.1 kg of food waste per customer was used for calculating waste from food preparation, buffet and customer plate leftover. The energy recovery was estimated by the utilization of the specific methane yield of food waste treated in anaerobic digestion plants, while the reduction of greenhouse gas impact from the hotels was calculated as well.

Keywords: Anaerobic digestion, energy recovery, food waste, hotel

1. Introduction
Waste management has become one of the largest environmental concerns in recent decades. The combustion of organic waste at higher temperatures need high levels of energy for the operation and more energy is consumed that can be produced. An alternative method of the elimination of organic waste was the anaerobic digestion. A clean fuel from renewable feedstock is provided by this process, which is divided into hydrolysis, acidification, liquefaction and transformation into methane of acetate, hydrogen and carbon dioxide (Fig. 1) [1-2].

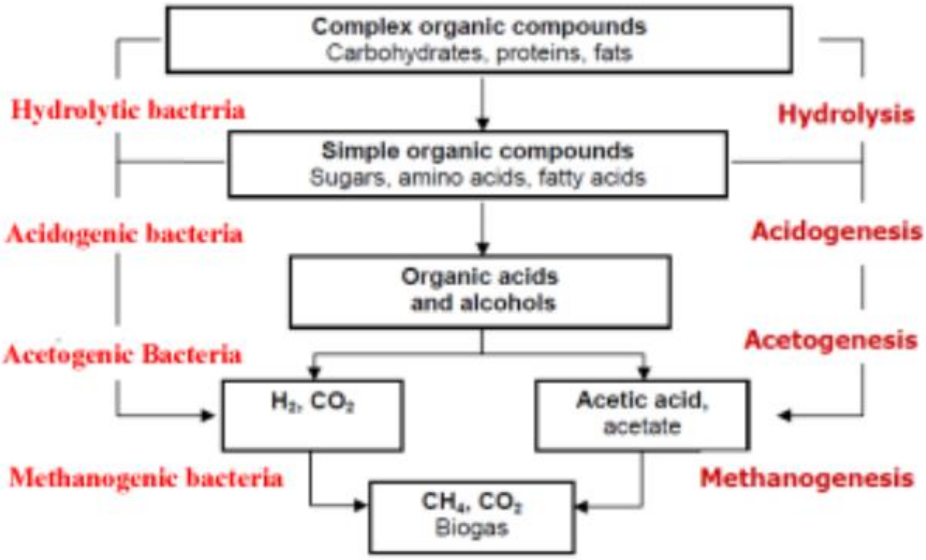


Fig. 1 Anaerobic digestion process [1].

Researchers discussed the food wastage in tourist hotels and its impact on sustainable hotel operations while a framework was proposed to identify and explain the patterns and drivers of food waste generation in the hospitality sector, with the aim of identifying food waste prevention measures [3-4].

The product group 'tourist accommodation' comprised the provision of tourist accommodation services and campsite services and any of the following auxiliary services under the management of the tourist accommodation provider [5]: (a) food services, (b) leisure or fitness facilities, (c) green areas, (d) premises for singular events such as business conferences, meetings or training events and (e) sanitary facilities, washing and cooking facilities or information facilities available to campsite tourists, travellers and lodgers for collective use.

The daily average of produced food waste per customer had been estimated to be 1.1 kg and divided into preparation, buffet and customer plate leftover waste (Fig. 2) [4].

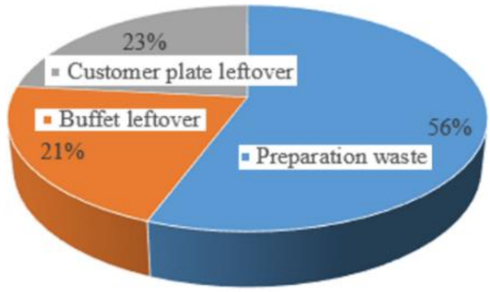


Fig. 2 Percentages of preparation, buffet and customer plate leftover waste in a hotel [4]

In 2016, the Plan for Waste Management was revised in the Region of Central Macedonia, Greece and data and information were presented about the hotel sector. Despite the fact that information was given for the number of beds, only the estimation for the produced sludge in waste water treatment plants took place [6]. Anaerobic digestion of biodegradable waste, co-incineration of waste in combustion plants (e.g. power plants) and in cement and lime production, waste incineration in dedicated facilities, production of waste-derived solid, liquid or gaseous fuels and other processes including indirect incineration following a pyrolysis or gasification step are included, in the main waste-to-energy processes [7]. According to European Commission’s study, in 2014 approximately 1.5 % of the total final energy consumption was met by recovering energy from waste through incineration, co-incineration in cement kilns and anaerobic digestion (i.e. around 676 PJ/year), while accordingly to relevant data, Europe counted with 17,240 biogas and 367 biomethane plants, as shown in Fig. 3 [8, 9].

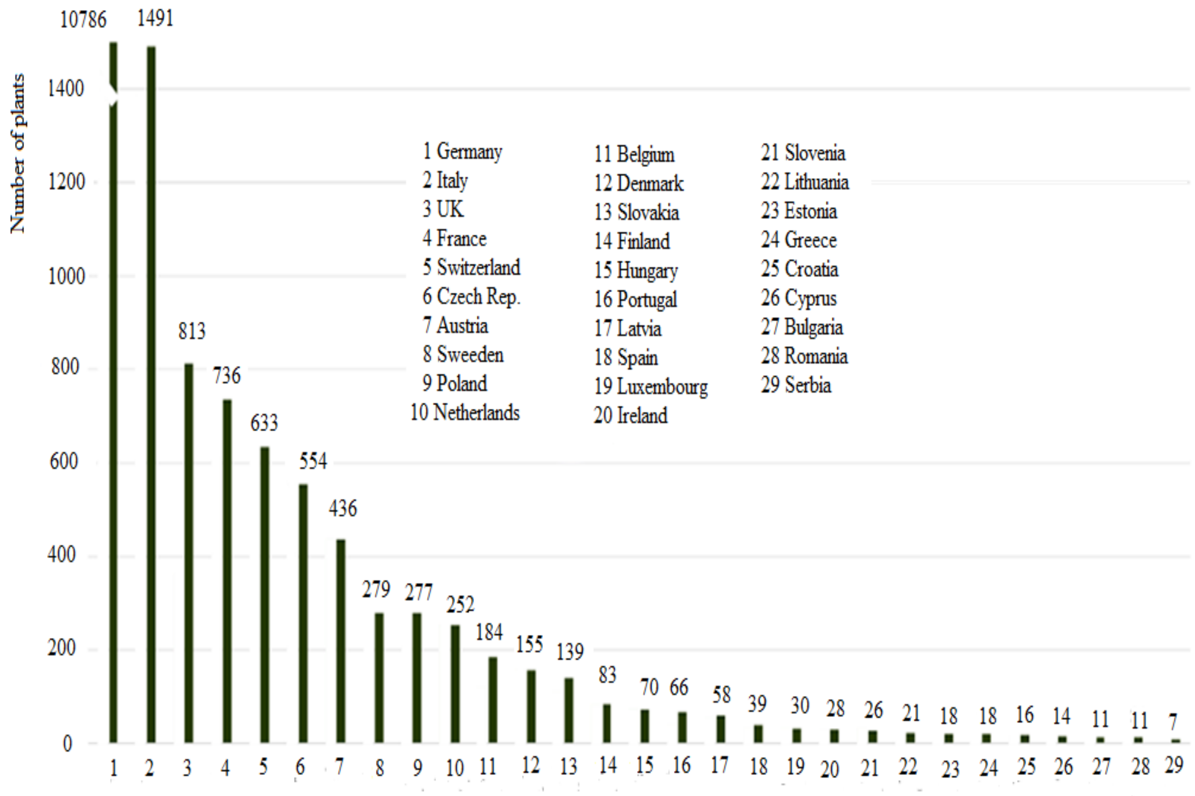
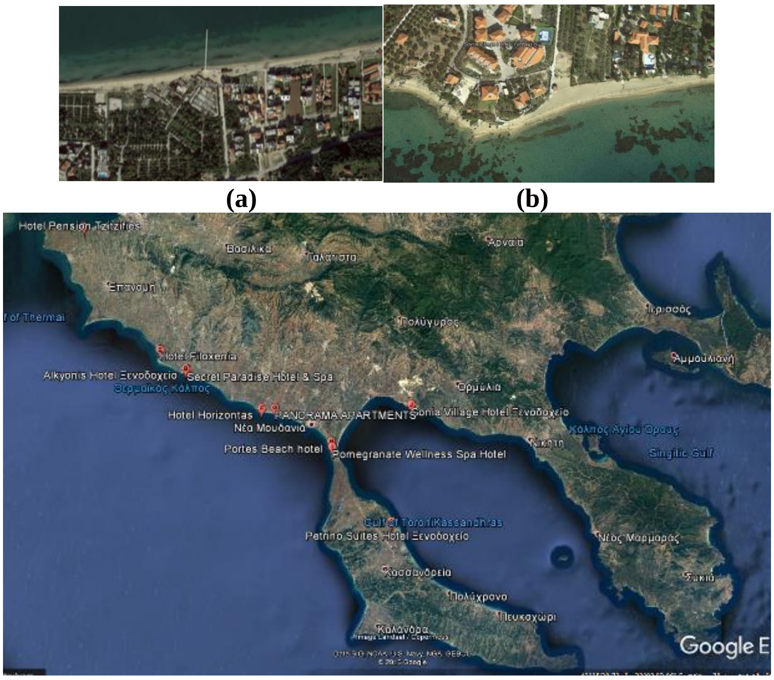


Fig. 3 Number of plants in each country in Europe in 2014 [9]

The aim of this study was to propose an economic and environmentally sustainable solution for energy recovery from food waste in hotels located in Central Macedonia, Greece, which is characterized by regional units with high tourist seasons, where hotels are located in urban and rural areas (Fig 3). As far as the methodology is concerned, the food waste quantities were calculated per each regional unit and then two options were proposed for the number and the location of anaerobic digestion facilities. Energy recovery and reduction of greenhouse gas flux were estimated in accordance with the each different option.



(a) (b)

(c)

Fig. 4 Examples of hotel location areas in urban (a) and rural (b) areas in Chalkidiki regional unit (c) (Source: Google Earth ®)

Materials and methods

2.1 Generation of food waste from hotels in the Region of Central Macedonia

Region of Central Macedonia is the largest region in Greece and its capital, Thessaloniki, is the second largest city in Greece in terms of population. The region has a population of 1,875,000 inhabitants, representing 17 percent of the country's population and produces 17 percent of the gross domestic product (second higher contribution after 37.7% of the region of Attica). In administrative terms, the Region of Central Macedonia is a public authority at the second degree of local government, operating at regional level. It is comprised of seven regional units (former "prefectures"): Chalkidiki, Imathia, Kilkis, Pella, Pieria, Serres and Thessaloniki. Its regional administration is structured at central and regional level. According to its structure, all the relative regional units organizationally belong to the central administration, which is seated in Thessaloniki (Fig 5). The total number of beds in hotels in the Region was estimated equal to 88,196 [6]. Chalkidiki had the most of them (46,495), followed by Pieria (20,089) and Thessaloniki (14,335) as it is shown in Fig. 6.

Fig. 5 The seven regional units of Central Macedonia: Chalkidiki, Imathia, Kilkis, Pella, Pieria, Serres and Thessaloniki.

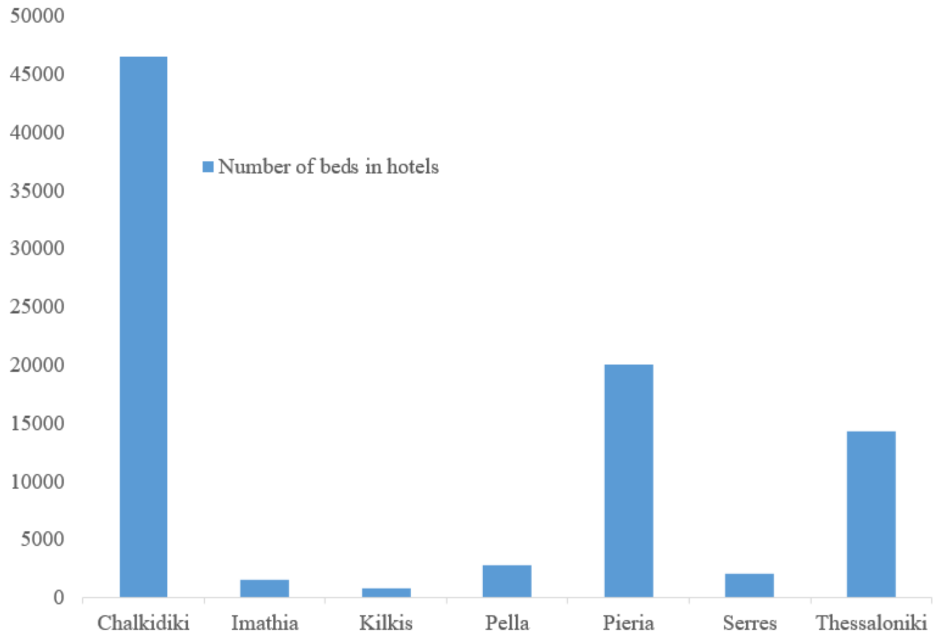


Fig. 6 Number of beds in hotels in the seven regional units of Central Macedonia.

The occupancy rate of beds in hotels during the tourist season has been estimated as 70% of hotels' capacity. An estimated sum of 68 t of food waste was derived by multiplying this percentage with the total number of beds (88,196) and daily average of produced food waste per customer (1.1 kg). The main food waste producer was the Chalkidiki (36 t/d) regional unit, with a percentage of 53% (Fig. 7 and Table 1).

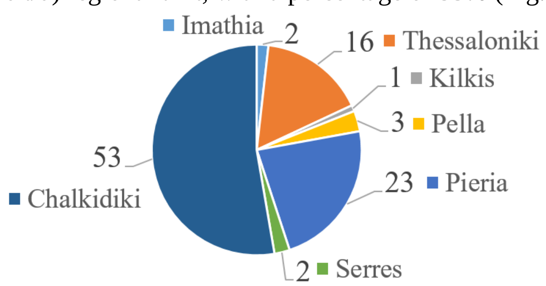


Fig. 7 Percentage of produced food waste in the regional units of Central Macedonia [6].

Table 1. Produced biowaste during the 6 months of tourist season in the regional units of Central Macedonia.

Regional unit	Number of beds in hotels	Produced biowaste (t/d)	Produced biowaste during 6 months (t)
Chalkidiki	46495	36	6444
Imathia	1586	1	220
Kilkis	825	1	114
Pella	2787	2	386
Pieria	20089	15	2784
Serres	2079	2	288
Thessaloniki	14335	11	1987
Total	88196	68	12224

2.2 Anaerobic digestion involved in food and other waste treatment

Numerous biogas plants have been involved in food waste treatment and have been constructed in recent years. Table 2 provides some of the crucial parameters of such projects in China.

Table 2. Anaerobic digestion pilot projects involved in food waste treatment [7]

Technical specifications	**Capacity**	**Estimated biomethane output** (10,000 m^3/year)
High-temperature hydrolysis, anaerobic digestion, co-digestion	Sludge: 435 t/d; food waste: 65 t/d	612-816
Co-digestion	Food waste: 500 t/d; sludge: 100 t/d; other bio-municipal solid waste: 50 t/d	1,429
Co-digestion	Sludge: 600 t/d and expired food	959-1,061
High-solids anaerobic digestion	Food waste: 300 t/d	551
Co-digestion	Sludge: 200 t/d; food waste: 50 t/d	306
Co-digestion	Food waste: 200 t/d; sludge: 250 t/d; dead livestock: 30 t/d	1,163
Co-digestion	Sludge: 300 t/d; food waste: 200 t/d	561
Impurity removal, oil-water separation, anaerobic digestion	Food waste: 2,200 t/d; sludge: 250 t/d.	1,470
Co-digestion	Biodegradable municipal waste: 600 t/d; food waste: 80 t/d	306
Co-digestion	Biodegradable municipal waste: 1,200 t/d; food waste: 500 t/d	571
Anaerobic digestion and pyrolysis	Sludge: 300 t/d; food waste: 200 t/d	561

The system economics that usually concerned anaerobic digestion facilities in the West were the following [8]: (a) tipping fees at operating plants varied from 40 to 100 Euro/t (the cleaner the feedstock lower the tipping fee), (b) capital expenses were different for each type of anaerobic digester and varied from 300 – 500 per installed annual ton of capacity and (c) operating expenses (2-3% of the capital expenses per ton processed). The mean value of the treatment cost of a facility with an annual capacity of 20 kt of biowaste was estimated to 62 Euro/t.

As far as the low budget biogas projects are concerned, the investment cost that was proposed by Chinese manufacturers for treating organic waste was the following:
(a) 0.3 million Euro for a 15 t/d food waste anaerobic digestion facility with a 50 kW generator (case 1) and
(b) 0.5 million Euro for a 38 t/d food waste anaerobic digestion facility with a 100 kW generator (case 2).
Thus, the treatment cost (Euro/t) in both cases 1 and 2 was calculated using the following equation (Fig. 8):

$$TC_{LC}=IC/(C\cdot LF) \quad (1)$$

where:
TC_{LC}: the treatment cost of low capacity anaerobic digestion facility for treating food waste (Euro/t);
IC_{LC}: the investment cost of low capacity anaerobic digestion facility (million Euro);
C: the annual facility capacity (t)
LF: the lifespan of the facility (20 years)

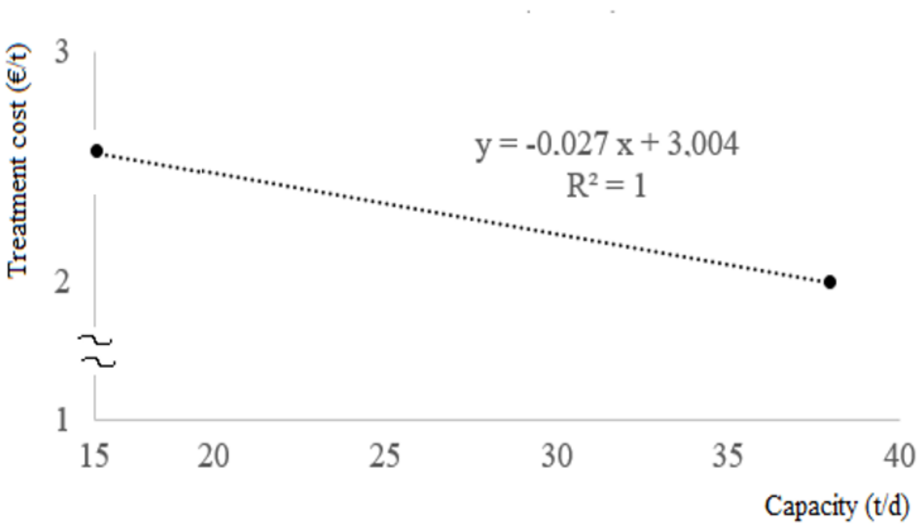


Fig. 8 Calculated treatment cost in low capacity anaerobic digestion facilities (15 – 38 t/d).

In accordance with a recent (2017) environmental assessment study in Greece, the cost for treating biowaste (14.6 kt cattle manure and 17.5 kt silage corn during the year) in an anaerobic facility project in Thessaly was amounted to 4.9 million Euro; with the application of equation (1), the treatment cost was calculated to be 5 Euro/t.

2.3 Contribution of anaerobic digestion process to climate

By diverting one tonne of biodegradable waste from a landfill towards anaerobic digestion to produce biogas and fertilisers could prevent up to 2 tonnes of CO_2 equivalent emissions as it was stated by a review of comparative Life Cycle Assessment of food waste management systems and by European Commission [10, 11]. Furthermore, the emission factor of 185 kg CO_2 eq./t of biowaste treated through anaerobic digestion was proposed by Smith et al. (2001) for calculating the total greenhouse gas flux, where the sum of fossil and sequestered C were taken into account [12].

3. Results

The potential of electrical energy recovery from produced biogas through the treatment of 12,240 t (= 30 days/month x 6 months x 68 t/day) of food waste was calculated to be 2,740 MWh in total during the six months of tourist season.

Table 3. Energy recovery potential during the 6 months of tourist season in the regional units of Central Macedonia.

Regional unit	**Number of beds in hotels**	**Produced biowaste** (t/d)	**Produced biowaste during 6 months** (t)	**Energy recovery during 6 months** (MWh)
Chalkidiki	46,495	36	6,444	1,444
Imathia	1,586	1	220	49
Kilkis	825	1	114	26
Pella	2,787	2	386	87
Pieria	20,089	15	2,784	624
Serres	2,079	2	288	65
Thessaloniki	14,335	11	1,987	445
Total	88,196	68	12,224	2,740

Two options could be available for the hotel industry to deal with the management of food waste. In accordance with the first option, the daily produced quantity of 68 t of food waste could be treated anaerobically for six months in one digestion facility in Chalkidiki that would have an annual capacity of 20,000 t. The same facility could serve the treatment of municipal or other kind of biowaste (as animal or agricultural waste) during the remaining months of the year (outside the tourist season). In this option, the total cost will run at least 25 million Euro, while the energy recovery was estimated to 15.2 GWh (=0,76 GWh/kt x 20 kt) per year.

In accordance with the second option, two low budget anaerobic digestion facilities could be located with lower daily capacities (from 15 to 38 t) in the borders of the following regional units: (a) Chalkidiki and Thessaloniki and (b) Pieria, Imathia and Thessaloniki. In this option, the total cost will run at least one million Euro, while the energy recovery could reach the sum of 1.2 MWh (= 0.4 + 0.8 MWh).

It follows from all the foregoing that the anaerobic digestion facilities will operate six months and thus they should receive other kind of organic waste as municipal solid biowaste, vegetable waste from food processing industry or animal manure during the rest months of the year, which should have a total sum of at least 8 kt/year (= 20 – 12 kt, c.f. the total sum of the column of ‘Produced biowaste during 6 months of Table 3).

Finally, the greenhouse gas emission savings by utilizing biogas from anaerobic digestion as a renewable energy source were calculated using the emission factor of 185 kg CO_2 eq./t of biowaste treated; these results are referred for each regional unit of Central Macedonia and concern only the six months of the tourist season (Fig. 9).

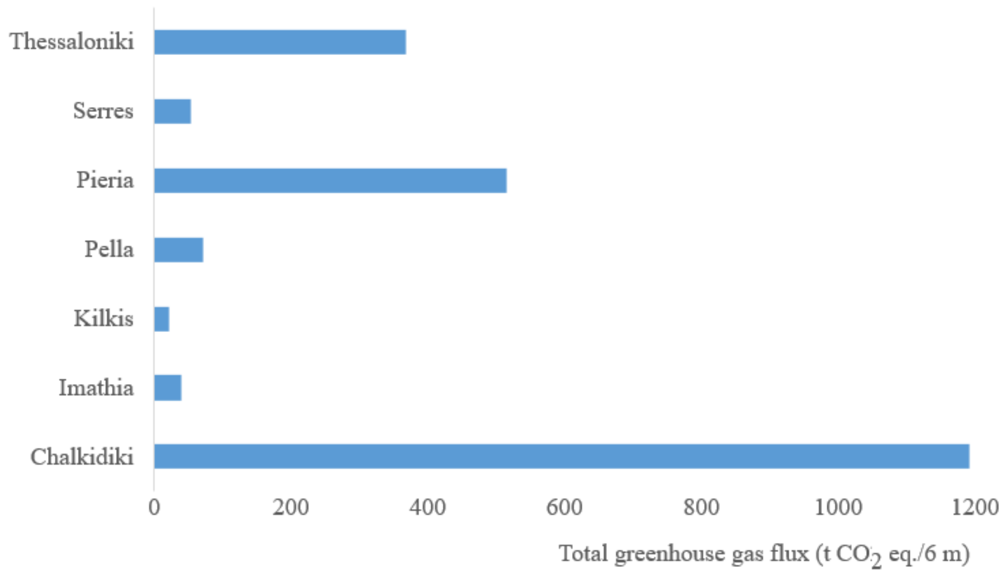


Fig. 9 The greenhouse gas emission savings from anaerobic digestion of hotel biowaste in the seven regional units of Central Macedonia during the tourist season of six months of the year.

4. Conclusions

The perspectives of energy recovery from food waste generated from hotels in the seven regional units of Central Macedonia were presented in the present manuscript. The anaerobic digestion treatment seemed to be an effective way for reducing the 8,923 t CO_2 eq. emitted from the current disposal to landfills of food waste from hotels during the tourist season in the regional units of Central Macedonia, Greece.

In case food waste from hotels is hauled to a centralized anaerobic digestion facility, the possible recovered energy of 2,740 MWh, during the 6 tourist months in a year, can be sold to the national grid and an economical benefit of 350,000 € can be achieved. Materials such as source-separated organics or other vegetable waste could be the income flow during the months of the year that do not belong to the tourist season.

In case low budget anaerobic digestion facilities will be utilized, then their installation capacity will be ranged from 15 to 38 t/day and they can provide solutions for food waste treatment. The amount of energy that can be recovered will be depended on their technologies that will vary considerably in their design, engineering and performance.

In both cases, the amount of food waste that has to be disposed in landfills in the regional units of Central Macedonia could be reduced by 10% w/w (68 t of food waste from hotels divided by the 35% w/w of 1,900 t of municipal solid waste that is produced daily as biowaste).

The total greenhouse gas emission savings from the anaerobic digestion of hotel biowaste in the seven regional units of Central Macedonia during the tourist season of six months were calculated to be 2,261 t CO_2 eq.

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