Original Research

Eco-Efficiency of Biowaste Management: Case Study of a Tehran Composting Operation

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Abstract

Composting has always been considered a way to optimize use of biodegradable wastes. The point which is perhaps less noticed is that this process is not necessarily always and everywhere economical. Energy consumption and greenhouse gas emissions are among factors that can impugn eco-efficiency of the process in composting factories. The present study is an eco-efficiency assessment of a composting factory in Tehran calculating the real economic and ecological efficiency of cthe omposting process by considering two main external burdens: energy consumption and greenhouse gas emissions over the period 2007-11. In this research, the instruction presented by the World Business Council for Sustainable Development [1] was followed up to quantify eco-efficiency indicators. The obtained results revealed that the composting factory experienced a negative energy eco-efficiency within the periods 2007-08 (-71.97%) and 2008-09 (-69.82%). In terms of CO_2 emission eco-efficiency, there were also inefficient periods in the plant in two time intervals: 2007-08 (-71.97%) and 2008-09 (-69.80%). Fortunately, this was a temporary situation so that at the ultimate year of 2011, the composting plant had an acceptable performance in terms of energy consumption (with an eco-efficiency of 166%) and CO_2 emission (with an eco-efficiency of 165.85%). Overall, although the composting process is an effective strategy for better use of resources, it will sometimes impose additional burdens on the environment if the external expenditures such as energy consumption and greenhouse gas emissions are neglected or less-intentioned.

Keywords: composting factory, eco-efficiency, municipal waste management, CO_2 emissions, energy consumption

Introduction

Composting has long been considered a strategy to dispose of food waste and recycle organic matter for improving structure and fertility of soil [2, 3]. It refers to the process of accelerated degradation of organic matter by microorganisms under controlled conditions, according to which the organic matter undergoes a thermophilic characteristic, resulting in eliminated pathogenic microorganisms and sanitization of organic waste [4-7]. The process can be applied either on a small scale known as "home composting" or in large scale so-called "centralized composting."

Centralized composting involves a variety of very common (constructing a pile of organic matter to let them degrade naturally) and advance technologies (vertical or horizontal reactors, rotating drums, etc.) [5-10]. Composting is one of the most common biological treatment processes of organic waste by which the organic substances are degraded by living micro-organisms. Aerobic decomposition of organic matter leads to compost

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products, which act as a soil conditioner and fertilizer in farming activities. The compostable materials should contain at least 25% volatile organic substances and 50% to 60% moisture. The pH should be between 5 and 8. The carbon-to-nitrogen ratio (C/N ratio (C:N)) should range between 20:1 and 40:1. These parameters have to be controlled and stabilized for municipal solid waste feedstock. Wastewater sludge can be added to municipal solid waste feedstock to meet better balance of C/N ratio and to increase the water content of municipal solid waste feed stock [8, 11]. Composting methods in general are categorized as either open non-mechanical composting (e.g. windrow or pile) or the closed-mechanical composting (e.g. silo-type or tunnel-type) [12, 13]. Despite the gains resulting from composting, there are a number of lesser known external costs affecting actual economic performance of centralized composting on a large scale. Accordingly, many researchers have focused on how to improve composting efficiency, reduce operating costs, and mitigate associated environmental damages [1]. Xi et al. examined the effects of inoculation methods on composting efficiency of municipal solid wastes. They finally concluded that inoculation of microbes in municipal solid waste and dry grass enhanced the biodegradation of aliphatics, proteins, and polysaccharides [14].

Xi et al. used a method to improve composting efficiency by seeding with Inoculum A (a blend of *Bacillus azotofixams*, *Bacillus megaterium,* and *Bacillus mucilaginosus*), Inoculum B (a blend of effective *cellulolytic strains*, i.e. *Trichoderma koningii*, *Streptomyces cellulosae*, and White-rot fungi), and Inoculum C (a mixture of Inoculum A and Inoculum B) [15]. Lu et al. examined the feasibility of high-rate composting of barley dregs and sewage sludge using a pilot scale bioreactor [13]. They used a central composite design to optimize the mix ratio of barley dregs/sewage sludge and moisture content. Zhao et al. presented a quantitative eco-efficiency analysis on municipal solid waste management in terms of greenhouse gas mitigation [16]. They concluded that the landfill gas utilization scenario would be a potential optimum scenario by the proposed eco-efficiency analysis. The necessity of paying attention to the environmental cost management system was also emphasized by Blengini et al.

Roberto Soares et al. assessed eco-efficiency of waste management in heathcare centers. They finally concluded that the microwave disinfection presented the best eco-efficiency performance among those studied and provided a feasible alternative to subsidize the formulation of the policy for small generators of healthcare wastes [17, 18].

Generally, all new methods, strategies, and approaches have been or are currently used to optimize waste management and the composting process in terms of both economic and ecological efficiencies [19]. The traditional view of efficiency focuses only on economic aspect while environmental issues of the modern world are an inevitable part of any analysis that must be given enough attention. In this respect, eco-efficiency (EE) assessment is a relatively new concept for sustainability analysis of waste management [20]. This could be quantified using indicators offered by the WBCSD (World Business Council for Sustainable Development) emphasizing economics and ecology as the ratio of "product or service value" in either economic term or mass production terms to "environmental burdens" [21].

The present study is an evaluation on eco-efficiency of a composting plant in Tehran Metropolitan City. Tehran is the capital city of Iran, with a population of 8.2 million, including 2.4 million households, generating 7,655 tons/day of solid waste in 2011. In recent years sustainable management of solid waste has seriously been considered by the municipality of Tehran so that the waste management organization (WMO) of Tehran has shifted toward decreasing landfill sites by enhancing the capacity of composting and recycling centers. According to the statistics of the WMO in 2010 [26], Municipal Solid Waste (MSW) includes 35% of dry waste in Tehran, 12-15% of which contains cans, glasses, PET (polyethylene terephthalate), papers, and metals that were recycled. The question now is whether such a large-scale composting factory has good efficiency or not. This will be answered by the research ahead.

Material and Methods

The Case Study Composting Factory

Arad Kouh Waste Processing and Disposal Complex (AKWPDC) are located in southern Tehran. With an area of nearly 1,400 ha, the center has processed the waste of Tehran City since 1976. Every day an average of more than 7,000 tons of waste is transferred into the center from a variety of sources including hospitals, healthcare centers, commercial sectors, etc.

The waste delivered in APDA, after being weighed, is sent to either a processing and composting plant or landfill sites. A major part of the wet waste in APDA, after passing through special equipment such as a crusher, vibrating screens, and metal absorption machines, is directed toward a fermentation site as feedstock organic matter for compost production. The composting process is done in APDA based upon open windrow method by which pills are agitated or turned in a regular manner. The wind-rows are 90 cm in height and 400 in width. Loaders with a long reach can build high wind-rows. Turning machines produce low, wide wind-rows. The top-turn mixing machines are used to control the moisture and aerate compost heaps. After a period of 2 months from the initial date of onsite processing the organic matter will be converted into compost along which other parameters such as humidity, temperature, moisture, etc. are controlled so as to meet the C/N of 25 to 30. It is required to keep the optimal moisture of 50-60% at starting and during the processing period. The moisture was measured by humidity meter at a depth of 90 cm [22]. It is worth noting that the APDA fermentation site, with an area of approximately 22 ha, is the largest fermentation site in the Middle East launched in 2008. A general schema of the waste management system in Tehran is depicted in Fig. 1.

Research Methodology

In the present study, all the relevant standards, instructions, and methods were initially collected in a database through literature reviews. The factory was visited for several times in order to get more familiar with the composting process, quantity and quality of input waste, all types of energy sources consumed, and CO_2 emissions. It should be mentioned that the data gap on energy consumption and conflicts of revenues from selling compost products was filled by observations, calculations, and interviews with officials and experts as well as reports and databases available in the factory. The research variables include the "amount of compost production" as an indicator for economic efficiency, and the "amount of consumed energy" and "CO_2 emissions" as indicators for environmental efficiency. After determining research variables, the eco-efficiency index was calculated through the following three steps:

Step 1: eco-efficiency assessment

In this research, the instruction presented by the WBCSD was followed to assess the eco-efficiency of the composting process in APDF using Eq. 1 [21-23].

$$EE_n = \frac{PQ_n}{\sum EN_{n,m}} \quad (1)$$

...where:

EE_n – eco-efficiency of the APDF

PQ_n – an indicator for economic efficiency representing total compost produced by a factory (tons)

$EN_{n,m}$ – environmental efficiency indicator

m – all environmental impacts caused by the composting process

'n' – the target composting factory

$\sum EN_{n,m}$ is a function (f) of total independent the environmental impacts in m types resulting from the composting process (e.g. energy consumption, CO_2 emissions calculated through Eq. 2)

$$\sum EN_{n,m} = f\left[\sum_{t=1}^{r} E_t , \sum_{t=1}^{r} (CO_2)_t \right] > 0 \quad (2)$$

...where: 't' denotes total sum of environmental impacts and 'r' is a symbol for all types of energy sources used. $\sum_{t=1}^{r} E_t$ is total energy consumption supplied from 'r' different sources, $\sum_{t=1}^{r} (CO_2)_t$ is total emission from 'r' types of energy sources.

Fig. 2 illustrates the conceptual model followed up to assess eco-efficiency of the composting process in APDF.

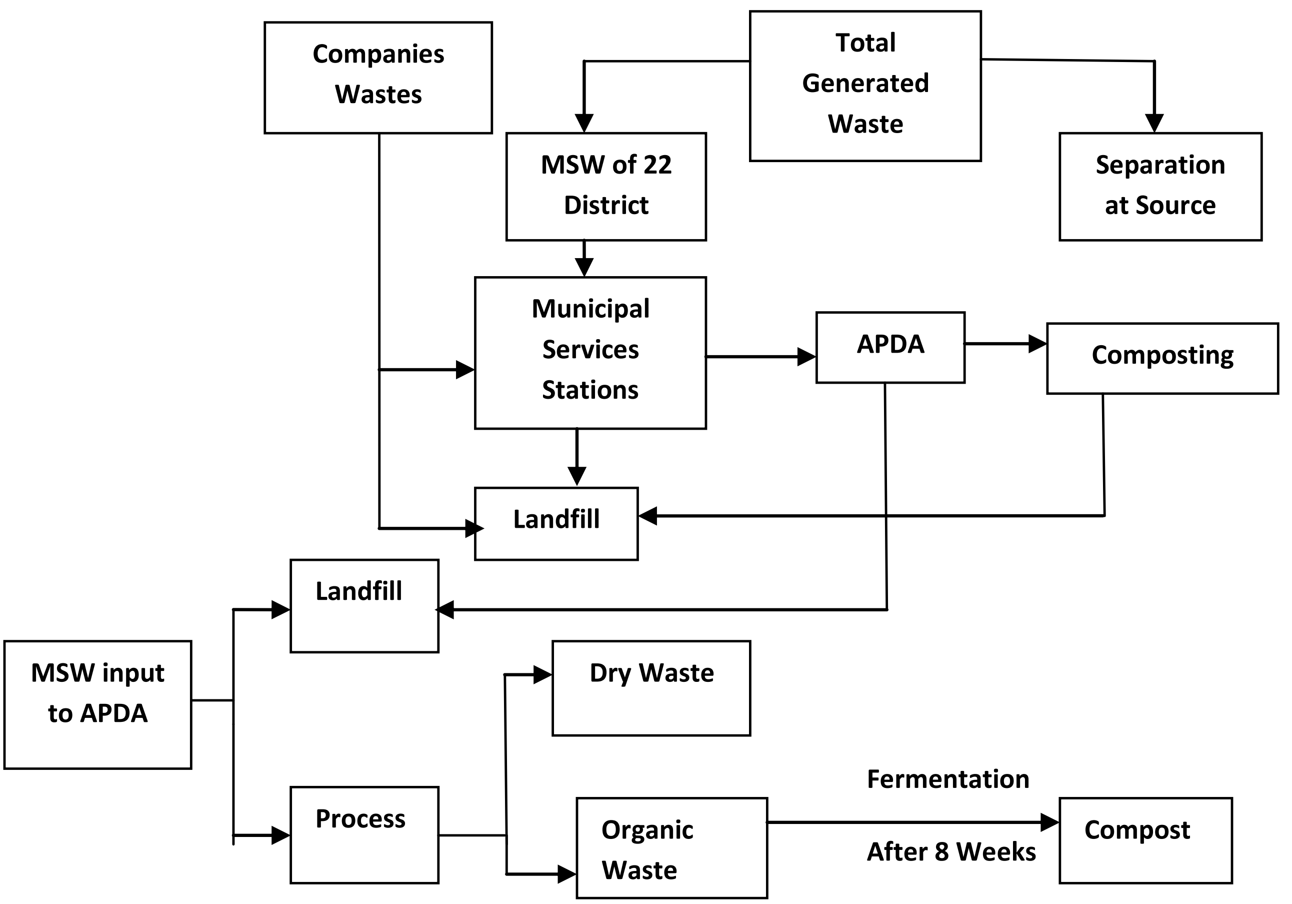


Fig. 1. Waste management system in Tehran and APDA.

Step 2: energy consumption eco-efficiency indicator

Energy consumption is one of the environmental burdens increasing the external cost of composting. Calculating total amount of energy consumption including fossil fuels and electric power by the compost production process, the annual eco-efficiency of energy consumption ($EE_{n(E)}$) was computed by Eq. 3 in 2007 and 2011.

$$EE_{n(E)} = \frac{PQ_n}{\sum_{t=1}^{r} E_t} = \frac{PQ_n}{(E_{n1} \times CF_1 + E_{n2} \times CF_2)} \quad (3)$$

...where PQ_n is the amount of compost production in the APDF (tons), representing total energy annually used in the composting system, $\sum_{t=1}^{r} E_t = (E_{n1} \times CF_1 + E_{n2} \times CF_2)$ which (E_{n1}, E_{n2}) in which (E_{n1}, E_{n2}) refers to the electricity and gasoil energies used in the composting factory, while (CF_1, CF_2) represent relevant conversion factors used to convert all energy sources including electricity in terms of Kwh and gasoil in terms of liters into a common unit of Giga-joules (GJ [24]. It should be noted that energy eco-efficiency is declared in tons/GJ.

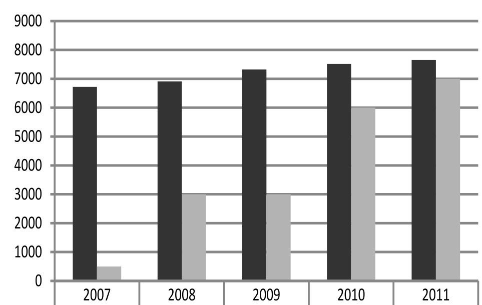
Step 3: CO_2 emission eco-efficiency indicator

Energy consumption by the factory could lead to a release of a considerable amount of CO_2 into the atmosphere. As one of the most important greenhouse gas emissions causing an environmental burden, it should be taken into consideration in calculations. Eq. 4 indicates how to measure the eco-efficiency of CO_2 emissions [$EE_{n(CO_2)}$] on an annual basis from 2007 to 2011. It is worth mentioning that the air quality analysis of the composting process at ARDA is done based upon clean air standard methods ASTMD 4096 and ASTMD 4536.

$$EE_{n(CO_2)} = \frac{PQ_n}{\sum_{t=1}^{r} (CO_2)_t} = \frac{PQ_n}{(E_{n1} \times CF_1 + E_{n2} \times CF_2)} \quad (4)$$

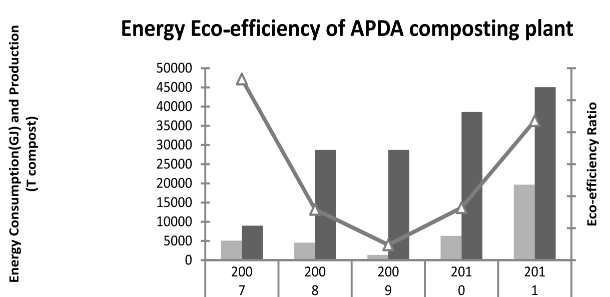
...where:

PQ_n – is the total amount of compost produced by the factory (tons), $(CO_2)t$ represents total carbon dioxide (CO_2) emission per year released from the composting process, (E_{n1}, E_{n2}) are a variety of energy sources, including electric and fossil fuels used by the composting factory, and (CF_1, CF_2) indicate emission conversion factors for converting the energy consumption to the equivalent weight of carbon dioxide (tons of CO_2 eq.) [25]. Accordingly, the eco-efficiency of emissions was calculated based on tons of CO_2 compost/tons of CO_2 equivalent.



	2007	2008	2009	2010	2011
Generated MSW (Ton/Day)	6719	6910	7324	7517	7655
Processed waste (Ton / Day)	500	3000	3000	6000	7000

Fig. 2. Municipal solid waste generating and processing trends at APDA over a period of 5 years.



	2007	2008	2009	2010	2011
Production (ton/year)	5083.5	4560	1377	6330	19662
Energy consumption (GJ/year)	8977	28726.5	28726.5	38601.5	45065.8
Energy ecoefficiency (ton/GJ)	0.5663	0.1587	0.0479	0,164	0.436

Fig. 3. Energy eco-efficiency indicator of APDA.

Results and Discussion

Waste Analysis of Tehran

As mentioned earlier, for an eco-efficiency assessment of APDA it was necessary to carefully study the quality and quantity of the municipal solid waste of Tehran, whereas the APDA is the only waste composting center of the city. This was done through literature reviews as well as the database of WMO. The results indicated that around 6,910 tons of waste was daily generated in the city in 2008, which was equivalent to 746 g per capita per day. This indicates the annual growth rate of waste generated in Tehran could be approximately 2.055% by the year 2008 [27]. As a subsidiary of Tehran Municipality, the WMO is in charge of collection and treatment of all types the waste such as industrial, hospital, and domestic wastes. In 2009 the WMO provided the "Integrated Plan of Tehran Municipal Waste Management" in which minimization of waste generation and maximization of recycling and reuse rates were underscored through emphasizing on composting and segregation at the source. In order to achieve the goals outlined in the plan, lots of actions were put on the agenda by the relevant authorities of which can be pointed to "plan for mechanization of municipal solid waste collection system" or "programs for training residents," according to which, face-to-face or mass media training strategies were adopted. These actions have had a significant effect on public participation in terms of segregation at the source, resulting in optimal disposal of waste materials. All wastes collected from 22 districts of Tehran are transported to APDA. Currently the main approaches for waste management in APDA include landfilling and composting. The wastes rejected from compost processing lines are transported to the landfill site for final disposal. Currently, there are a total of 11 waste collection stations in Tehran wherein the waste from all districts of Tehran are stored temporary. The collected waste is loaded onto semitrailer trucks to be transferred to APDA, which is approximately 30 km from the city. Because of the traffic jam during the day, most of these transportations are done during the night. According to the official statistics of the WMO, the total volume of municipal solid waste managed in the APDA in 2011 was 7,655 tons/day. The composition of Tehran's municipal solid waste in 2008 is presented in Table 1. As the table suggests, organic materials include over 68% of the entire solid waste in Tehran. The high volume of the organic materials indicates high potential of the waste for being composted. The APDA has been equipped with the latest composting technologies and machineries. In the composting process, first of all, the organic materials separated from dry waste are composted through an aerobic fermentation process. Dry wastes are then returned back to the recycling process. The capacity of the processing lines at APDA was increased from 500 tons/day in 2007 to 7,000 tons/day by 2011, and in consequent compost production was increased from 150 tons/day in 2007 to 1,020 tons/day in 2011, capitalized by private sectors in light of the WMO policies on enhanced recycling and composting capacity. Fig. 2 gives an overview of municipal solid waste generation and processing trends at APDA from 2007 to 2011. The figure reveals the fact that only a small fraction (500 tons/day, equal to 7.4%) of 6,719 tons/day total waste was processed at the factory by the year 2007. This difference was reduced significantly with time to reach its minimum in 2011, so that the annual processing capacity of the municipal soil waste was increased by approximately 92% in APDA in 2011, and it is still keeping an upward trend.

Energy Eco-Efficiency of APDA

According to the instruction by WBCSD, 2000, the indicators for environmental impacts include energy consumption, water consumption, use of raw materials, greenhouse gas emissions, and emissions of ozone -depleting substances. Since the composting process in the factory involves no water consumption and use of raw material, and there are no emissions of ozone-depleting substances, energy consumption and greenhouse gas emissions were considered as two environmental indicators for eco-efficiency assessment. Gasoil is a major source of energy consumption in factories, so CO_2 was considered a main greenhouse gas emission. It should be noted that the main aim of the present study is eco-efficiency assessment of the compost process to help decision-makers review factory efficiency within the operational period and make up decisions that lead the factory toward more sustainability. These tow indicators would be sufficient to meet the goals. The measured indicators are limited to the system boundary. In this research, CO_2 emitted from the combustion of fossil fuels was measured due to two reasons: 1) electricity consumption is very low compared to fossil fuel so that it can be said gasoline consumption share in CO_2 emissions is ignorable, and 2) electricity is generated beyond the boundary of the factory.

Energy consumption is one of the restricting factors of the natural environment so it was considered one of the environmental burdens in this research. The major energy sources in APDA are electricity and gasoline. The consumption rate of each energy source was calculated for the period 2007-11. Afterward, using converting coefficients, total energy consumption at the factory was converted to the same unit of GJ.

Fig. 3 demonstrates eco-efficiency of energy consumption in APDA 2007-11. Based on the figure, energy consumption was increased from 8977 GJ in

Table 1. Composition of municipal solid waste of Tehran in 2008.

Waste component	Share of total (%)	Waste component	Share of total (%)
organic matter	68.3	nonferrous metals	0.4
bread	4.4	fabric	1.2
plastic	2.6	glass	1.9
PET	1.2	wood	0.4
nylon	3.2	rubber	0.3
talc	0.6	leather	0.1
foam	0.2	soil	0.5
paper	5.5	tetra pack	0.3
cardboard	4.2	special waste	2.5
ferrous metals	2	other	0.2

Table 2. Changing trends of eco-efficiency indicator in APDA over the period of 2007-11.

Year	2007	2008	2009	2010	2011
processing capacity (tons/day)	500	3,000	3,000	6,000	7,000
Production of compost (tons/year)	5,083.5	4,560	1,377	6,330	19,662
% Change in production		(2007-08) -10.30% (↓)	(2008-09) -69.80% (↓)	(2009-10) 359.70% (↑)	(2010-11) 210.60% (↑)
Energy consumption (GJ)	8,977	28,726.5	28,726.5	38,601.5	45,065.8
% Change in energy consumption		(2007-08) 250% (↑)	(2008-09) 0% non change	(2009-10) 35.70% (↑)	(2010-11) 18.40% (↑)
Energy eco-efficiency (Ton/GJ)	0.5663	0.1587	0.0479	0.164	0.436
Comparison of eco-efficiency		(2007-08) -71.97% (↓)	(2008-09) -69.82% (↓)	(2009-10) 242.38% (↑)	(2010-11) 165.85% (↑)
CO2 emission (Ton of CO_2 eq./Year)	665	2128	2128	2859.5	3339
% Change in CO_2 emission		(2007-08) 220% (↑)	(2008-09) 0% non change	(2009-10) 34.40% (↑)	(2010-11) 16.80% (↑)
CO_2 emission eco-efficiency (Ton compost/Ton of CO_2)	7.6444	2.1428	0.6471	2.2137	5.8886
Comparison of eco-efficiency		(2007-08) -71.97% (↓)	(2008-09) -69.80% (↓)	(2009-10) 242.10% (↑)	(2010-11) 166% (↑)

(↑), Increasing; (↓), decreasing

2007 to 28726.5 GJ in 2008. This indicates a considerable increase of 250% as a result of increased capacity of processing lines. The factory experienced a constant period in energy consumption between the years 2008 and 2009, whereas there was no change in the processing capacity. The capacity was raised again to cause dramatic changes in energy consumption from 28,726.5 GJ in 2009 to 38,601.5 GJ in 2010 (equal to 35.70%), and 45,065.8 in 2011 (equal to 18.40% over the previous year). A decline of 97.71% in energy efficiency between 2007 and 2008 would be a consequence of a dramatic increase of 250% in energy consumption due to increased processing capacity. Furthermore, lack of adequate equipment for refining compost and the occurrence of unanticipated events such as malfunction machines and devices made the situation even worse. It should be mentioned that the commercial sector of the factory had somewhat poor performance on the matter as it experienced a fall of 10.3% in selling the compost products.

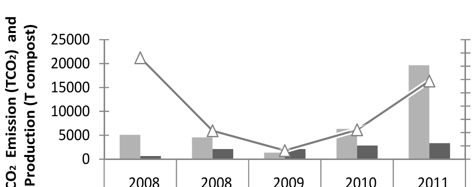
Overall, energy consumption in the factory has kept a downward trend. Among the factors affecting decreased energy consumption we can point to replacement of fans with top-turns as well as the establishment of an open fermentation site, which has a great share of energy savings in the factory. Power consumption by the factory includes fans, mills, electric screens, conveyors, and a lighting system. By the second half of the year 2008, fans, as the only aerating tool of fermentation, were excluded from the process. By establishing an outdoor fermentation site in the complex, top-turns were used for aerating purposes. Moreover, with the launch of new processing lines as well as increasing grading size, the mills were removed from the production line as well. Thereby both aforementioned processing changes have reduced power consumption in the factory. Gasoil consumers in the factory mainly include heating equipment and machineries such as loaders, trucks, top turns, and diesel-fueled screens. Given the climatic conditions of Tehran, the outdoor fermentation alternative seems reasonablel year round. By precipitation in cold seasons the heaps act like a sponge and this delays the fermentation process just a few days. In summer sunshine the mass is dried to a depth of 10-15 cm, which acts as a cover and keeps wet the layers underneath the mass. Therefore, the fermentation process is continued. Accordingly, the outdoor situation would not be that influential. Construction of the outdoor fermentation site has imposed a large impact on the aerating process so that the fuel consumption of top turn has considerably decreased and consequently a lower CO_2 emission was released into the surroundings.

CO_2 Emission Eco-Efficiency of APDA

The main sources of CO_2 emissions in the factory include all the gasoil-fueled machineries such as truck sand loaders for windrow-making as well as loading, transporting, and unloading of waste and compost, top turns aerating compost heaps, compost refining machineries, and diesel screens of the processing units. The results of CO_2 emissions by APDA are shown in Fig. 4. The obtained results indicated that there was an increase of 22% in CO_2 emission from 665 tons CO_2 equivalent in 2007 to 2,128 tons CO_2 equivalent in 2008. This was due to an increase in energy consumption. After over a year of no change in CO_2 emissions 2008-09, a considerable increase of 34.40% occurred so that the CO_2 emissions rose to 2,859.5 tons CO_2 equivalent in 2010 and reached its peak at 3,339 tons CO_2 equivalent by 2011. Since the majority of energy requirements in the factory are supplied from gasoil fuel and the main cause of releasing CO_2 emissions in the factory is fossil fuel, the trend of CO_2 emissions would be a function of energy consumption. Consequently, CO_2 emissions had generally a downward trend from 2007 to 2011. This was mainly due to construction of an open fermentation site and savings in energy consumption by top turns.

Taking a close look at the results, it was concluded that CO_2 emissions had not always positive efficiency within 2007-11 so that it experienced a decline of 71.97% from 2007 to 2008. Such a reduction was first due to decreased compost generation of 10.3% and then in consequence of a significant increase of 220% in CO_2 emissions. From 2008 to 2009 there was also another decline of 69.80% in efficiency of CO_2 emissions. This was strictly influenced by economic factors whereas CO_2 emissions had no changes within this period of time. The emission efficiency raised 242.10% as a result of increased production of 359.70%. It could overcome an increase of 34.4% in CO_2 emissions this year. In spite of an increase of 16.80% in CO_2 emissions from 2010 to 2011, there occurred growth of 166% in eco-efficiency of CO_2 emissions due to an upsurge of 210.60% in compost production.

In general, energy eco-efficiency of the APDA had a downward trend within the periods 2007-08 and 2010-11 (Table 2). The capacity of the processing lines was doubled in 2009, which led to increased energy consumption equal to approximately 35.70%. In spite of increased energy consumption, an increase of 359.70% in generating and selling compost products by 2010 was achieved by cooperation and assistance of the private sector and authorized contractors, the eco-efficiency of the factory was positive. Therefore, a sharp rise of 242.38% was observed in energy efficiency from 2009 to 2010, which is the highest amount of eco-efficiency within the studied period. Although no changes occurred in processing capacity and energy consumption between 2008-09, there was a decline of 69.80% in overall tonnage of the compost sales over the previous year. Accordingly, in this year, economic parameters have a greater influence than environmental factors in determining energy eco-efficiency, which was estimated equal to 69.82%. There was an increase of 165.85% in energy eco-efficiency between 2010-11. This was mainly due to an enhanced economic performance indicator equal to 210.60%, which could overcome the increased energy consumption (18.40%) compared to the previous year. At that time, the eco-efficiencies of CO_2 emission and energy consumption were almost aligned. Such an alignment would be expected whereas the main factor of CO_2 emission is fossil fuels and the main energy consumption source in the factory is gasoil.



	2008	2008	2009	2010	2011
Production (tons/year)	5,083.5	4,560	1,377	6,330	1,9662
CO_2 emission (tons CO_2 eq./year)	665	2,128	2,128	2,859.5	3,339
CO_2 emission eco-efficiency	76,444	21,428	0.6471	22,137	58,886

Fig. 4. CO_2 emission eco-efficiency indicator of APDA.

Conclusion

Composting has always been considered a commonly used appropriate strategy of sustainable waste management in the world, especially when organic materials constitute a significant percentage of total waste. The present study was carried out to show this approach is not necessarily efficient always and everywhere.

Revealing the fact that energy and CO_2 emission eco-efficiencies of the APDA had a downward trend in two periods, 2007-08 and 2010-11, it was outlined that composting sometimes is inefficient when all the environmental burdens caused by the composting process are quantified and valuated.

Overall, although the composting process is an effective strategy for better use of resources, it will sometimes impose additional burdens on the environment if external expenditures such as energy consumption and greenhouse gas emissions are neglected or less-intentioned. In a study by Friedrich and Trois in 2011, greenhouse gas emissions from waste processing in developing countries were compared to that of developed countries [28]. They concluded that highest GHG savings are achieved through recycling, and these savings would be even higher in developing countries that rely on coal for energy production (e.g. South Africa, India, and China) and where non-motorized collection and transport is used. Zhong et al. knew it as a cost-efficient way for animal manure management in China, even considering GHG emissions [29]. Their results are in line with the findings of the present study evaluating the overall situation of composting process in Tehran as cologically efficient.

The high volume of the organic materials, which exceed 68% of the entire solid waste in Tehran, indicates high potential of the waste for being composted. There are involved several concealed burdens affecting real cost-benefit of composting in Tehran. The composting process could be quite an appropriate strategy in the city if energy consumption and greenhouse gas emissions released will be controlled. There would also be a major problem with the culture of waste management in Iran among both planners and citizens. A variety of procedures should be adopted to meet the objective of sustainable solid waste management in Tehran. As such, citizens must learn how to minimize their waste to the least possible. They should also respect observations of separation at origin. This is in line with the findings of a study by Abduli in 1995. In this regard, fines and incentives could be a very good driving factor [30]. Recycling and reusing materials would be another proper alternative in this case. In general, achieving sustainable waste management in Tehran would not be possible unless implementing an integrated approach, which simultaneously focuses on culture-building, separation at origin, composting (conditional on compliance with environmental standards), reusing and recycling, and land filling. A similar conclusion was reported by Mahdavi Damghani in 2008 [31].

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References

1. WBCSD. Eco-efficiency: creating more value with less impact. World Business Council for Sustainable Development, Geneva, **2000**.
2. LI ZH., LU H., REN L., HE L., Experimental and modeling approaches for food waste composting: A review. Chemosphere. **93** (7), 1247-1257, **2013**.
3. BAI J., SHEN H., DONG SH., Study on eco-utilization and treatments of highway greening waste. Procedia Environ. Sci. **2**, 25-31, **2010**
4. LAZCANO C., GOMEZ-BRONDON M., DOMINGUEZ J., Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere **72** (7), 1013-1019, **2008**.
5. ANDERSEN J. K., BOLDRIN A., CHRISTENSEN T. H.,SCHEUTZ C., Home composting as an alternative treatment option for organic household waste in Denmark: An environmental assessment using life cycle assessment-modeling. Waste Manage. **32** (1), 31-40, **2012**.
6. BUTTOL P., MASONI P., BONOLI A., GOLDONI S., BELLADONNA V., CAVAZZUTI C., LCA of integrated MSW management systems: case study of the bologna district. Waste Manage. **27** (8), 1059-1070, **2007**.
7. GENG Y., TSUYOSHI F., CHEN X., Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki. J. Clean Prod. **18** (10-11), 993-1000, **2010**.
8. SÁ CAETANO, N., Composting. Encyclopedia of Environmental Management, In press DOI: 10.1081/E-EEM-120047119, **2013**.
9. WONG J. W. C., ON FUNG Sh., SELVAM A., Coal fly ash and lime addition enhances the rate and efficiency of decomposition of food waste during composting. Bioresource Technol. **100**, 3324-3331, **2009**.
10. KABBASHI N., Sewage sludge composting simulation as carbon/nitrogen concentration change. J. Environ. Sci. **23** (11), 1925-1928, **2011**.
11. XI B. D., SU J., HUANG G. H., QIN X. S., JIANG Y. H., HUO S. L., JI D. F., YA B., An integrated optimization approach and multi-criteria decision analysis for supporting the waste management system of the city of Beijing, China. Eng. Appl. Artif. Intell., **23**, 620-631, **2010**.
12. MOHAMADI FARDI H., Waste Management System Modeling of Tehran, EIA study of different MSW management models by using WAMPS model. Masteruppsatsexamen sarbete, Högskolani Borås, Institutionen Ingenjörshögskolan. September, Sweden, **2008**.
13. LU L. A., KUMAR M., TSAI J. Ch., LIN J. G., High-rate composting of barley dregs with sewage sludge in a pilot scale bioreactor. Bioresource Technol. **99** (7), 2210-2217, **2008**.
14. XI B. D., HE X. S., WEI Z. M., JIANG Y. H., LI M. X., LI D., LI Y., DANG Q. L., Effect of inoculation methods on the composting efficiency of municipal solid wastes. Chemosphere. **88**, 744-750, **2012**.
15. XI B., ZHANG G., LIU H., Process kinetics of inoculation composting of municipal solid waste. J. Hazard. Mater. **124**, 165-172, **2005**.
16. ZHAO W., HUPPES G., VAN DER VOET E., Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: a case study of Tianjin, China. Waste Manag. **31** (6), 1407-1415, **2011**. doi: 10.1016/j.wasman.2011.01.013. Epub 2011 Feb 12.
17. BLENGINIG. A.,BUSTOM., FANTONI M., FINO D. Eco-efficient waste glass recycling: Integrated waste management and green product development through LCA. Waste Manage **32** (5), 1000-1008, **2012**.
18. ROBERTO SOARES S., RODRIGUES FINOTTI A., PRUDENCIO DA SILVA V., ALVARENGA R. A. F. Applications of life cycle assessment and cost analysis in health care waste management. Waste Manage. **33** (1), 175-183, **2013**.
19. EIK A., Eco-efficiency of waste management, a case study of the Norwegian deposit and recycling system for PET bottles. PhD thesis in industrial ecology, Norwegian University of Science and Technology, Norway, **2005**.
20. VERFAILLIE H. A., BIDWELL R., Measuring eco-efficiency – a guide to reporting company performance. World Business Council on Sustainable Development, Geneva, **2000**.
21. THANT, M.M., CHARMONDUSIT, K., Eco-efficiency assessment of pulp and paper industry in Myanmar. Clean Technol. Environ. Policy, **12**, 427-439, **2010**.
22. CHARMONDUSIT, K., KEARTPAKPRAEK, K., Eco-efficiency evaluation of the petroleum and petrochemical group in the map Ta Phut Industrial Estate, Thailand. J. Clean Prod., **19**, 241-252, **2010**.
23. KHAREL G. P., CHARMONDUSIT K., Eco-efficiency evaluation of iron rod industry in Nepal. J. Clean. Prod. **16** (13), 1379-1387, **2008**.
24. NRTEE. National Round Table on the Environment and the

Economy, calculating eco-efficiency indicators: a workbook for industry. 344, Slater Street, Ottawa, Ontario, Suite 200, Canada, **2001**.
25. IPCC, 1996. Intergovernmental Panel on Climate Change. revised 1996 guidelines for national greenhouse gas inventories, reference manual, workbook and reporting instructions. http://www.ipcc-nggip.iges.or.jp/, accessed October **2006**.
26. WMO, Annual report of waste management in 2010. Waste Management Organization. Tehran municipality, Tehran, Iran, **2010**.
27. FARZADKIA M., JARFY S., RAVANIPOUR M., Surveying the integrated solid waste management program of Tehran city in 2013. Paper presented at the Iran 12th Convention on Environment Health, September, Tehran, Iran, **2009**.
28. FRIDRICH E., TROIS C., Quantification of greenhouse gas emissions from waste management processes for municipalities – A comparative review focusing on Africa. Waste Manage. **31** (7), 1585-1596, **2011**.
29. ZHONG J., WEI Y., WAN H., WU Y., ZHENG J., HAN SH., ZHENG B., Greenhouse gas emission from the total process of swine manure composting and land application of compost. Atmospheric Environment. **81**, 348-355, **2013**.
30. ABDULI M. A., Solid waste management in Tehran. Waste Management & Research, **13** (5), 519-531, **1995**.
31. MAHDAVI DAMGHANI A., SAVARYPOUR Gh., ZAND E., DEIHIMFARD R., Municipal solid waste management in Tehran: Current practices, opportunities and challenges. Waste Manage. **28** (5), 929-934, **2008**.