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## **ENERGY IMPACT OF SOLID WASTE RECYCLABLES IN CAMPINAS**

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**Abstract:** *The inclusion of selective collection of urban residual solids in the public policies is an issue adopted by many countries as a mean for reducing the impacts created by solid waste generation and destination. In Brazil, the selective collection of solid waste was implemented in Campinas, in 1991. The city is the third biggest in the state of São Paulo and has a population of about a million inhabitants. The amount of recyclable matter amounts to 1% of the mixed solid waste collected by the public service and deposited in sanitary landfills. In the present study, reports and data forwarded by the municipality public service and the private cooperative units regarding the selective collection of solid waste are analyzed from the energy saving view point. The analysis showed that about 10,900 liter of diesel oil is used to collect 329 tons/month of recyclables. The resulting energy economy is about 32 times the fuel energy used by the collecting trucks in the same period. This amount of recyclables led to an energy economy of 12,552 GJ/month, enough for a monthly equivalent electric consumption of 4000 residences.*

**Keywords:** Selective collection, solid waste, recyclables, energy impact.

### **1. INTRODUCTION**

The increase of the volume of municipal solid waste produced in the urban centers forced the governments to include in their public policies systems to reutilize the solid waste for incineration, composting and recycling. Some countries as Japan, Sweden, Switzerland, Belgium, Austria and Denmark show indexes of recycling of solid waste more than 90%. Other countries such as Poland, Turkey, Mexico and Brazil show recycling indexes less than 10%, where the predominant treatment system is burying in landfills.

The urban solid waste is usually composed of organic degradable matter (animal or vegetable leftover), organic non degradable matter, as plastics and of inorganic non degradable matter (glass, metal and others). Due to its physical and chemical composition, the non degradable matter can take centuries to decompose in the ambient and hence reduce the useful life of the deposition areas. This usually creates big problems in the big urban centers due to the lack of adequate areas for waste deposition.

As a form to increase the useful life of the deposition areas, specialists recommend recycling. This procedure permits entry of materials such as paper and cardboard, plastics, glass and metals back to the production chain as recycled matter to produce new products (Lino, 2009). In this process some economic, energetic, environmental and social benefits can be achieved, such as the use of less quantities of raw material in the industrial sector e consequently less natural resources withdrawn, reduction of energy and water consumption, creation of new jobs, increasing the useful life of deposition areas and reduction of public expenditure for treating waste in the deposition areas and finally the social inclusion of less quantified citizens in the active society working mass (McDougall et al., 2001; Kanayama, 1999; Figueiredo, 1995; Tchobanoglous et al., 1993).

The first step in a successful recycling process is the separation of the solid waste matter at home and also in the municipal collection posts (IPT/CEMPRE, 2000; SMA, 1998). In developed countries as Japan, USA and Germany the recyclables are separated and delivered by the population to specific localities (Sakata, 2007; Louis, 2004; González-Torre et al., 2003; Read, 1999). In developing countries such as Brazil, this process is predominated by selective waste collection from residences and consequently involves energy for transport (Lino, 2009).

For the sustainability of a recycling program, it must include the energetic, ambient, economic and social aspects (Teixeira, 1999). The present paper handles specifically the energy aspect, involving the activities of the municipality public service and the two active cooperative units which are included in the present analysis.

## 2. STUDY CASE: CAMPINAS MUNICIPALITY

The state of São Paulo, localized in the south east of Brazil, is formed by 645 municipalities, of which Campinas is the third in population, about 1039,297 inhabitant in 2009, about 99 km from the capital of the state of São Paulo and with territorial area of about 796 km<sup>2</sup>, as can be seen in Fig. 1.

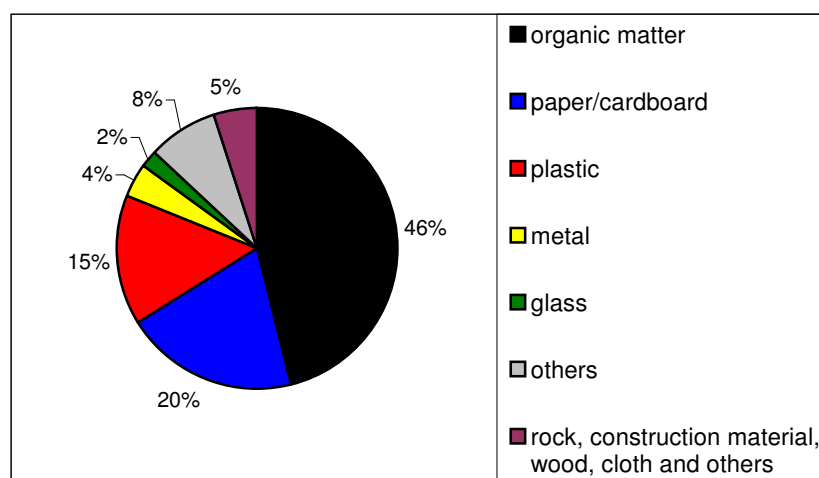


**Fig. 1. Geographic localization of Campinas, Brazil.**

Source: Seade, 2008

Campinas itself is formed of 14 regional management sectors and 4 districts. During the last fifty years, Campinas faced accelerated urbanization processes and population increase as a result of the intense regional industrial development. This accelerated expansion led inevitably, to serious management problems in the public services, and specifically in the solid waste management.

### 2.1. Municipal solid waste: generation and destination



**Fig. 2. Characterization of household solid residual waste in Campinas.**

Source: PMC (1996)

Campinas, as the third municipality in population, is also the third municipality in household solid waste. Each resident produces about 0.7 kg/day of solid waste. The public collection system covers 100% of the urban areas with adhesion index of 98% of the residences according to the recent statistics of the municipality government. The collection public service is realized by a contracted private firm (Lino, 2009).

Campinas is divided into 63 household waste collection sectors, in thirty of them the waste collection is realized daily, while in the other 33 sectors the collection is done three times a week from Monday to Friday twice during the day and once at night time (Lino, 2009).

According to the characterization process realized by the municipality organ responsible for this service, the composition of the household residual solid waste is 66% organic matter (food left over, paper, cardboard etc.) and 34% inorganic matter (plastic, glass, metal etc.). From this data, one can find that the recyclables amounts to 41%, as can be verified from Fig. 2.

## 2.2. The public service selective collection

The selective collection project was initiated in 1991 and in 2005 the recyclables collection was realized by two systems. In the first system dominated here as the residential collection, the mixed solid waste is deposited by the residents outside their homes which is then collected by compacting trucks. In the second system, dominated here as the centralized collection, big public and private waste generators such as schools, shopping, residential parks etc., usually place their solid waste in specific places where it is collected by the public service trucks attending collect specifically such establishments. The residential collection service is realized by a contracted private company, which also realizes the common mixed solid waste collection. In the centralized system, the collection is done by the department of urban services attending these specific localities called big solid waste generators. The sixty three collection sectors forty four of which handles 70% of Campinas urban area. Table 1 shows the evolution of the household solid waste collection over a period of 10 years from 1995 to 2005, as can be seen from Table 1.

**Table 1. Daily average residential solid waste collection.**

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Mixed collection (ton/day)	523.6	588.8	618.1	630.2	654.8	665.2	680.1	680.9	632.0	641.1	648.0
Selective collection (ton/day)	10.7	13.0	14.0	13.8	8.2	9.2	8.6	7.4	7.3	5.4	7.0
Collected total (ton/day)	534.3	601.8	632.1	644.0	663.0	674.4	688.7	688.3	639.3	646.5	655.0

Source: Lino (2009).

A quick glance at Table 1 shows that initially when the selective collection system was implemented, the advertisement campaigns, informative leaflets and propaganda on TV and radio realized by the local government led to creating a type of cooperative attitude which increased along the years reaching its maximum around 1997 and 1998. The reduction of the selective collection of household solid residuals in the subsequent years can be attributed to several factors, as the lack of informative and educational programs, no financial incentives offered by the local government, part of the collecting man power is attended by the federal government social security programs and its immediate reflex in reducing the interest in the selective collection program. To overcome these difficulties it is necessary that the local government initiates other intensive and continuous informative and awareness programs, introduces tax incentive policies together with special priority measures for cooperative collection.

According to Table 1, the sum of the common and selective collection of urban residuals is 655 tons/day. From this data the estimated potential for the recyclables in the city of Campinas in tons/day is 131.0 of paper and cardboard, 98.2 plastics, 26.2 metal and 13.1 glass summing a total of 268.5 tons/day.

Considering the population of Campinas, 1039.237 inhabitants, the estimated recyclables per day per inhabitant is about 0.26 kg/day. According to the municipality records the amount of recyclables collected by the public service is due to about 27,000 inhabitants or about 6700 residences, considering an average of 3.67 persons/residence.

Analysis of the official reports shows average recyclables of about 200 tons/month and an average travelled distance of 25,000 km/month.

## 2.3. Cooperative selective collection

Both, the public service sector and the two cooperative units called Aliança and Reciclar execute independently the selective collection in Campinas. According to the Campinas social inclusion program for generating jobs, implemented in 2002, the recyclable matter collected by the public service sector is divided between 11 cooperative units, of which the two units Aliança and Reciclar, participate with their own infrastructure, trucks and human labor. Analysis of the reports of the two cooperative units indicates that, collect together 125 ton/month and travel about 6000 km/month.

## 3. ANALYSIS AND DISCUSSION

In order to analyze the available data and put it in a quantitative form amenable for analysis and discussion the authors made estimates of the consumed energy in the primary production (using raw material), the energy consumed during the collection process and the energy economy due to recycling. The term energy economy refers to the difference between energy consumption in the production process when using raw material and the energy consumption when using recyclables. The calculations indicated an average energy economy due to recycling of about 35.5 GJ/ton.

The selective collection in the city of Campinas is realized by the municipality public service and also by two cooperative units. Analysis of their reports indicates an average total mass of recyclables in tons/month of 329.5 and a

total monthly traveled distance of 31,212 km/month. Based upon these values the recyclable mass per km is 10.5 kg/km.

From their reports, both those of the municipality and the cooperative units, one can calculate the real occupied capacity of the collecting trucks which in away represents the efficiency of the selective collection systems. The results indicate that the municipality trucks works with lower values of capacity ratio than the cooperative trucks and hence consume more energy per unit mass of recyclables. Also from their informative report one can calculate the real fuel consumption per km amounting to 0.5 l/km in case of the municipality trucks.

Based upon these global values one can calculate the fuel consumption per ton of recyclables for both the municipality public service and the cooperatives units coming up to 44.5 l/ton and 10.6 l/ton, respectively.

Lino (2009) estimates the energy potentially possible to be economized which is strongly dependent upon the composition of recyclables. From the available official reports (2009) was able to calculate the average composition of recyclables in the city of Campinas. In this way it was possible to estimate the primary energy consumed in the production process using both raw and recycled material, and consequently the possible primary energy to be saved by the industrial sector when using recyclables in the city of Campinas. These calculations, Lino (2009) indicates the return of 308 tons of recyclables (paper, cardboard, glass, metal and plastics) back to the industrial sector and which potentially save as much as 12,938 GJ/month which is more than 32 times the energy consumed in the selective collection process. This demonstrates that from the point of view of energy saving, the selective collection is feasibly sustainable even with a solid waste collection amounting to 2.6% of the potentially recyclable matter available in the city of Campinas.

#### **4. FINAL COMMENTS**

Based upon the results obtained one can conclude that, although the total recyclables selectively collected by the public service in the city of Campinas in 2005 corresponds to 1% of the total mass collected daily by the mixed collection system, it is still feasible from the energy saving point of view.

It is also found that the recyclables collected by both the public service and the two cooperative units represent energy savings of 12,552 GJ/month, which is more than 32 times the energy consumed by the collecting trucks.

The analysis of the results indicates that the energy savings due to recycling in the city of Campinas represents per month the equivalent electric energy consumption of 4000 average class residences or 14,000 inhabitants, considering an average class residence consumption of about 0.9 GJ/month and a thermal to electric energy conversion efficiency of 28%.

Based upon the results obtained it is important to recognize the efficient management of the cooperative units in selecting light trucks of low specific fuel consumption and adopting a committing and efficient registration scheme of residences and establishments along with awareness and adherence for the separation of recyclable matter. It is equally important to mention that the results indicate the urgent need for intensive and continuous public awareness campaigns, as well as preparation of a set of adequate and directive public policies together with including an efficient management and operation control.

Although the amount of recyclables is relatively small, an intensive campaign directed to the population, together with a small incentive, 1% of the collection tax and allowing more separation areas can contribute to possible massive adhesion to the selective collection which eventually can benefit the state, the population and the ambient.

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#### **6. REFERENCES**

- Figueiredo, P. J. M., 1995. A sociedade do lixo: os resíduos. a questão energética e a crise ambiental. Unimep: Piracicaba, Brasil.
- Fundação Sistema Estadual de Análise de Dados, SEADE, 2008. Informações dos municípios paulistas. Available in : <http://www.seade.gov.br>. Accessed in 20/07/2009.
- González-Torre, P. L., Adenso-Díaz, B., Ruiz-Torres, A., 2003. Some comparative factors regarding recycling collection systems in regions of the USA and Europe. *Journal of Environmental Management* 69, 129-138.
- Instituto de Pesquisa Tecnológica & Compromisso Empresarial para Reciclagem, IPT/CEMPRE, 2000. Lixo municipal: manual de gerenciamento integrado. São Paulo, Brasil.
- Kanayama, P. H., 1999. Minimização de resíduos sólidos urbanos e conservação de energia. Dissertação (Mestrado). Escola Politécnica da Universidade de São Paulo/USP. São Paulo, Brasil.
- Lino, F. A. M., 2009. Consumo de energia no transporte da coleta seletiva de resíduo sólido domiciliar no município de Campinas(SP). Dissertação (Mestrado). Universidade Estadual de Campinas. Faculdade de Engenharia Mecânica FEM/UNICAMP. Campinas, Brasil.
- Louis, G. E., 2004. A historical context of municipal solid waste management in the United States. *Waste management & research* 22, 306-322.

- McDougall, F. et al., 2001. *Integrated solid waste management: a life cycle inventory*. Blackwell Science published, 2. ed. USA.
- Prefeitura Municipal de Campinas, PMC, 1996. *Gestão dos Resíduos Sólidos Urbanos*. Secretaria de Serviços Públicos. Campinas, Brasil.
- Read, A. D., 1999. A weekly doorstep recycling collection. I had no idea we could. *Resources, Conservation and Recycling* 26, 217-249.
- Sakata, Y., 2007. A choice experiment of the residential preference of waste management services – The example of Kagoshima city. Japan. *Waste Management* 27, 639-644.
- Secretaria de Meio Ambiente do Estado de São Paulo, SMA, 1998. *A Cidade e o Lixo*. São Paulo, Brasil.
- Tchobanoglous, G., Theisen, H., Vigil, S., 1993. *Integrated solid waste management: engineering principles and management issues*. McGraw-Hill, New York, USA.
- Teixeira, E. N. e Bidone, F., 1999. Conceitos básicos. In *Metodologias e Técnicas de minimização, reciclagem e reutilização de resíduos sólidos urbanos*. Associação Brasileira de Engenharia Sanitária e Ambiental, ABES. Rio de Janeiro, Brasil.

## **7. Direitos autorais**

Os autores declaram que são os únicos responsáveis pelo conteúdo do material impresso, incluído no seu trabalho.