Research article

Analysis of the relationship between the amount and type of MSW and population socioeconomic level: Bahía Blanca case study, Argentina

Yamila V. Vazquez [a,b,*], Federico Barragán [c], Luciana A. Castillo [a,b], Silvia E. Barbosa [a,b]

[a] Planta Piloto de Ingeniería Química, PLAPIQUI (UNS-CONICET), Bahía Blanca 8000, Cno. "La Carrindanga" km 7, Argentina
[b] Departamento de Ingeniería Química, Universidad Nacional del Sur, Bahía Blanca 8000, Av. Alem 1253, Argentina
[c] Departamento de Geografía y Turismo, Universidad Nacional del Sur, Bahía Blanca 8000, 12 de Octubre 1198, Argentina

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ABSTRACT

The amount and type of municipal solid waste (MSW) in Bahía Blanca (Argentina) were assessed and correlated with population socioeconomic level. In this sense, seven areas with different quality of life were selected. In addition, a parallel study on a control area was performed and validated for obtaining a representative result to provide analogous conclusions for the whole city. From this study, a combination of sorting methodologies is proposed in order to reduce the actual amount of waste sent to landfill. If these methodologies are implemented in Bahia Blanca city, MSW in landfill could be reduced at least 80%. The proposed strategy is to combine waste sorting at source and at destination. An alternative separation at source could be proposed as follows: packaging (including plastic, cans and Tetra Pak), other plastics, paper and glass. The rest of MSW could be included in a container which would be collected daily or three times a week without changing inhabitants' habits and promoting their collaboration. Then, it could be separated at destination for waste-to-energy, composting, and biogas obtaining. Residuals from incinerators and biogas/composting plants would be sent to landfill. On the other hand, regarding the relationship between the proposed strategy and population quality of life, obtained results from this study could be useful to size and to efficiently locate disposal bins/containers for source separation as well as to redesign routes of municipal solid waste collection. Also, this strategy allows to add value to different components of MSW, improving working conditions of waste workers and creating new jobs in Bahia Blanca city.

1. Introduction

Bahía Blanca is an urban center located in the southwest of Buenos Aires province, Argentina. It is a medium-sized city with 301,572 inhabitants and a population density of 134 inhab/km^2, being the most developed city within its area of influence [1, 2]. It has one of the most relevant autonomous ports of Argentina and the largest deep-water one [3]. Besides this, it is a very important communicational node of roads, railways and aeronautics. Additionally, the city acts as a geographical node regarding tertiary, financial, banking and health sectors as well as services like drinking water, sewers, electricity, gas and telecommunications. Another noticeable characteristic is the academic activity given by two medium-sized national universities which attract a big number of young people from different parts of the country. All these factors have complemented and encouraged the installation and development of an industrial complex constituted mainly by petrochemical industries. Finally, Bahía Blanca is considered the center for domestic trade and exportation of agricultural and livestock products as well as fruits and vegetables from the region [4, 5].

All the city facilities promote people migration from the influence area, increasing the number of inhabitants. As a consequence, in addition to economic fluctuations and people changing habits, municipal solid waste (MSW) has doubled its generation rate per inhabitant during the last decade. This increase was from 623 g/day in 2006 to 1194 g/day in 2018 [2, 4, 6]. The entire generated MSW is daily collected from livings (House to House collection - 20 bags every 100 m) and disposed of in landfills [1, 7, 8]. This fact leads to a rising problem against sustainability as a consequence of waste accumulation with high costs and social impact [9]. Because of that, it is necessary to design an integrated solid waste management in order to increase sustainability.

On the other hand, Argentina has several founded projects as part of different Latin-American initiatives promoted by the Inter-American Development Bank (IDB) [10]. Regarding MSW management, there are two projects that are strongly related to this subject. One of them is

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* Corresponding author.
  E-mail address: yvazquez@plapiqui.edu.ar (Y.V. Vazquez).

entitled "Development Program for Metropolitan Areas Outside the Capital II" [11], which involves the implementation of different strategies to enhance the quality of life of the population in metropolitan areas, including the improvement of urban services (including waste transportation) and infrastructure. In this regard, Bahía Blanca is part of this project as an "emerging city"[1]. All these aspects are directly related to the other project called "Integrated Urban Solid Waste Management Program" [12]. This project arises from the national ENGIRSU strategy that pretends to reduce the environmental impact from MSW by improving their management system. Its main motivation is the eradication of open-air dumps and the reduction of waste in landfills [13, 14]. In this way, to achieve this purpose there are several methodologies which add value to MWS [15]. For example, in the case of plastic, glass, wood and metals, the 3R rule (reduce, reuse and recycle) is the easiest and most effective way to avoid final disposal of this kind of waste [16]. On the other hand, composting and bio-digestion are the most promising alternatives for organic waste valorization, with the consequent energy production [17]. In addition, nowadays there is a worldwide trend towards waste incineration to produce energy, known as waste-to-energy. However, in this case there are restrictions related to the legal framework of each particular country [18, 19].

Several studies found in literature indicate that one important factor related to amount and type of MSW is the socioeconomic level of the population. Monaravi et al. [20] carried out their work in Ahvaz (Iran), an industrial city with 1,115,133 inhabitants. They determined the related socioeconomic parameters based on field surveys, selecting 400 sample households using a stratified random sampling methodology from five different socioeconomic groups. From statistical analysis, they claim that MSW generation and composition are highly related with socioeconomic parameters. They indicated that income and education level are the most influential factors in the reduction of MSW rates and the variation in its composition. In accordance to this, Khan et al. [21] reported that family income, education, and occupation factors are closely related to the MSW generation rate in Dhanbad city (India). The study area is a coal industry-based city with 290,000 inhabitants. Questionnaire surveys were made on 30 households which represent the overall socioeconomic status of the study area. Within several types of MSW, main differences were found in ash and plastic waste. Lower socioeconomic groups generate the highest amount of ash waste since they use coal and wood as fuel for cooking. Meanwhile, plastic waste is maximum in higher socioeconomic groups because of food packages. Also, they claim that population groups with medium socioeconomic level generate the highest amount of MSW. Similar studies were performed by Villalba et al. [22] in Tandil city (Argentina). It has 116,500 inhabitants and the main economic activities are based on agriculture, livestock, tourism and steel industry. Authors performed the first door-to-door MSW characterization stratifying more than 80 households into three socioeconomic status (high, medium and low) using geographical information systems and census data. Three sampling campaigns were carried out in three different seasons within two years (2016–2017). Each campaign comprises a whole week. From statistical analysis they conclude that overall composition of waste remained stable during the three sampling campaigns and household waste generation rate increased steadily. They report that this increment can be explained by the lower consumption rates during 2016 in Argentina, and the subsequent economic recovery in 2017. Trang et al. [23] used a regression model to determine the dominant factors that might influence the MSW generation and its composition in Thu Dau Mot (Vietnam). From this study they claim that high socioeconomic level groups generate less MSW, particularly because they perform their activities outside home. The most evident finding revealed that high income groups are used to go

out for lunch and dinner; meanwhile low income ones must cook in their houses. This work evidences that, despite socioeconomic factors are closely related with MSW generation and composition, the way that they affect MSW amount and type, depends on cultural and consumption habits of each country, and their cities in particular. On the other hand, the same conclusions were obtained for different European countries by Namlis and Komilis [24]. They selected ten European countries in order to cover a wide range of socioeconomic levels and standards of living within Europe. Also, countries were selected considering that there was available information for almost all solid waste streams for the period of study (2008/09–2015). This work investigates the impact of four indexes (gross domestic product, human development index, unemployment rate, and CO_2 emissions) on the generation rates of the considered solid waste streams. They carried out a regression modeling between the waste generation rates and each of the four indexes, obtaining representative correlations. From these results, one of the main claims is that besides correlations are reasonable, there exist other factors that influence waste generation and cannot be directly quantifiable. These factors are country/regional legislations (such as implementations of waste prevention policies), geographical variations within the same country, educational level, cultural differences, consumption habits, cultural inhabitants' behaviors, industrialization level, etc. From the above studies it is evident that results for different places around the world are not generalizable as they depend on the population habits and characteristics. Then, each place needs to be analyzed by itself in order to obtain good results for sustainable waste management.

In this way, the aim of the work is to assess the amount and type of MSW in Bahía Blanca city (Argentina), relating them to the socioeconomic level of the population to propose methodologies for enhancing the MSW management. In this sense, the present study would allow to design a sustainable strategy to minimize the amount of waste sent to landfill as well as to add value to different components of MSW stream.

2. Methodology

2.1. Socioeconomic analysis

Socioeconomic analysis was performed in order to select representative waste collection routes and to obtain a relationship of MSW type and amount with the socioeconomic status of the population.

In Argentina, the Instituto Nacional de Estadística y Censos (INDEC) determines a quality of life index (QLI) which involves general indicators that do not represent the actual habitability and well-being of the population in particular cases. This index gives a measure of the average socioeconomic reality of Argentina. However, if a detailed analysis on a specific city is needed, this index does not correctly represent the reality of the population under study. For example, a particular area in Bahía Blanca city presents a QLI which indicates a low-income population group due to the unpaved streets. However, this area involves gated communities with high-income levels. This "kind of incoherencies" is typical in Latin-American countries where urban planning is poor [25, 26]. For this reason, an *ad hoc* quality of life index (QLI*) was defined in this work to obtain a more realistic description of the habitability, well-being, and socioeconomic level of population, for an appropriate analysis of the generated MSW. Thus, QLI* was determined from certain information of population and living by census radius acquired from the INDEC [2]. It is important to note that this information is reported nationally, provincially, by city, by neighborhoods and/or area of a particular city. The following indicators were selected as variables for the assessment of QLI*: 1) *percentage of analphabets* (negative); 2) *percentage of population who attended primary school* (positive); 3) *percentage of population who did not finish a certain educational degree* (negative); 4) *percentage of population with medical care insurance* (positive); 5) *percentage of population without drinking water* (negative); 6) *percentage of population without bathrooms in their livings* (negative); 7) *index of building materials quality* (positive); 8) *percentage of population which accomplish with at least*

one condition of the Unsatisfied Basic Needs Index (positive); and 9) *percentage of overcrowding* (negative). Parentheses include the nature of the indicators which is represented as negative or positive direction. A positive direction means that higher values of the indicator represent a better situation; meanwhile a negative direction involves worse situations. These indicators were selected considering that they have the greatest influence on the actual representation of the population's well-being and habitability of different societies [27, 28, 29]. The values of all indicators for each studied area were acquired from INDEC.

A linear approximation was used for the determination of QLI*, where the indicators were transformed into homogeneous units directly integrable, following the standard method of "correspondence points". This methodology was developed by the United Nations Research Institute for Social Development (UNRISD) and is widely used from 1972 [30, 31]. In order to normalize these indicators values, Eqs. (1) and (2) were used:

Positive indicators

$$ind_j = [(X - MIN_j)/(MAX_j - MIN_j)]*100 \qquad (1)$$

Negative indicators

$$ind_j = [(MAX_j - X)/(MAX_j - MIN_j)]*100 \qquad (2)$$

where ind_j is any of the selected indicators, X is the indicator value, MIN_j and MAX_j represent the possible minimum and maximum values, respectively, that an indicator can reach, and 100 is the possible maximum value to obtain in the normalized scale. Thus, this transformation allows that indicators values for QLI* calculus can range from 0 up to 100, being able to be added and averaged.

To achieve a quantifiable result about quality of life, QLI*$_{linear}$ was determined from the sum of the selected indicators values. In this regard, a higher value of QLI*$_{linear}$ represents a better quality of life. This method

assumes that all indicators have the same importance in the assessment of QLI*. In this way, considering 9 indicators, QLI*$_{linear}$ can be determined by the expression represented in Eq. (3).

$$QLI*_{linear} = \sum ind_j = ind_1 + ind_2 + ind_3 + \ldots + ind_9 \qquad (3)$$

The aforementioned method of "correspondence points" is applied to normalize QLI*$_{linear}$. The QLI* is obtained by the Eq. (4), where MAX and MIN represent the possible maximum and minimum values of QLI*$_{linear}$, respectively.

$$QLI* = [(QLI*_{linear} - MIN)/(MAX - MIN)]*100 \qquad (4)$$

Thus, QLI* can vary from 0 to 100, as the indicators involved in it, according Eqs. (1) and (2). Then, in order to become these quantitative variables in a qualitative information [32], QLI* is divided into five ranges that represent different life qualities: Very Bad (0–19.9), Bad (20–39.9), Regular (40–59.9), Good (60–79.9) and Very Good (80–100).

Figure 1 shows the map of Bahía Blanca city divided in different areas according to QLI* values, using a colorimetric scale to identify socio-economic levels. This map was built using ArcGis 9.3 software [33] relating land registry and census radius of the city [34] with waste collection routes, selected study areas, and QLI* calculated in this work.

2.2. Analysis of the relationship between municipal solid waste and QLI* - selection of collection routes

Collection of MSW in Bahía Blanca is carried out through sixteen routes to cover all the city. The design of these routes was done by the company in charge of collecting waste with arbitrary criteria. In order to perform a realistic study of the actual MSW amount and type, five collection routes were selected from these sixteen ones, comprising the whole range of QLI* in the city. Also, the selected circuits were less
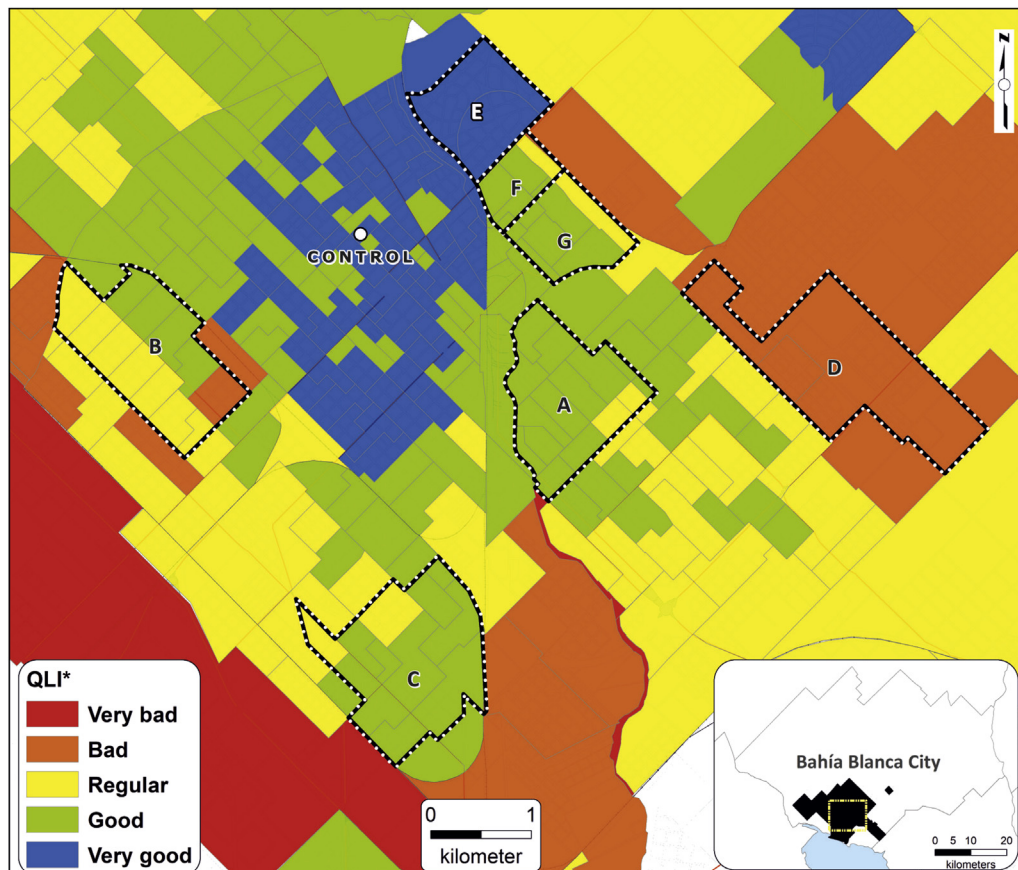

Figure 1. Cartographic distribution of Bahía Blanca population according *ad hoc* quality of life index (QLI*) and considered areas.

affected by informal collectors in order to minimize errors in this study. It is important to highlight that informal collectors take off more valuable waste from the richest areas of the city. This situation generates a wrong estimation of the quantities and quality of waste in these areas. From the five routes, seven areas of analysis (A, B, C, D, E, F and G) were chosen, relating them with the corresponding QLI* value. On the other hand, a parallel study of a control area was performed and validated for obtaining a representative result to provide analogous conclusions for the whole city. In this sense, a condominium inhabited by people with Bahia Blanca mean QLI* was selected and analyzed (named Control in this study).

2.3. Sampling, sorting and characterization

2.3.1. Municipal solid waste collection

MSW collection in Bahía Blanca city is performed using municipal compacting trucks that daily collect waste bags from each individual trash bin on the street, involving 20 bags per 100 m approximately [1, 8]. It is important to highlight that MSW bags in Bahía Blanca are left outside

in each living, not in a common container. For this study, in order to take a representative sample in each study area, 2 bags per 100 m were collected one hour before the municipal collection and following the same route of compacting trucks. This procedure was selected taking into account the proposed by Edjabou et al. [35] to avoid changes of the normal waste collection (see Figure 2). In this regard, it was possible to ensure that, by that time, all the neighbors which live along the route took the waste out. Sampling was performed once a day during 1.5 month in the spring season. This represents a final sample of 500 kg/day per area. In order to favor the sorting step, waste bags were not compacted. Additionally, samples from the control area were collected at the same time. These samples were about 200 kg per day and they were stored in a separate big bag. After collection, MSW big bags per each area and the control one were taken to the recycling plant.

2.3.2. Municipal solid waste sorting by type

Sorting step was made taking into account seven classifications: organic, metal, paper, glass, plastic, Tetra Pak and miscellaneous as well as diapers and absorbents. Organics include every biodegradable MSW,
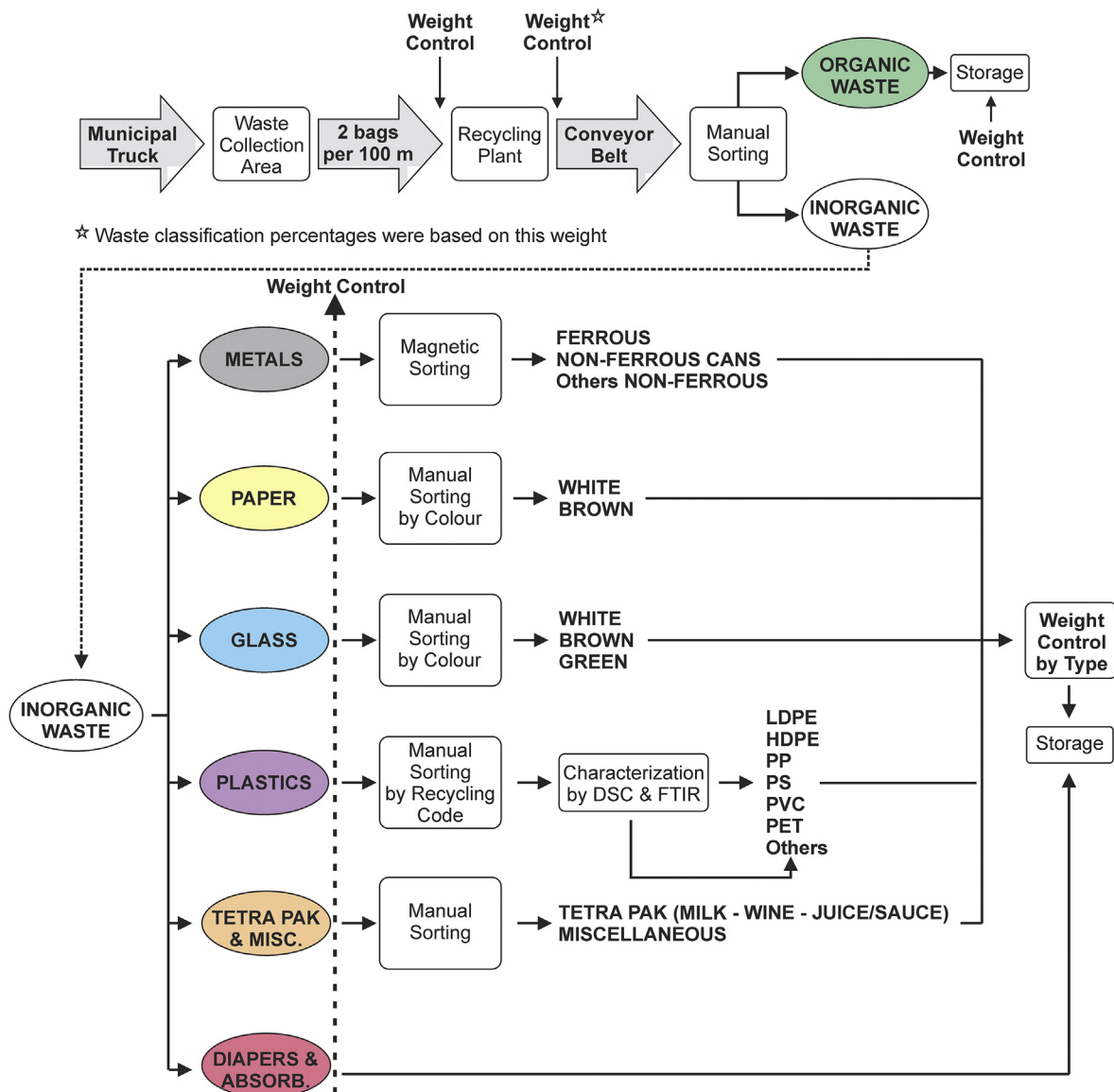

Figure 2. Scheme of municipal solid waste (MSW) sampling, sorting and characterization procedure. Ref: Differential Scanning Calorimetry (DSC), Fourier Transform Infrared Spectroscopy (FTIR), Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC) and Polyethylene Terephthalate (PET).

basically food, plants, etc. Metal was classified in ferrous and non-ferrous which, at the same time, was sub-classified in cans and other metals. Regarding paper, it was sorted according to their color in white or brown. Glass was also divided by color in white (transparent), green or brown. Plastic classification is the most extensive due to its wide variety. Taking into account the most common plastics, they were divided by type as follows: High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET) and others plastics, which are the minor fraction or less common plastics, including samples composed by two or more plastics. Concerning Tetra Pak and miscellaneous, usually they are called "others", but they are materials with multiple components that can be recycled [36]. Additionally, Tetra Pak was sub-classified according to its content in wine, milk and sauces/juices. On the other hand, miscellaneous includes multi-material samples like metallized plastics, plastic-coated papers, etc. Finally, diapers and absorbents (D&A) are considered as a separated stream in order to evaluate their potential valorization for energy production.

MSW classification and sub-classification per area were made according to the following procedure: i) big bags were weighed upon arrival at the recycling plant (percentages of each waste type were based on this weight); ii) MSW was classified using a conveyor belt at the recycling plant; iii) a big bag per each type of MSW was daily generated and weighed; and iv) after a week of collection, MSW big bags per type were mixed to perform a quartering followed by the corresponding sampling to calculate sub-classification percentages.

2.3.3. Municipal solid waste characterization

For sub-classification of two materials groups (metal and plastic), special techniques were required. For metal, magnetic classification allowed to separate ferrous and non-ferrous ones. In the case of plastic, most of its components were not identified with the corresponding recycling code, although Argentinean normative recommends the incorporation of these codes according to the standard IRAM 13700 [37]. For this reason, a visual differentiation of plastics could not be done and separation by type became more difficult. In this sense, calorimetric and spectroscopic analysis were performed in order to determine plastic types. Differential Scanning Calorimetry (DSC) is a thermoanalytical technique that measures heat change transitions, which allows identifying plastic material. A Perkin Elmer Pyris I calorimeter was used to perform this study. Samples were heated at a rate of 10 °C/min from 50 °C to 250 °C, where transitions of typical plastic MSW occur. On the other hand, when the aforementioned characterization was not conclusive (atypical behavior or samples with more than one plastic), Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed. This technique allows a complete material identification through the detection of characteristic chemical bondings. Spectra were made in transmittance mode using a Nicolet Nexus FTIR 520 on films of 70 μm thickness obtained from non-identified plastic samples by using a heated hydraulic press. It is important to highlight that these two simple and fast techniques allowed determining plastic composition by type of MSW.

3. Results and discussion

Weight percentage of each waste type for analyzed and control areas is presented in Figure 3. In this regard, the mean value of each type of waste for every area with the corresponding standard deviation was included. It is possible to observe that there is a small change in the mean value of each kind of waste in all areas, except for paper and glass. However, all of them keep their variations within data errors. In the case of paper and glass, mean value of certain areas duplicates the corresponding to other ones, although measurements have significant standard deviations. From these results, a representative mean value for the whole city of each type of waste was determined.

Figure 4 shows the mean value for each type of waste in Bahía Blanca city. Mean value determined for organic (wet basis), metals and glass agree with the reported ones for Argentina provided by the Secretaría Nacional de Desarrollo de Medio Ambiente y Desarrollo Sostenible [9, 38]. However, there are differences in the proportion of plastic and paper. The main reason for these variations proceeds from the specific waste separation performed in the present work. Usually, Argentinean national statistics of MSW classification include less categories (organic, metals, paper, plastic, glass and others) than those defined for this
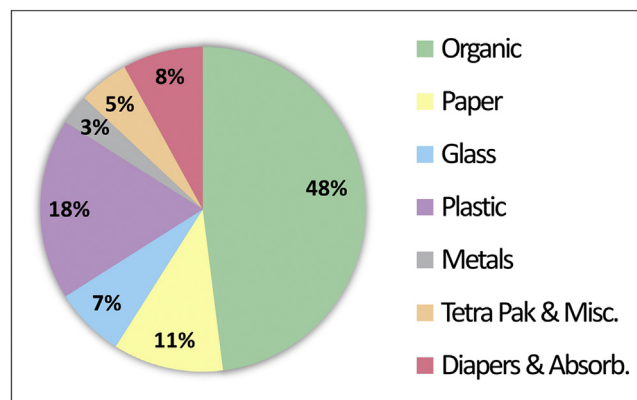

Figure 4. Mean composition of municipal solid waste (MSW) in Bahía Blanca.
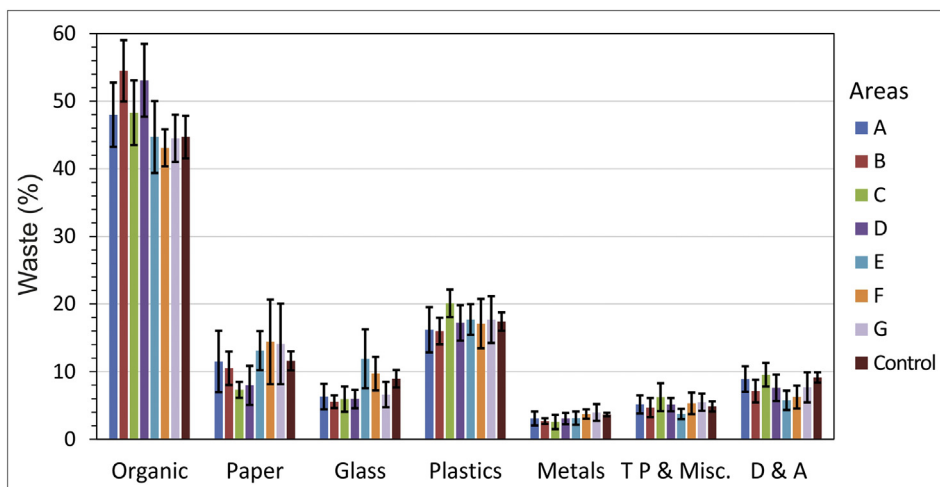

Figure 3. Municipal solid waste (MSW) classification per area vs. weight percentage.

analysis. Particularly, "others" classification was not included, meanwhile categories like "Tetra Pak and miscellaneous" and "diapers and absorbents" were considered in the present study.

In order to analyze the relationship between the waste generation and socioeconomic level of the population, a comparison among different MSW types (with their corresponding sub-classifications) and QLI* distribution along the city was performed. From this analysis, it is possible to conclude several facts which are explained below.

The mean value of organic waste represents the 48 wt% of the total amount of MSW, being similar in all analyzed areas as shown in Figure 4. This kind of waste contains mainly food rests that were previously separated from packaging or containers. A slight increase in the mean value is observed with the decrement of QLI*. This trend is in accordance with a global report [9] which indicates that, the lower socioeconomic level, the higher the concentration of organics in MSW. Also, Namlis and Komilis [24] observed the same behavior in different European countries as well as Alfaia et al. [39] in Brazil. Finally, in Tandil, an Argentinian city, the same tendency was reported by Villalba et al. [22]. However, although this is a global trend, there are some particular cases where the opposite relationship occurs as it is reported by Monaravi et al. [20] for Ahvaz city (Iran) and by Khan et al. [21] for Dhanbad city (India). In both cases, it can be attributed to cultural customs of oriental countries. Analyzing the type of organic waste proceeding from low income areas, a lot of rotten fruits and vegetables were found. This observation was attributed to the kind of food that people consume since poor persons in Argentina usually eat market discards, mainly grocery ones. In addition, a particular situation to remark was the systematic collection of a bag with human feces in C area during the whole study. At the beginning, it seemed to have no relationship with QLI* because, according to government information, this area presented livings with bathrooms. However, it was checked that there were railway wagons in the corresponding collection route which were kept by homeless people as livings, but they did not have bathrooms.

Regarding paper, total amount by area is presented in Figure 3 while relative proportions of brown and white type for each area are included in Figure 5. In this case, percentages were calculated on a dry basis in order to quantify the actual amount of paper that can be effectively recycled as itself. Approximately 60 wt% of collected paper can be reprocessed, discarding contaminated paper. From these results, it is possible to observe that the higher QLI*, the higher percentage of paper waste. This trend was also observed in Tandil, another city of Argentina with a third of the population of Bahía Blanca, which was reported by Villalba et al. [22]. Results show that mean values for white and brown paper are 31 wt% and 69 wt%, respectively. Brown paper represents the major content in all areas except for B one, where both kinds of paper represent almost the same amount. It is possible to attribute the last result to a relative high proportion of kids with respect to the rest of the areas [2]. On the other hand, it is expected that areas with higher QLI* through away bigger amounts of brown paper, mainly from packaging. This fact is corroborated with the proportions of different paper colors, where the amount of brown paper (or cardboard) increases when QLI* is high; meanwhile white paper quantity decreases. This trend is also observed in Thu Dau Mot (Vietnam) with 417,000 inhabitants [23], and Islamabad (capital city of Pakistan) having 1,015,000 inhabitants [40], where people with high income levels generate more cardboard waste associated with packaging.

Total amount of glass in MSW increases according high QLI*. This behavior agrees with results reported by Villalba et al. [22] for Tandil city (Argentina) having 116,500 inhabitants, and Kamran et al. [41] for Lahore city (Pakistan) with 1,344,000 inhabitants. The mean values of different glass color proportions are 4 wt%, 32 wt% and 64 wt% for brown, white and green, respectively. Main components of this kind of waste are bottles and also some jars or flat glass. It is notable that the amount of brown glass is lower than the others in all areas. This fact does not seem to correspond with beer bottles which are mainly commercialized in brown glass. It is important to mention that beer is the most

consumed beverage in Argentina as it is reported by Mata and Costa [42]. The low amount of this type of glass is a consequence of a good commercial strategy based on returnable bottles [43]. On the other hand, the main component of white glass was reserve jars and flat glasses; and just a small number of bottles were found. Green glass proceeds only from wine bottles. It is important to note that there is a notable increase in the quantity of collected green glass in E area which has the highest QLI* (Figure 1). In this case, glass waste was mainly constituted by bottles according to the income of this area. This particular behavior was only observed in E area. On the other hand, there is not a neat tendency of the color glass relative proportions with QLI* (Figure 5).

Concerning metals stream, it was classified in ferrous, non-ferrous cans and others non-ferrous (Figure 5). In some areas, it was only composed by cans, particularly in those with low QLI*. This fact is probably associated with the reuse/recycling of different objects made of aluminum, copper and other metals, by the people who live in these areas. On the other hand, aluminum cans are the best paid and most requested by recyclers being this reason which explains why they were not a common MSW in low income areas. Regarding others non-ferrous category, it contains mainly aluminum from food packaging and foils as well as small amounts of copper and bronze. The tendency of this kind of metals with QLI* is not clear. In the case of ferrous metals, the main contribution came from automotive heavy parts like engines. For this reason, its relative weight proportion is higher than the others and does not allow to perform an adequate analysis. Despite there is no clear correlation between the kind of metal with the QLI*, the total amount of metals agrees with results reported by Trang et al. [23] for Thu Dau Mot (Vietnam) and by Zia et al. [40] for Islamabad (Pakistan). In these cases, it was found that the higher socioeconomic level, the higher the amount of metals.

Plastic waste stream is composed of a wide variety of these materials. For this reason, a physicochemical characterization was carried out, allowing determining its composition. Main components of plastic MSW are those coming from packaging and containers which are made of LDPE, HDPE, PP and PS. In addition, bottles of water and sodas are another principal constituent of the plastic stream, where the main component is PET. This finding is in accordance with Villalba et al. [22] for Tandil, Argentina. Another kind of plastic found in MSW is PVC that comes mostly from toys and pipes. Polyurethanes (PU), polycarbonates (PC) and polytetrafluoroethylene (PTFE) are the main components within the group "others". The mean values of each plastic were: LDPE 26.00 wt%, HDPE 18.01 wt%, PP 22.36 wt%, PS 7.00 wt%, PVC 1.62 wt %, PET 21.59 wt% and others 3.36 wt% (Figure 6). The observed trend for plastic types was also found by Hahladakis and Aljabri [44] in Qatar (United Arab Emirates). However, variations in percentage values can be appreciated with respect to those determined in this work, mainly associated with consumption habits of the arab population. On the other hand, Burange et al. [45] reported that, in general, HDPE is one of the major fraction of plastic MSW. It is important to remark that polyethylene (HDPE + LDPE) represents 44 wt% of the total amount of plastic stream. Also, small quantities of nylon, rubber, ethyl-vinyl-acetate (EVA foam), acrylonitrile-butadiene-styrene (ABS) and silicone are included in this category in "others" subclassification. In Figure 3 it is possible to observe that the total amount of plastic waste is the most constant, but its composition by type presents a notable variation depending on the area, whose proportions are included in Figure 6. During collection in areas with low QLI*, the presence of milk bags, t-shirt type bags and a few rigid packages was detected. On the other hand, these last packages were predominant in areas with higher QLI*, mainly associated with personal care and cosmetics products, as it is reported by PlasticsEurope association [46] for the whole European Union, and Dahlbo et al. [47] for Finland. A particular fact regarding plastic stream is that the amount of PET packages and delivery plastic trays were very high, although QLI* was almost regular. This fact is associated with consumption habits of people regarding take-away food.
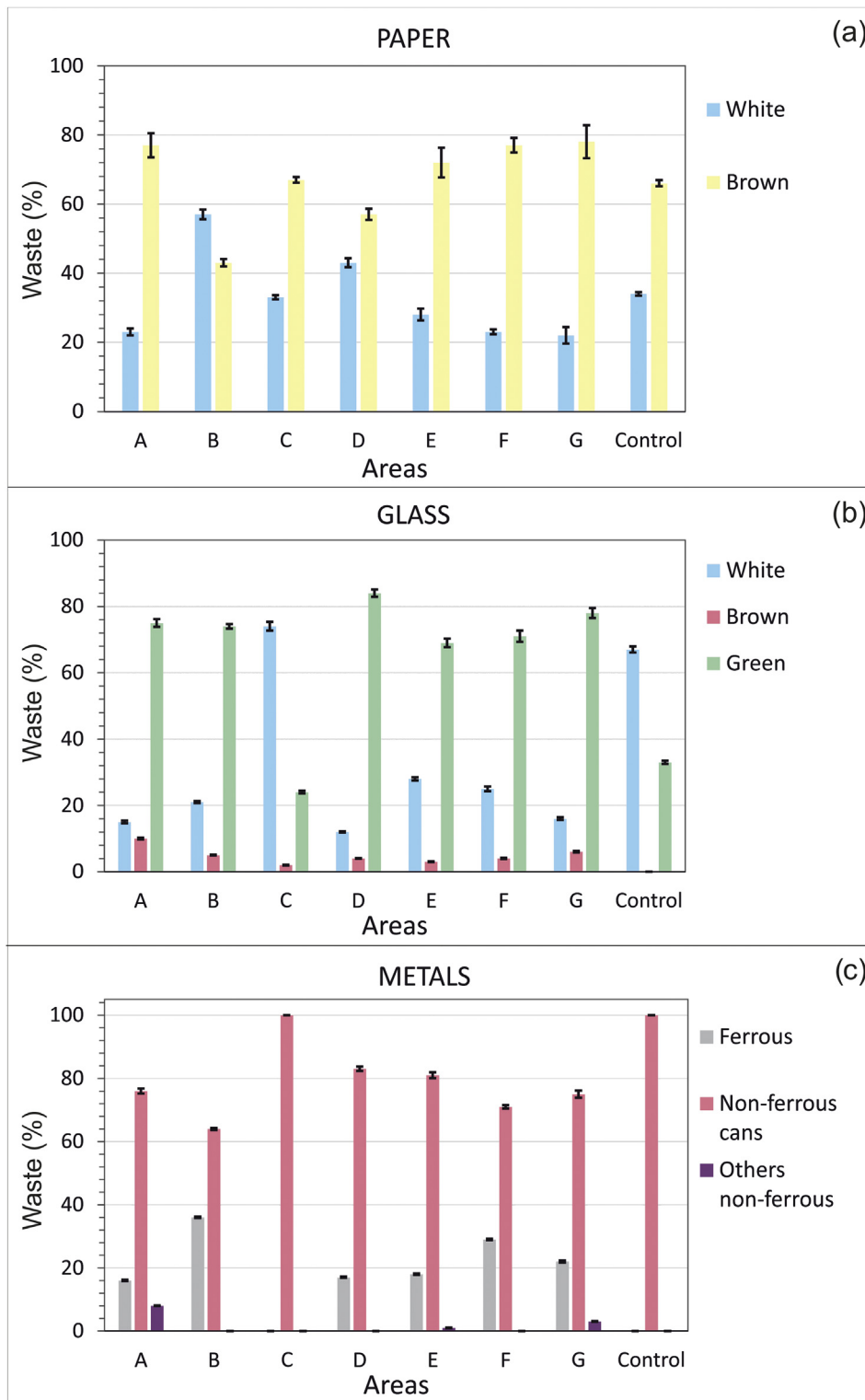
Figure 5. Intrinsic composition of: (a) paper stream, (b) glass stream, and (c) metals stream; for all studied areas.

Waste named as "Tetra Pak and miscellaneous" proceeds from objects made with more than one material which are difficult to manually separate. Also, this category comprises every kind of waste that cannot be included in the others categories. Plasticized card boards, multilaminated packs (Tetra Pak), canvas and fabrics, plastic objects with metals parts, metallized plastics, among others, are considered in this category. However, taking into account that Tetra Pak is the main component of this waste (mean value: 13 wt%) and it can be also recycled

without separation; this category was divided in Tetra Pak and miscellaneous (Figure 7). Moreover, it can be appreciated that Tetra Pak waste was classified according to its content (wine, milk and sauce/juice) to analyze its relationship with QLI*. Mean proportion of milk Tetra Pak represents 50 wt% of the total amount; meanwhile wine Tetra Pak, 13 wt % and sauce/juice ones, 37 wt%. These values show a great variation depending on the analyzed area with respect to the QLI*. Tetra Pak total amount increases with the decrement of QLI*. This trend is also observed
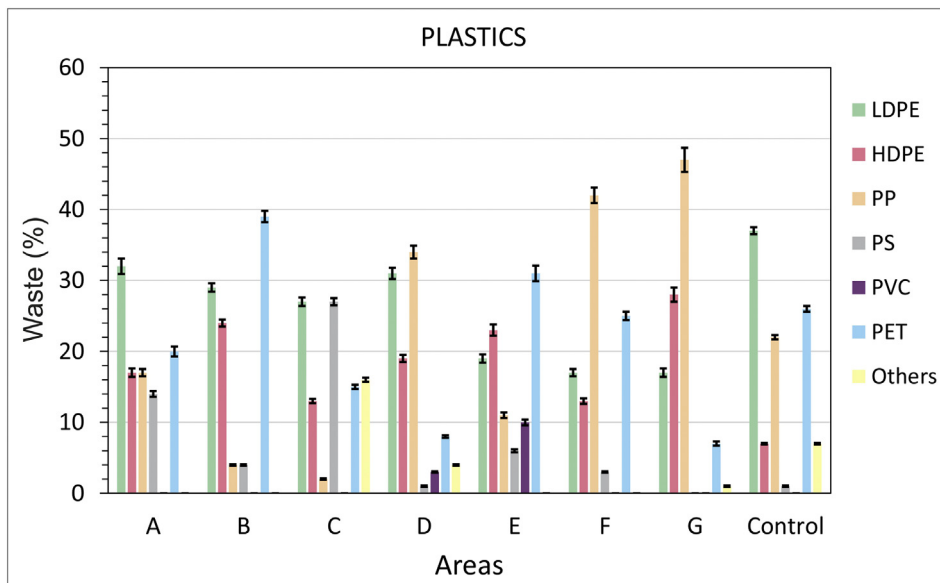
Figure 6. Intrinsic composition of plastics stream for all studied areas. Ref: Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVC) and Polyethylene Terephthalate (PET).
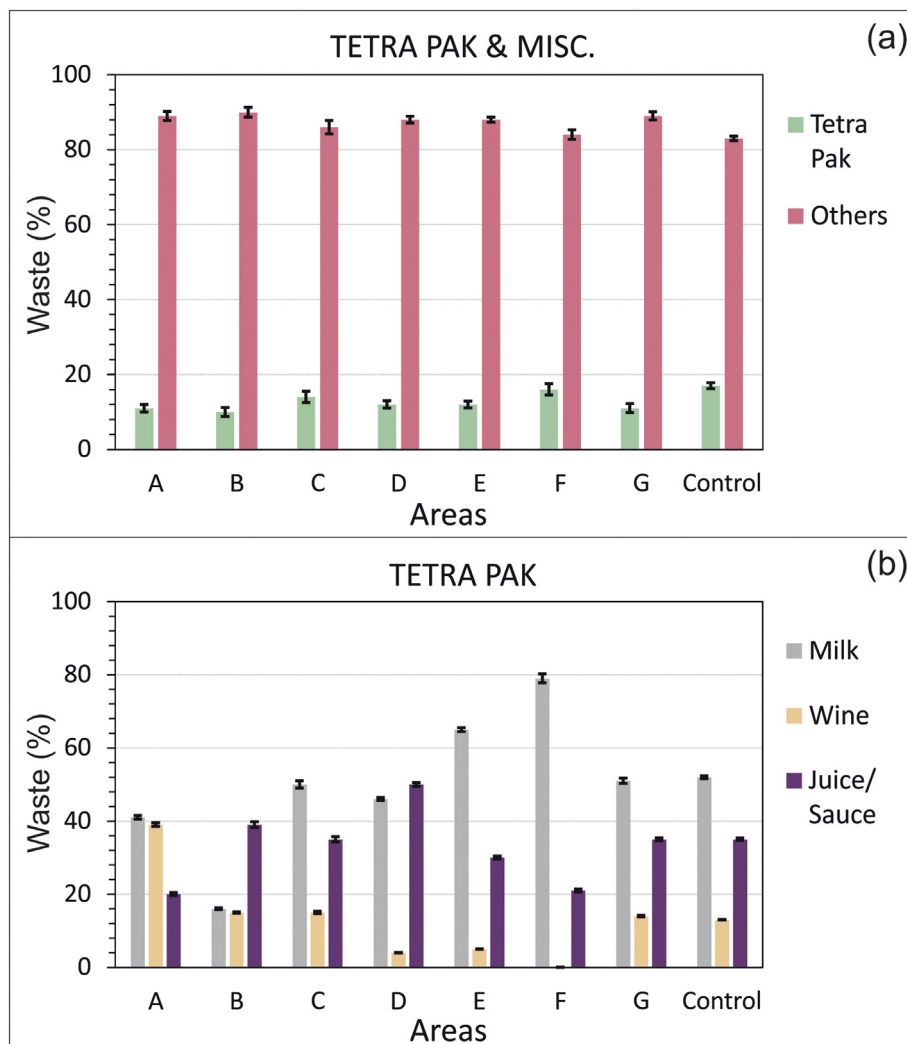

Figure 7. Intrinsic composition of: (a) "Tetra Pak and miscellaneous" stream, and (b) Tetra Pak stream; for all studied areas.

in another Argentinean city which is smaller than Bahía Blanca [22]. However, the opposite behavior is evidenced in Islamabad, the capital city of Pakistan [40]. In this country Tetra Pak is used for milk products, tea, and juices. This waste is high in summer because of the increase of juices consumption due to high temperature. Also, it is high in winter due to the increment in milk consumption. Concerning this particular waste, the low income group in Islamabad generates the lowest amount of it because this population sector buys fresh milk from a street seller instead of pasteurized milk in Tetra Pak. In Argentina, the most expensive liquid milk is the one packaged in Tetra Pak and its consumption is higher in areas with high QLI* than low ones. However, contrary to what happens in Pakistan, high amounts of milk Tetra Pak were also found in areas with low QLI*. This fact is related to government social programs which provide long-life milk in Tetra Pak, probably masking a consumption tendency. On the other hand, the amount of wine Tetra Pak in Bahía Blanca city increases with the decrement of QLI*, as expected. However, in A area the amount of wine Tetra Pak is the highest and QLI* indicates a good socioeconomic level. This observation was further discussed with sociologists which suggested that this fact proceeds from cultural habits of this neighborhood. Finally, the amount of sauce/juice Tetra Pak seems to be related to the age range of the population instead of QLI*. In this way, neighborhoods included in B, C, D, G, and control areas have a low age range in comparison with the rest of the considered areas [2]. Young people's consumption habits involve this kind of sauce and juice packages as their less effort that its use implies.

It is important to highlight that "diapers and absorbents" waste stream represents a considerable amount (8 wt%) of the total MSW. This waste seems to have a stronger relationship with the population age by area than with QLI*. For example, E area has a population with a higher average age than C and A areas [2]. In these last areas, the population of children is notably higher and, consequently, the amount of disposed diapers. Also, there is not an important contribution of elderly people' diapers in this waste stream. Regarding this waste trend, it was also observed by Karman et al. [41], during the winter season in Lahore city, Pakistan. This behavior was associated with reductions in infants baths because of the low temperature during that season. This fact is also related with cultural customs of people from that part of the world. On the other hand, according to Zia et al. [40] the generation of diapers waste in Islamabad, capital city of Pakistan, was highly related to income levels of the population regardless of the season.

Finally, a very important fact is that the hypothesis based on a control area (condominium) that represents the MSW mean value of Bahía Blanca city was corroborated. In all cases, for every kind of waste, the mean value of the control area represents the mean of the city and also, because of its low error, is more conservative. This result could allow to perform the study only considering this specific condominium, being possible the MSW analysis during long periods of time. In this sense, obtained results for the control area can be directly extrapolated to the whole city. Besides, it will be possible to evaluate another kind of information such as general seasonal variations, incidence of actual socioeconomic situation, advertising incidence, among others, on MSW amount.

From these results, if a proper separation at source can be achieved it would be possible to implement several waste management methodologies according to each type of waste. Taking into account that glass, paper and plastic could be recycled by reprocessing [48], around 30 wt% of MSW can be valorized by this methodology. Other authors proposed the same in different parts of the world such as Spain [45], Thailand [49], and Jordan [50]. In the case of multi-material and miscellaneous waste, it contains materials that can be either recycled by reprocessing (i.e. Tetra Pak) or used for waste-to-energy (i.e. plasticized paper) [51, 52]. For "diapers and absorbents" stream (around 10 wt%), which contains multi-material and faeces, the most efficient valorization methodology is waste-to-energy [53, 54]. Organic waste (around 48 wt%) can be used to generate compost [55], biogas [56] or energy [57]. However, the last option is the less chosen since the organic stream must be partially dried

before being fed in a waste-to-energy process with associated high costs [58]. Despite metals waste represents a minor proportion of MSW, its recycling is widely known and carried out in Argentina [59].

From the above analysis, it is clear that there is not a unique methodology to valorize the overall MSW streams. Then, a convenient strategy is to combine sorting at source and at destination followed by specific methodologies depending on MSW type. Paper, glass and plastic can be separated at source using disposal bins by area. If recyclable multi-material and miscellaneous waste (including Tetra Pak) want also to be classified, an alternative separation at source could be proposed as follows: packaging (including plastic, cans and Tetra Pak), other plastics, paper and glass. The rest of MSW could be included in a container which is collected daily or three times a week without changing inhabitants' habits and promoting their collaboration. Then, it could be separated at destination for waste-to-energy and biogas or compost plants. Residuals from incinerators and biogas/compost plants would be sent to landfills. Thus, in order to improve sustainability, several changes should be done in the current MSW management system of Bahía Blanca city.

4. Concluding remarks

In this work the assessment and correlation of the amount and type of MSW with population socioeconomic level in Bahía Blanca city (Argentina) was performed. This study was carried out in the frame of IDB-funded projects regarding integrated waste management systems. Besides, a parallel study in a control area was performed and validated to obtain a representative result that provides analogous conclusions for the whole city. From the obtained data, a reduction of at least 80 wt% of the actual amount of waste sent to landfill could be achieved if a combination of sorting methodologies would be implemented in the city. Moreover, valorization of the different MSW streams can be reached by the implementation of these strategies, consolidating an integrated MSW management. Consequently, more jobs could be created as well as salary and working conditions of current waste workers could be improved in every step of the waste management. On the other hand, regarding the relationship between the proposed methodology and population quality of life, obtained results from this study allow dimensioning and efficiently locating disposal bins/containers for separation at source, as well as, restructuring MSW collection routes. Also, results could be useful to design social campaigns to improve MSW management by generating environmental awareness of inhabitants.

Declarations

Author contribution statement

Silvia E. Barbosa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Luciana A. Castillo, Yamila V. Vazquez: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Federico Barragán: Analyzed and interpreted the data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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