

*Original Research*

# Using Material Flow Analysis for Waste Management Planning

**Dragana Neskovic Markic<sup>1\*</sup>, Hristina Stevanovic Carapina<sup>2</sup>, Drazenko Bjelic<sup>1</sup>, Ljiljana Stojanovic Bjelic<sup>3</sup>, Predrag Ilic<sup>4</sup>, Zeljka Sobot Pesic<sup>1</sup>, Olivera Kikanovic<sup>2</sup>**

<sup>1</sup>DEP-OT Public Utility Regional Landfill, Banja Luka, Bosnia and Hercegovina

<sup>2</sup>Faculty of Environmental Protection, Educons University, Sremska Kamenica, Serbia

<sup>3</sup>Faculty of Health Sciences Pan-European University Apeiron, Banja Luka, Bosnia and Hercegovina

<sup>4</sup>PSI Institute for Protection and Ecology of the Republic of Srpska, Banja Luka, Bosnia & Hercegovina

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## Abstract

The main objectives of waste management are environmental preservation, the safeguarding of human health, and natural resources conservation. Material flow analysis/ substances flow analysis (MFA/SFA) method takes into account the consideration of the “metabolic” system of waste management, which means monitoring waste flows and substances within the model for waste management, and examining all inputs and outputs in the system, as well as their evaluation and comparison. Modeled scenarios in the Banjaluka region of the Republic of Srpska (RS) were developed in accordance with both the European Union (EU) and RS legislation, as well as relevant municipal waste management strategic documents. Modeled municipal solid waste (MSW) management scenarios are compared with the current waste management system. Using MFA/SFA (waste flow, carbon, and nitrogen), a complete view of flow, transformations, and final waste disposal and substances in modeled scenarios of waste management is realized. Results of this study suggest that in the future, more activity should be based on the separate collection and recycling, compared to the current, inadequate MSW management system that is based only on the disposal of waste. The combination of material and substance flows analyses is an effective tool in the decision-making process for the development and improvement of MSW management.

**Keywords:** waste, waste management, material flow analysis, substance flow analysis

## Introduction

Traditionally, the term “waste” has a negative connotation and implies something that is unwanted that people reject, and all because of inadequate thinking about waste [1]. In the context of integrated sustainable

waste management, waste can have a negative context only if it is not used as a resource not utilized to its full potential, and which is not used for energy or new products [2-3]. The conventional approach to waste management involves its formation, collection, and waste disposal, where all planning operations are viewed independently of the others [1]. Municipal solid waste (MSW) management is defined as the systematic control of the formation, collection, storage, transport,

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\*e-mail: dneskovic@dep-ot.com

source separation, treatment, recovery, and disposal of solid waste. Developed countries tend to have less waste that ends up in a landfill, and to take as much waste for recycling and repeated use.

Integrated MSW is a comprehensive approach to prevention, recycling, and efficient waste management with the aim of preserving human health and the environment [4]. The integral concept of MSW management is trying to establish a balance between the three dimensions of waste management: the efficiency of environmental protection, social acceptability, and economic acceptability (acceptable price).

Waste disposal is still the least expensive and most widely used treatment of waste around the world [5-6]. UNEP in its report evaluated the 50 largest active illegal dumps in the world, with the greatest numbers located in Africa, Asia, and Latin America, and only two in Europe (Serbia and Ukraine) [7]. These illegal dumps have in common the fact that they pose a risk to the environment and human health. Disposal of waste at landfills in Europe is still present in developing countries, including some members of the European Union (EU) as well as Romania, Cyprus, Greece, Malta, and Turkey [8]. MSW management in the countries of the former Yugoslavia (excluding Slovenia) is still at a very low level, and represents an important issue in policy for waste management with the Balkan countries [9]. Waste disposal in landfills is still the only way to treat municipal waste in Bosnia and Herzegovina (B&H), and there were 90 landfills in B&H in the year 2014 [10-11]. Of these, only five landfills are sanitary and the remaining 85 landfills are open dumps. The reasons for such a bad situation in the sector of MSW management can be listed as: the lack of strategic investment plans for this sector, the limitations of the instruments for the promotion of recycling and waste prevention, and the lack of capacity in the sector of hazardous and industrial waste management [12].

A variety of analytical tools and methods are used to help the decision-making process in waste management. Analytical methods used in the waste management system can be classified into two groups: engineering models and models of system assessment. The engineering models are cost-benefit analysis (CBA), the prediction models (FM), optimization models (OM), etc. The models of system assessment consist of analysis of material flow analysis/substances flow analysis (MFA/SFA), life cycle assessment (LCA), etc. [13-14].

The research topic of this study is the quantification of the flows of MSW and substances (carbon, nitrogen) in order to provide scientific support in the decision-making process of municipal waste management in the region of Banja Luka, entity of Republic of Srpska (RS), B&H. The aim of this study is to investigate and propose future strategic and conceptual directions and draw conclusions on the effectiveness of the new MSW management system in terms of the objectives of waste management, the EU legislation, and the legislation of RS.

## Materials and Methods

### Waste Management in Banja Luka Region

Banja Luka is the second largest city in B&H, and the largest city in the entity of RS. It is located in the northwestern part of B&H and is situated at 44°57' north latitude and 17° 11' east longitude. Banja Luka is the administrative, economic, and cultural center of RS entity. The current method of treatment and MSW management in the region of Banja Luka is waste disposal from the city of Banja Luka and seven municipalities in the region [15]. According to the census from 2013, the region has a total population of 399,469 residents and 126,811 households. In the MSW of the region of Banja Luka, organic fraction (31.14%) dominates, and the amount of packaging waste (paper, plastic, metal, glass) that could be recycled is about 49% [16] (Table 1). The amount of MSW that was disposed of in Banja Luka landfill in 2016 is 89,246 t.

### MFA/SFA

Material flow analysis (MFA) is a systematic assessment of the flows and supplies of material in the system, which is defined in space and time [17]. It connects sources, pathways and transitional or final disposition of the materials. MFA can be carried out on two levels: level of substances and level of goods. If it is at the level of substances, then we are talking about substance flow analysis (SFA), and the MFA regulates the level of goods or materials. During the last decade, MFA has attracted a lot of attention and is included in the official statistical reports of the EU [18]. This is a typical analytical tool that is based on the material balance [19].

MFA methodology application in making MFA study consists of the following steps [20-21]:

- Defining the object and purpose of the study.
- Determining the limits of the system in time and space.
- Defining materials and substances.
- Balancing the inputs, outputs and stock through the processes.
- Schematic representation and interpretation results.

MFA/SFA is used as a tool in a number of studies on waste management, throughout the quantification

Table 1. Composition of MSW waste in Banja Luka region [16].

MSW composition	%	C (%)	N (%)
Paper and carton	25.92	44.41	0.54
Metals	7.62	0	0
Plastics	11.54	63.06	0.56
Glass	3.91	0	0
Organic fraction	31.14	45.79	4.69
Bulky waste	19.87	38.8	1.47

of waste flows and waste substances [22-28]. Knowing the flow of substances in the waste management system allows us to see whether some of the analyzed substances are a resource, if they are contained in certain materials, or present a burden to the environment. Carbon is an indicator of resource potential such as energy and biomass, but it also presents risk and is harmful to the environment, such as greenhouse gases and stable and toxic organic compounds. Nitrogen compounds through emissions to water, air, or land can create many problems in the environment, such as eutrophication, acidification, climate change, or as a catalyst for the formation of tropospheric ozone [29]. By optimizing the MSW management system, emissions of greenhouse gases can be reduced [25].

In the waste management system, it is necessary to define the final destination for permanent or at least long-term disposal of unwanted and hazardous materials that are not recycled, in the hope that these materials will not again be found in the waste, and to avoid their negative environmental impact. The target processes are defined as the place where the substances are concentrated as a result of the process or treatment, and the destination is a place where these substances remain for a long period of time (hundreds or thousands of years). If the concentration of some substances is greater than the natural concentration, negative effects are achieved by storage or directing these substances in a particular medium [30].

The appropriate destination for the waste is defined as a plant or process that ensures that the entry is stored or removed safely, and that what comes out in the environment is sufficiently slow that it will not harm the capacity of the environment such as lakes, sea, groundwater, soil, sediments, or atmosphere [30].

Atmosphere is defined as the final destination of carbon, only in the form of CO<sub>2</sub> obtained by mineralization, or the combustion of waste, as a substitute for the same amount of energy that could be obtained from fossil fuels [25]. The atmosphere represents an appropriate destination to molecular nitrogen (N<sub>2</sub>), but not NO<sub>x</sub>. Nitrate emissions in the hydrosphere represent an unsuitable destination. Nitrogen and carbon are preferred elements in the recycled or new products [30].

### Scenario Development

As a basis for the development of scenarios we took the EU and RS legislation, where a goal for MSW has been set through: minimizing the negative impact of waste (waste treatment) to environment and human health, preservation of resources, and reducing the amount of *waste* that is disposed of in a landfill.

The EU Directive on landfill waste [31] defines the technical requirements for construction of the landfill and prohibits common disposal of MSW and reducing the amount of biodegradable waste that is disposed of in a landfill to 35% of the total amount of biodegradable

waste produced between 1995 and 2016 (or for some countries by 2020).

The directive of the European Parliament on packaging and packaging waste [32] has been made in order to prevent or reduce the impact of packaging and packaging waste on the environment. According to this directive, by the end of 2008, EU member states must recycle at least 55% of packaging waste.

According to the regulation on packaging management and packaging waste [33] and the regulation on the reduction of packaging waste [34] in the RS, general objectives are to use or recycle 25% of packaging and packaging waste for 2015 and 35% for the year 2016.

In accordance with the mentioned requirements, two scenarios and two sub-scenarios for MSW were developed:

- Scenario S0: Status Quo - The current method of MSW management in the Banja Luka region mainly characterizes disposal of all collected MSW on the landfill.
- Scenario S1: The management of MSW in this scenario would imply the separation of waste at the source and in households. Organic waste would be collected separately to a percentage of 25%, packaging waste (paper, metal, glass and plastics) would be separately collected in the second waste bin (25%), and the remaining waste would be collected in a third waste bin. Separately collected organic waste would undergo the composting process and would be stabilized to the valuable compost to be used in agriculture. Separately collected packaging waste would be sent to the separation plant for separate fractions (MRF – material recovery facility). Then separate fractions of paper, glass, metal, and plastic would be further recycled. The residue waste would then be disposed of in a landfill. Within scenario S1, two sub scenarios have been developed:
  - Scenario S1a: MSW management in this scenario would include the separation of waste at source in households or as in the previous scenario. The percentage separation of organic waste would be 50%, and 35% of packaging waste. Further treatment of the organic, packaging, and the rest of the waste would be treated as in scenario S1.
  - Scenario S1b: MSW management in this scenario would imply the separation of waste at source and in households, as in scenario S1, including the separation of waste at source in households or as in the previous scenario. The percentage separation of organic waste would be 65%, and 55% of packaging waste. Further treatment of the organic, packaging, and the rest of the waste would be treated as in scenario S1.

Scenario S0, i.e., the current MSW management in the Banja Luka region, which implies the disposal of its collected waste to the landfill, meets the requirements for the construction and operation of the landfill, but does not meet the requirements of the EU directive on landfill waste [31], which requires the reduction of the amount of biodegradable waste deposited in the landfill. On the other hand, in scenario S1 (and sub scenarios S1a and S1b), the requirements for reducing the amount of biodegradable waste that are deposited at the landfill, and the separate collection and recycling of packaging waste is in accordance with the EU directive on packaging and packaging waste [32]. Starting from scenario S1 through S1a to S1b, the quantities of biodegradable waste and packaging waste that are separated were increasing, respectively. Scenario S1b has achieved the highest requirements regarding the reduction of disposal of biodegradable and packaging waste on the landfill and fully meets the requirements of the EU directives [31-32].

### Data

The functional unit is the total amount of MSW that was generated in 2016 in Banja Luka region (89,246 t), and includes MSW that is disposed of in a landfill. The spatial border is defined by a regional organization of waste management in the Banja Luka region, or a territorial unit consisting of the city of Banja Luka and seven municipalities in the region that dispose of waste at Banja Luka landfill. Households, handicraft shops, catering, and commercial facilities, as well as small and medium enterprises, are generators of municipal waste.

A period of one year was taken for the time limit, in order to be able to look at all flows of materials and substances in the waste management system in the region. An exception must be taken into account when it comes to the landfill, because it is a specific facility that can pollute for hundreds and even thousands of years after the landfill is closed [35-36]. Therefore, a period of 100 years was taken for the landfill as a time limit.

Since the subject of the research is MSW in the Banja Luka region, mixed MSW is defined as material. When modeling different scenarios of waste management, in addition to the analysis of the flow of MSW, flow fractions of the waste will be analyzed, including:

- Paper (paper and cardboard).
- Glass.
- Metal (metal and aluminum cans).
- Plastic (plastic, foil, PET).
- Organic waste (garden waste, waste from green areas and from the kitchen).
- Solid waste residue (rubber, wood, textile, construction waste, electronic waste, and animal waste).

The processes that are defined in order to develop the model are:

- Landfill: disposal of MSW is the simplest and cheapest waste treatment method [37]. The emission of landfill leachate and landfill gas can cause environmental

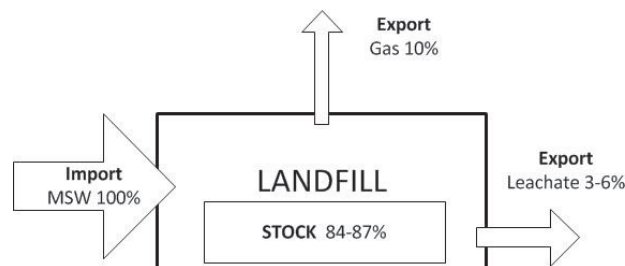


Fig. 1. Input and output flows for landfill [43].

pollution. Leachate from the landfill is highly contaminated wastewaters containing dissolved organic substances, inorganic substances such as  $\text{NH}_3$ , Ca, Mg, Na, K,  $\text{SO}_4^{2-}$ , Fe, Cl, and heavy metals (Cd, Cr, Cu, Pb, Ni), as well as xenobiotic organic substances [38]. If the leachate is discharged into surface waters or leaching into the soil, groundwaters can have a negative effect on human health and the environment [39-41]. Landfill gas is a mixture of  $\text{CH}_4$  (40-60%),  $\text{CO}_2$  (35-50%),  $\text{N}_2$ ,  $\text{O}_2$ , and other compounds [42], and it is necessary to systematically collect and treat it in order to prevent negative effects on the environment and human health. Most of the waste (84-87%) remains as the stock in the body of the landfill. By its decomposition, landfill gases (10%) and the leachate (3-6%) are formed [43-44] (Fig. 1). Based on available literature data, transfer coefficients for waste and substances are defined for landfill of MSW for a time period of 100 years (Table 2).

- Composting: composting is defined as fast partial decomposition of wet solid organic matter primarily of waste from kitchens, gardens, parks, and waste from green areas with the help of micro-organisms [45]. Final products of composting are  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{N}_2\text{O}$ , minerals, and stabilized organic matter that is not harmful to the environment. Considering the requirements of the directive on landfill waste [31] and the prohibition on the disposal of biodegradable materials in landfills, composting has gained importance as an option of waste treatment. Organic waste prior to the composting process has to pass the pre-treatment, where impurities such as second fractions of waste (plastics, metal, and glass) are extracted. Then it is sent to be chopped. Chopped organic waste is piled to a height of 1.8 to 2.1 m, and a width of 4 to 5 m, where the composting process takes place with the help of microorganisms. A mass

Table 2. Transfer coefficients for landfill of solid waste for a time period of 100 years [44].

Substance	Mass share	C	N
Landfill gas	0.10	0.457	0.005
Leachate	0.06	0.003	0.375
Landfill body	0.84	0.540	0.620



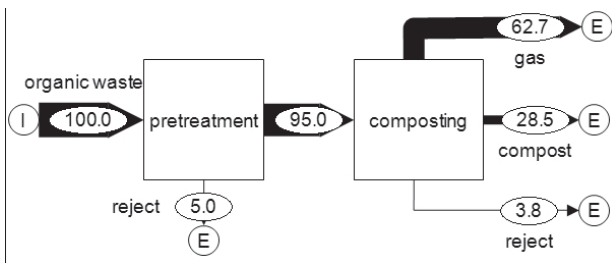


Fig. 2. Mass balance for composting process by pile method [46-47].

balance of composting process in stacks is shown in Fig. 2. Transfer coefficients are essential for the modeling of the mfa/sfa composting process [46-47] (Table 3).

- Separate collection and recycling: the benefits of recycling are multiple, such as conservation of natural resources (reserves of natural materials), reducing environmental pollution by saving on space in which this waste would be disposed, or reducing the amount of waste that is burned. In order for useful components of waste to be recycled, it is necessary to separate it from MSW. Depending on whether the packaging waste is separated directly on the site in a separate container, and then separated to fractions in the separation facility (MRF), or if useful components are separated from MSW, varying the level of separated useful components from waste. A far greater level of separation is achieved if we have separately collected packaging waste in one container, while a much smaller level of separation is achieved if all solid waste is collected in a single container and then separated in the MRF plant. After separating the waste in the MRF plant, the separated components are pressed and transported away for recycling. The loss of material in the recycling process for the glass and metal is 11%, 25% for plastics, and for paper and cardboard loss is 9% [48-49].

Using the data for the Banja Luka region, the developed scenario was modeled using STAN software.

### Results and Discussion

Fig. 3 shows the analysis of the material flows of the current MSW management system in the Banja Luka region. By analyzing the flow of materials, it can

Table 3. Transfer coefficients for composting of organic waste [47].

	Mass share	C	N
Gas	0.66	0.55	0.30
Compost	0.30	0.27	0.30
Reject from composting	0.04	0.18	0.40

be concluded that most of the waste ends up as stocks within the landfill (84%). Air emissions through landfill gas recovers 10% of waste, and leachate recovers 6% of waste through the lithosphere and hydrosphere. The flow of carbon in the current MSW management system in the Banja Luka region is shown in Fig. 4. 54% of carbon from waste is permanently stored in the body of the landfill, and 45.7% carbon from waste is transformed into landfill gases, and only 0.3% in the leachate. Most nitrogen from waste remains as stock in landfill (62%) and is transmitted through the leachate (37.5%) into the surface and groundwaters and into the soil. Through the landfill gas, 0.5% of nitrogen is recovered from solid waste (Fig. 5).

Fig. 6 shows the analysis of the material flows or waste for scenario S1. Of the total amount of waste (89,246 t), 74,111 t (83.04%) is disposed of at the landfill. In this scenario, the largest quantity of waste remains as stock in the body of the landfill (69.75%). 8,535 t of recycled packaging waste is sent to the new products by recycling, which represents 9.56% of MSW. 2.1% of waste is transformed into compost. The waste that is decomposed through the landfill processes is recovered

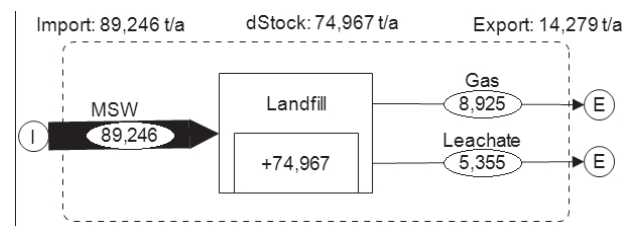


Fig. 3. Material flow analysis of waste management system for scenario S0.

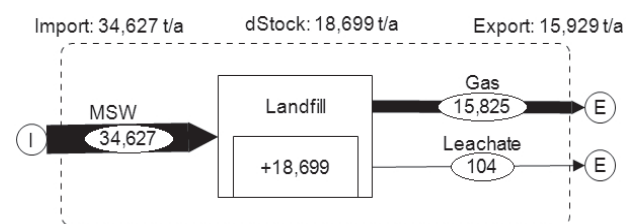


Fig. 4. Substance flow analysis of the waste management system for carbon for scenario S0.

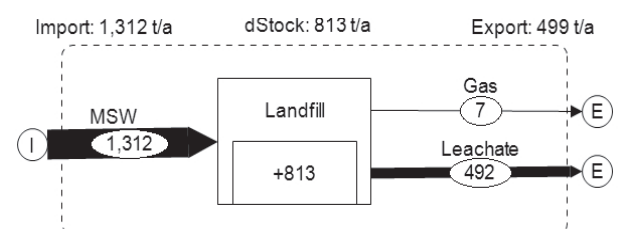


Fig. 5. Substance flow analysis of waste management system for nitrogen for scenario S0.

as landfill gas (8.30%) and as a leachate (4.98%). By the composting process, 4.88% of gas is recovered. Through the analysis of carbon flow in scenario S1 (Fig. 7) it can be seen that the largest amount of carbon remains stored in the body of the landfill as stock (44.3%), while 37.49% of carbon from waste is transformed through landfill processes in the gas. 9.24% of carbon from MSW returns in new products through recycling, and 4.16% of carbon

goes into the compost. The process of composting returns 3.94% of carbon from waste into gas. The least amount of carbon is present in the landfill leachate (0.24%) and the rest of the composting process (0.62%). The largest amounts of nitrogen from waste in scenario S1 (Fig. 8) remain as stock in a landfill (45.65%), and in the leachate from the landfill (27.65%). Part of the nitrogen from waste returns to new products (2.74%) through recycling

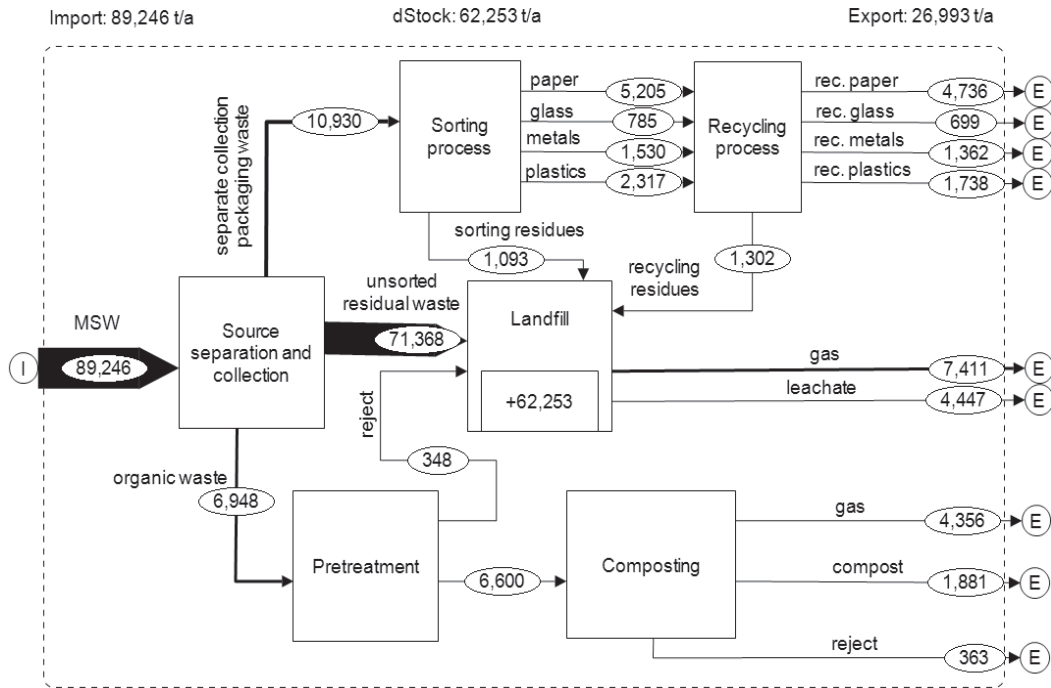


Fig. 6. Material flow analysis of waste management system for scenario S1.

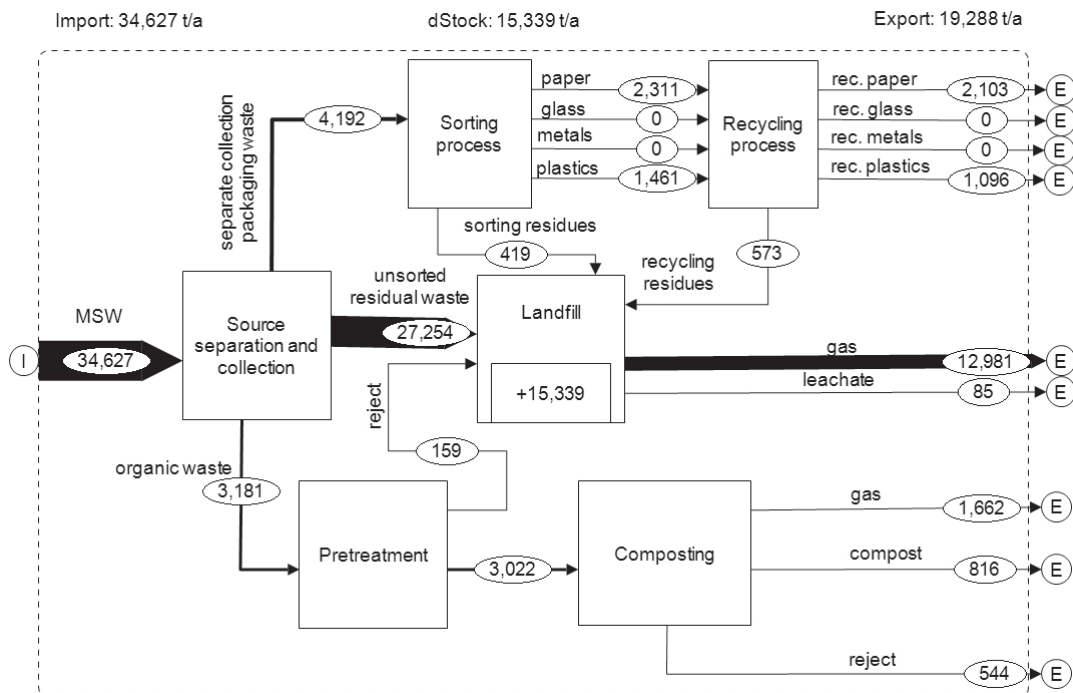


Fig. 7. Substance flow analysis of the waste management system for carbon for scenario S1.

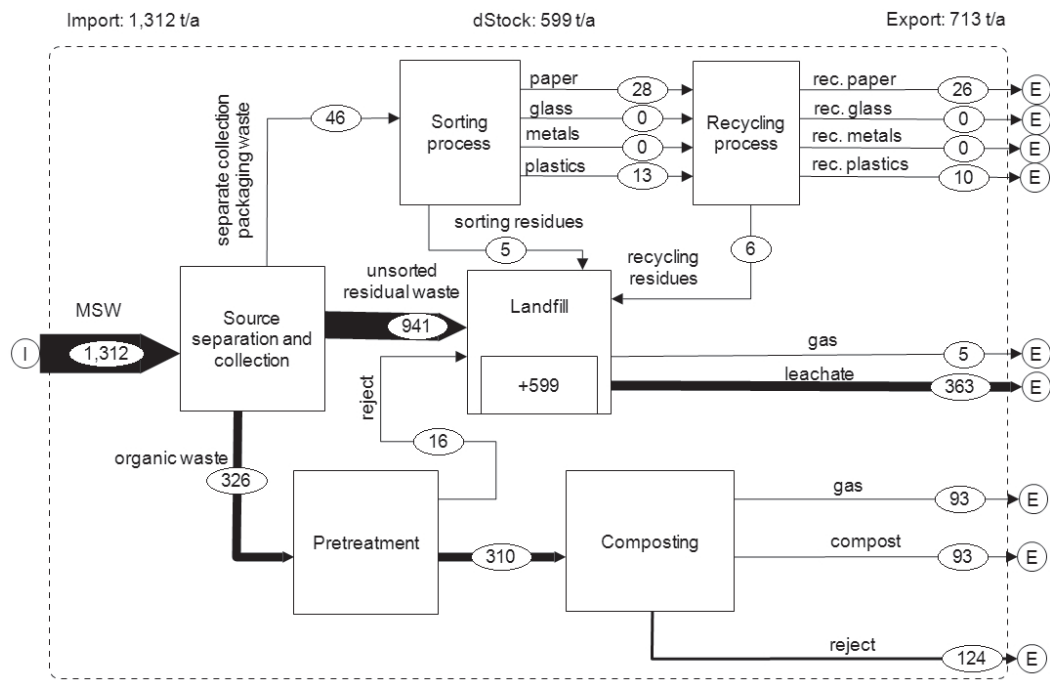


Fig. 8. Substance flow analysis of the waste management system for nitrogen for scenario S1.

processes, while 17.67% of nitrogen is transformed into a gas through a composting process. A minimum amount of nitrogen is in the landfill gas (0.38%), compost (4.48%), and the rest of the composting process (1.43%). Table 4 and Fig. 9 show the flows of waste in scenarios S0, S1, S1a, and S1b.

Table 4. Summary of material flow analysis for scenarios S0, S1, S1a i S1b (in t).

Scenario	S0	S1	S1a	S1b
Organic waste collection		6 948	13 896	18 064
Compost		1 881	3 960	5 148
Gas from composting		4 356	8 713	11 326
Reject from composting		363	528	686
Reject from pretreatment to landfill		348	695	904
Packaging waste collection		10 930	15 303	24 047
Recycled paper		4 736	6 631	10 420
Recycled glass		699	978	1 537
Recycled metals		1 362	1 907	2 996
Recycled plastics		1 738	2 433	3 824
Rest from recycling chain		2 395	3 354	5 270
Leachate	5 355	4 447	3 845	3 199
Landfill gas	8 925	7 411	6 410	5 331
Storage in landfill	74 967	62 253	53 841	44 779
Total landfilling	89 246	74 111	64 096	53 308

From the analyzed scenarios for MSW, the largest amount of waste is disposed of in a landfill site in Scenario S0. Separate collection of packaging and biodegradable materials reduces the amount of waste deposited in a landfill, which fulfills the requirements of EU directive on landfill waste [31] and the EU directive on packaging and packaging waste [32]. The amount of waste disposed to a landfill in scenario S1 is reduced by 17%, in the scenario S1a to 28%, and in the scenario S1b for 40% of the total amount of generated and disposed waste. Reducing the amount of waste that is disposed of in a landfill has the effect of reducing the amount of leachate, landfill gas, and supplies of waste, which remains stored in the body as a landfill stock. Separate collection of organic waste, or increasing the degree of such collected waste in households from 25% or 50% up to 65%, also increases the generated compost and gas, which is recovered during the composting process. By increasing the level of collection and recycling of

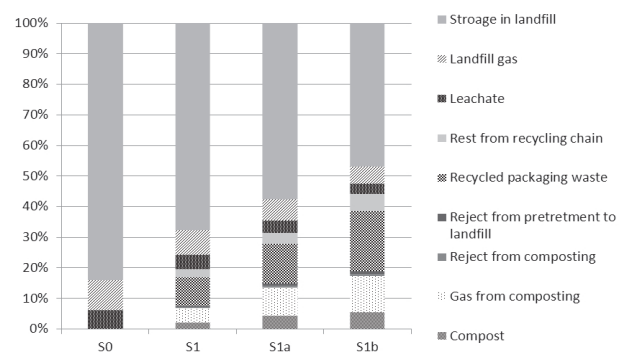


Fig. 9. Waste flow analysis in scenarios S0, S1, S1a, and S1b.

Table 5. Summary of carbon flow analysis for scenarios S0, S1, S1a i S1b (in t).

Scenario	S0	S1	S1a	S1b
Organic waste collection		3 181	6 363	8 272
Compost		816	1 632	2 122
Gas from composting		1 662	3 324	4 322
Reject from composting		544	1 088	558
Reject from pretreatment to landfill		159	319	414
Packaging waste collection		4 192	5 869	9 222
Recycled paper		2 103	2 945	4 628
Recycled glass		0	0	0
Recycled metals		0	0	0
Recycled plastics		1 096	1 534	2 411
Rest from recycling chain		992	1 390	2 183
Leachate	104	85	73	59
Landfill gas	15 825	12 981	11 015	9 017
Storage in landfill	18 699	15 339	13 016	10 655
Total landfilling	34 627	28 405	24 104	19 731

waste in scenarios S1, S1a, and S1b, the amount of waste recycled to raw materials and products is increased, too (from 9.6% or 13.4% to 21%). Processing of waste into new raw materials or into new products has a great benefit in terms of preserving natural resources, as those new products would otherwise use raw materials from natural resources for its production.

Table 5 and Fig. 10 show a summary of the flow of carbon waste management scenarios. With the current method of waste management in the Banja Luka region (Scenario S0), which is disposal of all generated waste to the landfill, carbon, which is present in the mixed solid waste, in the highest percentage remains trapped in the body of the landfill and is recovered as landfill gas. Since landfill gas consists of CO<sub>2</sub> and CH<sub>4</sub> [42], in terms of the category of the environmental impact global warming

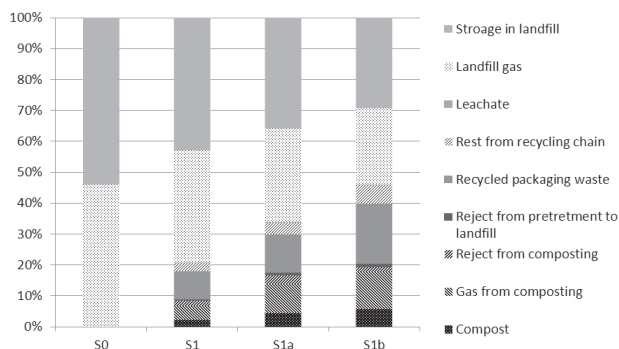


Fig. 10. Carbon flow analysis in scenarios S0, S1, S1a, and S1b.

Table 6. Summary of nitrogen flow analysis for scenarios S0, S1, S1a i S1b (in t).

Scenario	S0	S1	S1a	S1b
Organic waste collection		326	652	847
Compost		93	186	242
Gas from composting		93	186	242
Reject from composting		124	247	321
Reject from pretreatment to landfill		16	33	42
Packaging waste collection		46	63	100
Recycled paper		26	36	56
Recycled glass		0	0	0
Recycled metals		0	0	0
Recycled plastics		10	13	21
Rest from recycling chain		10	14	23
Leachate	492	363	242	161
Landfill gas	7	5	3	2
Storage in landfill	813	599	399	266
Total landfilling	1 312	968	644	429

(GW) and from the point of photo-chemical ozone formation (POF), those two are not preferred compounds [50]. Starting a separate collection of packaging and organic waste reduces the amount of carbon in the waste disposed of on a landfill, which means that the amount of carbon in the landfill gas and the carbon stored in the landfill body is also reduced. By reducing the amount of carbon in the landfill gas, the emission of CH<sub>4</sub> and CO<sub>2</sub> into the atmosphere would be reduced, too, which has a favorable impact on GW and the POF, and that would represent a benefit for the environment. In MSW, or the waste fractions such as plastics, paper, and organic waste (Table 1), the carbon is present in a high percentage. Therefore, with the separate collection and recycling (composting) of these waste fractions, a significant portion of carbon is directed to recycling or in raw materials and new products (compost). From the

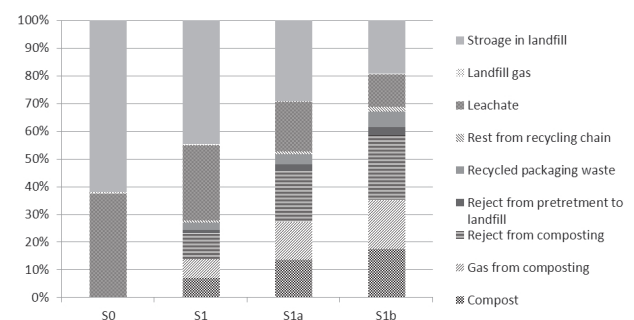


Fig. 11. Nitrogen flow analysis in scenario S0, S1, S1a, and S1b.



point of destination into which the carbon is directed through the treatment processes, carbon from the waste that is directed to the raw materials and products through recycling is sent to a destination, and it is preferable that more and more carbon is directed to new products. By achieving the separate collection of packaging and organic waste in the amount of 55%, the amount of carbon in the rest of the waste that ends up on a landfill would be reduced by 43%.

Table 6 and Fig. 11 show summarized flow of nitrogen in the waste management scenarios. Unlike carbon, which is in a significant percentage present in the solid waste, nitrogen is in a far smaller percentage present in the solid waste and waste fractions (Table 1). With the current method of waste management in the Banja Luka region (scenario S0), which is disposal of all generated waste to the landfill, nitrogen from waste is stored in the landfill body in the amount of 62%, in the leachate in the amount of about 37.5%, and a slight quantity of nitrogen ends up in landfill gas. Nitrogen in leachate, which is in the form of nitrate, nitrite, and ammonium ions, may present a risk to the environment and human health. The above nitrogen compounds and their emissions to the aquatic environment can have a negative effect on the categories of environmental impacts such as acidification (AC) and nutrient enrichment (NE) [50]. Starting the process of separate collection of packaging and organic materials would reduce the amount of nitrogen in the waste that is disposed of in a landfill. This means that the amount of nitrogen in the leachate and stored in the landfill body would also be reduced. By reducing the amount of nitrogen in the leachate, emissions of nitrogen compounds into the aquatic environment are also reduced, which has a favorable impact on AC and the NE, and that would represent a benefit for the environment. Separate collection and recycling (composting) of packaging and organic waste directs a significant proportion of nitrogen into recycling or into raw materials and new products (compost). From the point of destination into which the nitrogen is directed through the treatment processes, nitrogen from the waste that is directed to the raw materials and products through recycling is sent to a proper destination, and it is preferable that more and more nitrogen is directed to new products. By achieving the separate collection of packaging and organic waste in the amount of 55%, the amount of nitrogen in the rest of the waste that ends up on a landfill would be reduced by 67.3%. That is, the emission of nitrogen from the waste that goes into the hydrosphere or into an inadequate destination is reduced to 32.7% compared to the current method of waste management in the Banja Luka region.

## Conclusions

By applying the MFA/SFA as an example on the Banja Luka region, we can see a large difference between the current method (scenario S0) and modeled scenarios of MSW (scenario S1, S1a, and S1b), which have been

developed in accordance with the EU and national legislation.

MFA has been applied for analysis material flow analysis for waste flows (MSW) and waste fractions. On the other hand, the SFA is focused on the transformation of waste by processes of waste treatment and monitoring hazardous substances and their transformations through the entire waste management system. SFA has been applied for evaluating different waste management systems regarding environmental protection and resource conservation.

By analyzing MSW streams in scenarios S0 and S1, S1a and S1b, respectively, we can notice the following:

- For the current method of disposal of all collected waste at the landfill (Scenario S0), the largest quantity of waste ends up in storage in the landfill body in the form of landfill gas and leachate.
- The amount of compost increases from S1 through s1a to s1b as the amount of organic waste is increased.
- By increasing the collection of packaging waste from S1 through s1a to s1b, the share of waste that recycles into new raw materials (products) is increased.
- By increasing the collection of organic and packaging waste (S1, S1a, and s1b), the amount of waste deposited in the landfill has been reduced, affecting the storage of landfill space and reducing the generation of leachate and landfill gas.

By analyzing carbon flow in the modeled waste management scenarios, we can notice the following:

- In scenario S0, the largest amount of carbon remains stored in the landfill body, while a part of the carbon through landfill gas is transformed into  $\text{CH}_4$  and  $\text{CO}_2$ .
- Separate collection of packaging and organic waste also reduces the amount of carbon that ends up in the landfill, as well as the amount of carbon in the landfill gas.

By analyzing nitrogen flow in the modeled waste management scenarios we can notice the following:

- The largest quantity of nitrogen remaining in storage in the body of the landfill and the leachate is in scenario S0.
- Separate collection of packaging and organic waste increases the share of nitrogen in new products and compost, and the amount of nitrogen in the landfill gas and in the landfill body is reduced.

The current system for MSW in this region (scenario S0), which is based on the disposal of all generated municipal waste to a landfill, has by far the worst performance in terms of environmental protection and human health. Setting up a separate collection of packaging waste and its recycling and processing into new materials or products, as well as biological treatment of organic waste, has a great benefit for preserving natural resources, environmental protection, and human health. The benefits to the environment and preservation of natural resources are important in the case of achieving a high level of separate collection of packaging waste (55%) and organic waste (65%) (Scenario S1b).

With regards to the Banja Luka case study, the combination of MFA/SFA with scenario analysis shows good potential for indicating the difference between the current waste management and the investigated options for progress. Improvements in the MSW management system in Banja Luka region in the future must go in the direction of separate waste collection with its achievement at the highest possible level. MSW management in the Banja Luka region is taken as an example. Because a similar situation in waste management is not only present in the RS and B&H, but also in the countries in the region, the results and recommendations on the improvement of existing inadequate waste management can be applied to them as well. MFA/SFA can be used as help and support the decision-making process of waste management in other regions.

### Conflict of Interest

The authors declare no conflict of interest.

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