Environmental Systems Analysis of Municipal Solid Waste Management in Chisinau, Moldova

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ENVIRONMENTAL SYSTEMS ANALYSIS OF MUNICIPAL SOLID WASTE MANAGEMENT IN CHISINAU, MOLDOVA

Current situation and future perspectives

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Moldova is a picturesque country - all rolling green hills, whitewashed villages, placid lakes and sunflower fields with an old-world charm that's hard to manufacture.

Source: Lonely Planet’s website
ABSTRACT

The increasing scale of economic activity, i.e. industrialization, urbanization, rising standards of living and population growth, has led to a sharp increase in the quantity of waste generated. The environment has a limited capacity for waste assimilation. If too much waste enters the environment rather than being recycled or reused, the assimilative capacity of the environment is put under too much stress to be able to handle the total quantity of waste generated. Nowadays, due to improper treatment, waste management is something that affects people. In the Republic of Moldova handling of all types of waste such as municipal, hazardous, industrial etc. relies on landfilling only.

This thesis is a basis for decision-making for local authorities and is about environmental systems analysis and computer modelling of municipal solid waste management in Chisinau.

The ORWARE model was used for systems analysis, aiming to examine the environmental impacts that could be expected from different future alternatives (scenarios) for future municipal solid waste management. By having a strong foundation in life cycle assessment, ORWARE intends to cover the environmental impacts through the entire life cycle of waste management. The model consists of several submodels starting from the generation point; collection, transportation, biological treatment, incineration and final disposal. Moreover, the model comprises material recycling of plastics and cardboard.

Different solid waste management scenarios were constructed, simulated and compared with each other. The first scenario was the current waste management in Chisinau that contains only landfilling. Three other scenarios for future waste management in (2020) were constructed and simulated. They took into consideration that a certain amount of materials will be recycled in 2020; consequently the same amount of materials was assumed to be recycled in all future scenarios. The business as usual scenario had as a basis landfilling with greater amount of waste as in the year 2005. The incineration scenario had a mixture of landfilling and incineration with energy recovery. The last scenario, the biological treatment scenario, differed from the incineration scenario in that 25% of the organic waste was treated by anaerobic digestion with biogas production and fertilizer for spreading on arable land.

The simulation results show that the incineration and anaerobic digestion scenarios have great environmental advantages over the landfill scenario. Even though only one forth of the organic waste is treated biologically, the last scenario is the most environmentally friendly treatment option. If more organic waste will be separated and treated biologically, the impact will be further reduced. Economical aspects were not included in this study, due to limited time but a further analysis of the costs is necessary for a proper decision making.
I started my Master of Science thesis on Environmental Systems Analysis of Municipal Solid Waste in Chisinau Moldova in the middle of August 2005. I was an especially lucky student to have two exceptional supervisors in Björn Frostell and Monika Olsson. When it came to making a decision, it was very fast and effective. I am very grateful for their support, advices and our interesting discussions. I have learned a lot about environmental systems analysis, municipal solid waste management while my skills as a researcher were shaped. Thank you for your constructive comments, for being friendly and tolerant to extra meetings.

Probably, my thesis work would have required much more time to be finished if I would not have had the possibility to access the facilities at the Division of Industrial Ecology. At this cosy division, I enjoyed both the work and the social environment. I would also like to thank the teachers and colleagues from the division for the invaluable coffee breaks, lunches and different other activities that we had together. It was also really entertaining to play one of the most famous Swedish games called innebandy every Thursday with Stefan Johansson and the guys from the Chemistry Department.

What I have learned for sure is that hard work always gives a positive result. When you deal with systems analysis, the most important attribute is to be patient. I always wanted to do things at once but in the reality it does not happen like that, especially if you work with a computer model. I am proud to say that I have improved that. Thanks to Getachew Assefa who assisted me with the ORWARE model and who used to tell me dig in, be patient and you will find the mistakes. I remember those days when I used to solve three model errors with red marks and to have five or six new ones after running the model again. One day, it happened that the simulation command “runpavel” just ran … so that was the most tremendous achievement of my work.

I am grateful to my EESI colleges, course teachers and friends. I had never met so many nationalities before my studies in Sweden. It was a fantastic experience to learn about different cultures and different peoples’ perceptions. It was, nevertheless, very exiting.

Last but not least I would like to extend my gratitude and my love to my family for their never-ending care and support.

Stockholm, March, 2006

Pavel Gavrilita
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Abbreviations

CHP - Combined Heat and Power
HDPE – High Density Poly Ethylene
GWP - Global Warming Potential
IW - Industrial Waste
LCA – Life Cycle Analysis
LCC – Life Cycle Costing
LDPE – Low Density Poly Ethylene
LFG - Landfill Gas
MFA – Material Flow Analysis
MSW - Municipal Solid Waste
MSWM - Municipal Solid Waste Management
NOx – Nitrogen Oxides
RM – The Republic of Moldova
SFA – Substance Flow Analysis
TJ – Terra Joule
VOC - Volatile Organic Compounds
WM - Waste Management
GLOSSARY OF TERMS

**Compensatory process**: process of conventional production of a function, which is added to a system as a means to circumvent the problem of different functional output of systems in a comparative study.

**Core system**: part of analysed system that is directly related to the function of a system, includes those activities that may be directly affected by decisions based on the study. In this study, it mostly relates to the function of handling and treating of solid waste.

**Down-stream process**: part of analysed system that takes place as a successor of activities in the core system.

**Environmental systems analysis**: systems analysis for assessment of environmental impacts and/or natural resource use caused by the studied system (a product, service, economy, or project), often focused on quantification of material and energy flows in subsystems of nature and society and the evaluation of the future sustainability of different alternatives of action.

**Functional unit**: quantified measure of functional output from a system for use as a reference unit in a life cycle assessment.

**Model**: simplified representation of reality, in the context of this thesis generally meaning a computerized mathematical model.

**Organic waste**: solid waste mainly as food scrap, which is readily biodegradable in biological treatment such as composting or anaerobic digestion.

**ORWARE**: an acronym for ORganic WAste REsearch. It is a computer-based model for calculation of substance flows, environmental impacts, and costs of waste management.

**Scenario**: description of a possible future situation, based on assumptions about the future, and is characterized by choice of system boundaries, allocation methods, technology, time, and space.

**Municipal Solid Waste**: refers to a mixture of different wastes with a low overall content generated by household, business, street, traditional market and industry (excluded non-hazardous materials).

**Sub-model**: smaller, detachable entities of an entire model, i.e. landfill and incineration submodels of a model of a solid waste management system.

**System boundary**: delimitation in time, space and function between a system and its surroundings.

**System**: a set of related entity that interact with each other in some way.

**Upstream process**: part of analysed system that provides necessary input to the core system, e.g. extracting and processing resources used by the core system.
1. INTRODUCTION

Definition of Municipal Solid Waste

The majority of human activities will inevitably result in the generation of waste, due to the imperfect utilization of energy and resources. Waste is a source of pollution and land degradation of growing concern. It seems that the production of waste cannot be avoided. The generation of waste is closely related to economic and population growth, and changes in consumption patterns. There are numerous definitions of what exactly constitutes waste, and many classifications, which attempt to categorize waste flows. According to the European environmental Protection Act (1990), “waste is any substance, which constitutes scrap material or any effluent or other unwanted surplus substance arising from the application of a process, or any substance or article, which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled”. By nature, municipal solid waste (MSW) is one of the most difficult sources of waste to manage due to its complex composition and diverse sources of generation (Read, 1999). MSW is defined to include refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings. Management of MSW is a major responsibility of local governments.

The Waste Management Hierarchy

Management of waste is a complex task, which requires appropriate organisational capacity and cooperation between numerous stakeholders in the private and public sectors. Although it is essential to public health and environmental protection, solid waste management in most cities of developing countries is highly unsatisfactory. In general, there are five main categories of socially acceptable waste handling options available (waste hierarchy), namely (1) prevention, (2) re-use (3) recycling (4) waste to energy (incineration) and (5) landfilling (EU 1999). However, not every waste handling option is suitable for every category of waste. Each waste handling option has its own economic and environmental characteristics. Waste prevention or minimization is usually the most favoured waste handling option, but may be difficult to achieve in our consumer society. Re-use and recycling of waste have clear environmental advantages. By re-using and recycling materials, less virgin materials need to be used, ultimately resulting in a closed production cycle in which no or at least very few virgin materials are actually required. The economic costs of re-use and recycling, however, are substantial, and there may be technical problems preventing re-use and recycling on a large-scale. Moreover, it should be noted that even recycling and re-use might cause environmental damage. Biological treatment is also one way of recycling and it is one of the most environmentally favoured methods of the organic waste treatment. Energy can be obtained through incinerating waste. Incineration provides a major contribution to reaching the targets set by the European government for the use of energy from renewable resources. Landfilling of waste predominant until a decade ago in developed countries and still the only option in most developing countries is the least preferred option for waste treatment. Although it is relatively cheap, it also leads to relatively high environmental risks due to emissions into the air and groundwater.

The Waste Management Problem

The increasing scale of economic activity, i.e. industrialization, urbanization, rising standards of living and population growth, has led to a sharp increase in the quantity of waste generated. The environment has a limited capacity for waste assimilation. If too much waste enters the environment rather than being recycled or reused, the assimilative capacity of the environment is put under too much stress to be able to handle the total quantity of waste generated. This may result in pollution and resource degradation and consequently economic damage (Turner, 1995).
According to the mass balance principle, which can be derived from the second law of thermodynamics\(^1\) “mass inputs must equal mass outputs for any process”. This implies that any virgin materials used in both the production and consumption process must eventually be returned to the environment as higher entropy waste products or pollutants (Ayres, 1989).

It is not yet possible to achieve a one hundred percent recycling rate. A society is, however, to some extent able to choose the quantity and quality of waste it will generate. The transformation of a useful product into waste strongly depends on the functions it has for the owner and its economic value. Waste management is inevitably linked to the economy, as waste is defined by its relative economic value. It is likewise linked to ecology, since left on its own waste is likely to affect the environment. Finally, it is a social issue, as waste is mainly a social construct and it raises the question about the responsibilities of individuals towards society (Ludwinget et al., 2003).

\(\textit{1.1 Strategic Aspects of MSWM}\)

To achieve a sustainable and effective waste management, development strategies must go beyond purely technical considerations to formulate specific objectives and implement appropriate measures with regard to political, social, economic and ecological aspects of municipal solid waste management (MSWM):

\textbf{Political aspects}

Political aspects concern the formulation of goals and priorities, determination of roles and jurisdiction, and the legal and regulatory framework:

- Society’s goals and priorities regarding environmental protection and equitable service access must be clearly articulated in order to mobilise popular support and resources required for their realisation.
- A clear definition of jurisdiction and roles is essential to the political sustainability of MSWM systems. The strategic plan for MSWM provides a basis for putting the defined roles of government authorities and other actors into effect.
- By laws, ordinances and regulations for MSWM should be few in number, transparent, explicit and reasonable (Schübeler et al., 1996).

\textbf{Social aspects}

As soon as waste is out of sight it is no longer perceived as a problem. Social acceptance problems arise mainly from local opposition when new plans to build a waste treatment facility in peoples’ neighbourhood are established (Ludwing et al., 2003). Social aspects of MSWM include the patterns of waste generation and handling of households and other users, community-based waste management and the social conditions of waste workers:

- Waste generation patterns are determined by people’s attitudes as well as their socio-economic characteristics. Attitudes towards waste may be positively influenced by awareness-building campaigns and educational measures.
- Even where municipal waste collection services are provided, user cooperation is essential to efficient MSWM operations. Cooperation may be promoted through general awareness-building programmes as well as focused MSWM information campaigns (Schübeler et al., 1996).

\(^1\) The second law of thermodynamics, the law of conservation of mass/energy, states that physical processes always require conservation of energy/mass. In other words, energy and matter cannot be created or destroyed (Perman et al., 1996)
Economic aspects
The economic problems of the waste are due to the fact that, by definition, waste is material with no value. Classical economic mechanisms of supply and demand controlling the flow of goods, therefore, fail for waste materials. As a consequence, they tend to accumulate in the natural environment without any measures of authorities (Ludwing et al., 2003). Economical aspects of MSWM are concerned with the impact of services on economic activities, cost-effectiveness of MSWM systems, macro-economic dimensions of resource use and conservation, and income generation:
- Solid waste generation and the demand for waste collection services generally increase with economic development.
- Economic evaluation constitutes an important input to strategic planning and investment programming for MSWM.
- Measures should be introduced which discourage wasteful use of materials and encourage waste minimisation. The best way to promote efficient use and conservation of materials is to internalise the costs of waste management as far as possible in the production, distribution and consumption phases (Schübeler et al., 1996).

Ecological aspects
Industrial civilization relies on materials that are mined from enrichment deposits and are hence very different in composition from the resources that natural systems draw on. Our civilization leaves chemical footprint in the environment i.e. it changes chemical composition of some sensitive ecological compartments such as air, water, soil, etc (Ludwing et al., 2003).

1.2 Goal and objectives

The goal
The goal of this thesis is to provide improved knowledge and information on systems aspects of waste management in Chisinau, Moldova. Since Moldova aims to join the European Union and has signed a number of environmental agreements, current waste management (WM) definitely must be changed since it does not comply with the European Waste Regulation.

The objectives
1. Provide an analysis of material flows that constitute the municipal solid waste in Chisinau.
2. Analyse current and future waste management treatment alternatives
3. Describe environmental systems analysis of waste management in general and specifically with the ORWARE model.
4. Simulate the Chisinau waste management system in the ORWARE model.
5. Discuss advantages and disadvantages of future scenarios.
6. Based on the study results, suggest the means of achieving improvements in the Chisinau municipal solid waste management.

1.3 The limitations of the study

ORWARE consists of a number of separate sub-models. One of the challenges of this thesis is the collection of data before performing a simulation. Since Moldova is deeply focused on economical aspects of the country, such advanced environmental systems thinking as in Sweden have not developed yet. That way it is so difficult to find data and in most cases it simply does not exist even in the capital of the country, Chisinau. Thus several assumptions had to be made in order to perform the simulations. The assumptions were based on the experience from other
countries and were always discussed with my supervisors. Due to lack of data, only one stream as a source of waste including households, institutions, market, etc. were considered. Also it was quite complicated to forecast what will happen in 15 years from now. How will people’s manners change and to what extent will they become more environmentally alert in the coming years? How much will be recycled? What will be the quality of recycled materials? Another challenge of this thesis is the timeframe, thus influencing system boundaries. The attempt to cover as much as possible is limited by the same frame. Due to the same reason, just a few applications of ORWARE are used in this thesis, which can be seen in the subsection “ORWARE in decision-making”.

2. THE STUDY AREA

The following section provides a brief description of Chisinau city, capital of the Republic of Moldova, as well as the country itself including its socio-economic and environmental features. The existing waste management system and the waste characteristics of Chisinau city are analysed. Moreover, the anticipated municipal solid waste amount and composition is also estimated.

2.1 General information

The Republic of Moldova (map 2.1) is a small country, favourably situated in the south-eastern part of Europe, neighbouring Romania to the West and Ukraine to the East. With a population of 4.3 million inhabitants, it occupies a territory of 33700 km² (slightly larger than that of Belgium), which stretches a maximum distance of 350 km from north to south and 150 km from east to west at its widest point. On August 27, 1991, the Moldovan parliament and its General Assembly declared its independence. Following Moldova’s declaration of independence in 1991, two regions of the republic subsequently declared their own independence establishing the self-proclaimed Republic of Gagauzia (comprising a region in the south of Moldova dominated by a Turkish-speaking, Christian-Orthodox population) and the self-proclaimed Republic of Transnistria (consisting of the region located on the left bank of the south-flowing Nistru river and it is not under control of Moldovan authorities). The independence of these regions was and is not recognized by the Moldovan Government, nor has it been by any other nation. The capital of the country, city of Chisinau, situated in the middle of the country and occupying 120 square km is the main administrative, economic, scientific and cultural centre of the Republic of Moldova. The population of Chisinau municipality on January 2005 was 716700 people (Tab. 2.1), which makes it the largest and the most developed city in Moldova.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Urban area</th>
<th>Rural area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chisinau municipality</td>
<td>716.7</td>
<td>647.7</td>
<td>69</td>
</tr>
<tr>
<td>Chisinau city</td>
<td>592.6</td>
<td>592.6</td>
<td>-</td>
</tr>
<tr>
<td>Total population of Moldova without Transnistria</td>
<td>3386</td>
<td>1308.8</td>
<td>2077.2</td>
</tr>
</tbody>
</table>

Source: Internet data (Statistical Yearbook of Moldova 2004)

Economic features

The Republic of Moldova is an industrial-agricultural country and still remains one of the poorest countries in Europe, despite recent progress from its small economic base. Since Moldova has no mineral resources, the economy depends heavily on agriculture, featuring fruits, vegetables, wine,
and tobacco. Moldova must import almost all of its energy supplies from Russia. Energy shortages contributed to sharp production declines after the break-up of the Soviet Union in December 1991. The share of agriculture and industry in real GDP constituted 37% in 2003. Approximately 75% of the Moldovan territory is covered by rich black soil (chernozem), which together with the mild climate, makes the country a naturally productive region for agriculture. About 51% of the country’s active population is involved in agriculture. The main products imported by Moldova are natural gas, petroleum products, transport machinery, and equipment.

After independence, Moldova introduced a convertible currency, freed prices, stopped issuing preferential credits to state enterprises, backed steady land privatization, removed export controls, and freed interest rates. The economy returned to a positive economic growth of 2.1% in 2000, 6.1% in 2001, 7.2% in 2002, 6.3% in 2003, and 6.8% in 2004. The economy remains vulnerable to higher fuel prices, poor weather, and the scepticism of foreign investors.

Environmental features
The only existing means of waste management in the Republic of Moldova is landfilling, which in many cases is unauthorised. Currently, only 331 out of 1781 landfills fulfil international standards. Many landfills are overloaded in comparison to existing permits and are not maintained in a proper way, causing more pollution. The total surface of landfills in the country constitutes 1144 ha, with an amount of 29.4 million m³ of waste. All types of wastes; municipal, industrial, medical and hazardous are disposed of together that cause a danger to the environment and human health. In Moldova, no landfill gas capturing method is practiced, as is used in many other countries because it is not seen as a business. An important problem is the general environment impact caused by anthropogenic activities since the population is not environmentally educated.

The management of waste should definitely be improved but since considerable investments are required, this development is slow. There is also an important need to achieve public participation in waste separation and recycling.

Since Moldova searches membership in the European Union, it started to create strategic development plans. One of them is the Strategic Plan for social-economic development of the Republic of Moldova, whose main environmental objectives are:

- Rational utilisation of non-renewable materials and transfer to alternative sources of raw materials and energy. Start to reuse and recycle renewable resources.
- Develop and promote cleaner technologies with the purpose of reducing the use of raw materials and minimizing the generation of industrial waste until their elimination.
- Maximum reduction of MSW generation, separation, composting and increased use of secondary raw materials.

Why is there a need for changes?
Environmental degradation remains the most important factor contributing to a decreasing quality and longevities of life in Moldova. Due to the social and political situation, the waste management in Moldova remains at the same stage of management as 20 years ago. Until now, no sufficient actions were taken in the direction of improving the current waste management. The existing way leads to growing impacts. The recommendation from the European Union for waste management is formulated in the waste hierarchy (EU 1999): 1. Waste prevention; 2. Re-use of products; 3. Recycling of materials; 4. Recovery of energy; 5. Final disposal. This guideline seems impressive and attractive but Moldavian legislation has not supported this hierarchy by any laws. Even though a “National Program of Capitalization of Industrial and Municipal Solid Waste” was created, no serious measures were taken to change the current situation. Final disposal or landfilling is a process under almost no control with high emissions and it is the least preferable waste treatment. Due to shortcoming in technological capacity for collection, reuse and recycling, most generated waste is landfilled even though it contains useful materials such as
glass, metal, plastic etc. These materials have a value which is wasted when the products are dumped.

Note: Paper production from recycled paper needs only 15-20% of the energy needed for direct paper production. It can also save around 25 m³ of water, 25% of bleaching chemicals and reduce air pollution with 95%. One recycled tonne replaces 4m³ of raw wood. Five adult trees (80-100 years of age) are needed to produce one tonne of paper.

Recycling of glass reduces air pollution with 20% in comparison to the production of glass from virgin materials. It is even more important to know that glass can be reused 25-30 times before recycling. Production of one tonne of recycled glass can save such as 630 kg of sand, 40 kg of feldspar, 112 kg of limestone, 180 kg of caustic soda and other materials.

Plastics constitute around 10% of the total MSW quantity in Moldova. Its decomposition takes 100 to 1000 years with a negative impact on the environment. Since MSW contains many different types of plastic, it is quite difficult to recycle it. In the view fact that plastic has a high calorific value, unsorted plastic has to be incinerated.

### 2.2 Solid Waste in the Republic of Moldova

The composition of MSW is a mirror of society’s consumption patterns. Figures show that in developed countries, more waste is generated per capita compared to developing countries. Based on the same figures in low income areas the main components of MSW are readily biodegradable waste, this fraction is less dominant in highly developed cities (Ludwing et al., 2003). In Tab. 2.2, the total amount of generated waste in urban areas in the Republic of Moldova divided in different types of waste is given. The greatest amount of waste in the country is produced by quarrying industry and food and drinks production industry. Due to a high demand for real estate, waste from quarrying industry is growing every year.

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste of quarrying industry</td>
<td>235</td>
<td>417</td>
<td>943</td>
</tr>
<tr>
<td>Waste of animal production</td>
<td>371</td>
<td>485</td>
<td>281</td>
</tr>
<tr>
<td>Waste of foodstuff and drinks production industry</td>
<td>1051</td>
<td>1086</td>
<td>567</td>
</tr>
<tr>
<td>Waste of municipal economy</td>
<td>207</td>
<td>599</td>
<td>478</td>
</tr>
<tr>
<td>Household waste</td>
<td>8</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Waste of inorganic chemistry</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Waste of plant growing</td>
<td>48</td>
<td>62</td>
<td>47</td>
</tr>
<tr>
<td>Waste of forestry industry</td>
<td>17</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Secondary raw materials from ferrous metallurgy</td>
<td>19</td>
<td>7</td>
<td>103</td>
</tr>
<tr>
<td>Secondary raw materials from non-ferrous metallurgy</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2040</strong></td>
<td><strong>2754</strong></td>
<td><strong>2538</strong></td>
</tr>
</tbody>
</table>

*Source: Statistical Yearbook of Moldova, 2004*
Figure 2.1 indicates that the generation of municipal solid waste decreased considerably after the collapse of the Soviet Union. The waste generation drop is caused by fall in the demand, consequently industrial activities were reduced. Since those times, it has remained quite stable during a transition to market economy.

The amount of waste disposed of varied considerably between 2001 and 2002 (Fig. 2.2). A probable explanation is a variation in industrial activity due to economical instability.

### 2.3 Current situation of MSW in Chisinau

According to the Statistical Yearbook of Moldova 2003, 29.4 million tonnes of waste were disposed of in the county. Most of the waste was produced in big cities mainly in the capital of the country. Every inhabitant in the capital produces annually 350-400 kg of MSW that constitute 1m³. A larger amount of waste, around 1.6 m³ per year, was generated by small houses residents. The generation of MSW has a grown more or less 2.5% per year since 2002. The volume of transported waste was given by Regia Autosolubritate (the waste management company in Chisinau city) can be seen in Tab. 2.3.

| Tab. 2.3 Volume of transported MSW in Chisinau, Moldova,(thousands of m³) |
|-----------------|--------|--------|--------|
|                 | 2002   | 2003   | 2004   |
| Apartments      | 491    | 484    | 479    |
| Private houses  | 24     | 26     | 32     |
| Businesses, institutions, agencies | 202 | 222 | 242 |
| Transported by companies, own transport means | 24 | 20 | 20 |
| **Total**       | **741** | **752** | **773** |

Source: Regia Autosolubritate
Composition of MSW

The average composition of MSW in Chisinau city is shown in Tab. 2.4. The quantity of each fraction was calculated based on the total volume of transported waste from the Tab. 2.3. The total volume of waste was converted to total mass of waste based on the relation 1 m³ = 0.4 tonne. With this conversion factor, the generation of waste was 300800 in 2003 and 309200 tonnes in 2004.

**Tab. 2.4 Calculated average composition and quantities of MSW in Chisinau, Moldova**

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Weight percentage</th>
<th>Quantity, tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average 2003/2004</td>
<td>2003</td>
</tr>
<tr>
<td>Paper and carton</td>
<td>5.1 %</td>
<td>15 341</td>
</tr>
<tr>
<td>Organic substances (food rest)</td>
<td>64.6 %</td>
<td>194 317</td>
</tr>
<tr>
<td>Organic substances (leaves, branches)</td>
<td>3.9 %</td>
<td>11 731</td>
</tr>
<tr>
<td>Glass</td>
<td>4.1 %</td>
<td>12 333</td>
</tr>
<tr>
<td>Metals</td>
<td>3.1 %</td>
<td>9 325</td>
</tr>
<tr>
<td>Plastics</td>
<td>9.7 %</td>
<td>29 178</td>
</tr>
<tr>
<td>Textiles</td>
<td>4.9 %</td>
<td>14 739</td>
</tr>
<tr>
<td>Waste of construction (wood)</td>
<td>1.7 %</td>
<td>5 114</td>
</tr>
<tr>
<td>Waste of construction (stones, mortar)</td>
<td>2.9 %</td>
<td>8 723</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>300 800</strong></td>
</tr>
</tbody>
</table>

Source: Regia Autosolubritate and own calculations

Transportation

All solid wastes are collected in containers and transported to the Cretoaia landfill, located 44 km from the city centre. Most of the collection and transport is carried out by the company Regia Autosolubritate. A small amount of waste is transported by big companies by means own waste transport vehicles. The transport services are provided for approximately 500 thousand inhabitants of Chisinau city and also for private companies, agencies, institutions etc. The trucks used for waste transportation and their capacity are presented in Tab. 2.5.

**Tab. 2.5 Waste transportation trucks in Chisinau, Moldova**

<table>
<thead>
<tr>
<th>Type of trucks</th>
<th>Number of trucks</th>
<th>Capacity, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAZ 53</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>KO 413</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>MAZ</td>
<td>9</td>
<td>35</td>
</tr>
<tr>
<td>KAMAZ</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>MAN</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>63</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: Regia Autosolubritate

The transport from the city to the landfill is carried out in 2 stages. First, waste is transported to the edge of the city by trucks with smaller capacities such 11 and 14 m³ for an average distance of 11 km. Here, waste is loaded into trucks with bigger capacity (from 35 to 50 m³). The distance from the edge of the city to the landfill is 33 km. For waste transportation, the types of vehicle...
from Tab. 2.5 are used. The annual amount of consumed fuel for waste transportation can be seen in Tab. 2.6 and is included due to its impact on the environment from gas emissions to the atmosphere.

Tab. 2.6 Consumed fuel for transportation of MSW to the landfill during 2003

<table>
<thead>
<tr>
<th>Type of fuel</th>
<th>Quantity, thousand litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>246</td>
</tr>
<tr>
<td>Diesel</td>
<td>1152</td>
</tr>
<tr>
<td>Liquid Natural Gas</td>
<td>424</td>
</tr>
</tbody>
</table>

Source: Regia Autosolubritate

**Landfill**

The landfill with an area of 19.4 ha and a capacity of 44 million m$^3$ is located 5 km from the villages Cretoaia and Tintareni (Map 2.2).
Approximately 3000 m$^3$ of waste is disposed of daily, 5 days per week on this landfill. Based on the initial landfill project, the thickness of each layer of waste should be 2 m which should be covered with 40 cm of soil. At the moment, this condition is not respected. Due to the absence of more advance treatment technologies, the volume of accumulated waste in the landfill is growing steadily. The annual accumulation is circa 750 thousand m$^3$ of MSW. For instance, in 2003 it was 752 thousands m$^3$ and in 2004 the disposed amount was 773 thousands m$^3$. Until 2004, a total of 11500 thousand m$^3$ of waste, representing 25% of the total capacity of the landfill, had been disposed of. There is no landfill gas collection system installed and the leachate emissions are poorly controlled.

### 2.4 The anticipated MSW situation of Chisinau in 2020

Currently, the MSW generation rate in Chisinau is growing steadily, by 2.5% per year. Since Moldova has a quite high GDP growth per year (2004 it was 6.8%) and the population tends to move to urban areas, it is presumed that the waste generation rate will increase up to 4% per year in the future. It is probably reasonable to assume an average growth rate of 3% per year for the next 15 years. Following this, the annual generation of waste in Chisinau may be expected to grow to 1204 thousand m$^3$ that correspond to 482 thousand tonnes of MSW in 2020. Indeed, not only changes in the generated amount of waste may be expected but also a change in their composition. It is well known that waste composition depends on country GDP. The GDP of Moldova in 2020 was estimated based on previous years annual growth. Looking at the GDPs and waste composition of Western (Denmark, Germany, Sweden) and Eastern (Romania, Hungary, Slovakia) European countries, the future waste composition in Moldova (2020) was forecasted (Tab. 2.6).

Tab. 2.6 Average waste composition in different countries 2005 and predicted Moldova composition 2020, (weight percentage)

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Western European Countries 2005</th>
<th>Easter European Countries 2005</th>
<th>Moldova 2005</th>
<th>Moldova 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and carton</td>
<td>26</td>
<td>14</td>
<td>5.1</td>
<td>11</td>
</tr>
<tr>
<td>Organic material</td>
<td>27</td>
<td>42</td>
<td>68.5</td>
<td>55</td>
</tr>
<tr>
<td>Glass</td>
<td>6</td>
<td>5</td>
<td>4.1</td>
<td>5</td>
</tr>
<tr>
<td>Metals</td>
<td>4</td>
<td>5</td>
<td>3.1</td>
<td>4</td>
</tr>
<tr>
<td>Plastics</td>
<td>7</td>
<td>9</td>
<td>9.7</td>
<td>10</td>
</tr>
<tr>
<td>Textiles</td>
<td>2</td>
<td>5</td>
<td>4.9</td>
<td>5</td>
</tr>
<tr>
<td>Bulk</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other waste</td>
<td>25</td>
<td>20</td>
<td>4.6</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: Internet data (MSW composition in USA, European Union and Developing Countries, 2005)

Here, the concentration of organic waste is considered as a development indicator of the country. The more developed a country is, the lower is the value of this indicator. This is reflected in the figures for Western Europe, where it is 27%, compared to Eastern Europe at 42%. Even though presently Moldova has a high economic growth, it will not reach the same level as the Eastern European countries in the next 15 years. It is assumed that Moldova in 2020 will approach the
Romanian development level in 2004. That way it was assumed that the fraction of organic waste will be reduced from 68% to 55% and not less between the year 2005 and 2020. With the same assumption, the function of paper and carton was expected to increase from 5 to 11% during the same period of time. Other types of waste were assumed to maintain their relative generation rates.

In Tab. 2.7, the generated amount of MSW in 2004 has been compared to the anticipated amounts in 2020. A considerable increase (more than 3 times) in the generation of paper and carton waste is anticipated. The generation of plastic, metals and textile waste will increase by a factor of two in the same period.

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>2004 %</th>
<th>tonnes</th>
<th>2020 %</th>
<th>tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and carton</td>
<td>5.1</td>
<td>15 769</td>
<td>11</td>
<td>53 020</td>
</tr>
<tr>
<td>Organic material</td>
<td>68.5</td>
<td>211 802</td>
<td>55</td>
<td>265 100</td>
</tr>
<tr>
<td>Glass</td>
<td>4.1</td>
<td>12 677</td>
<td>5</td>
<td>24 100</td>
</tr>
<tr>
<td>Metals</td>
<td>3.1</td>
<td>9 585</td>
<td>4</td>
<td>19 280</td>
</tr>
<tr>
<td>Plastics</td>
<td>9.7</td>
<td>29 992</td>
<td>10</td>
<td>48 200</td>
</tr>
<tr>
<td>Textiles</td>
<td>4.9</td>
<td>15 150</td>
<td>5</td>
<td>24 100</td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other waste</td>
<td>4.6</td>
<td>14 223</td>
<td>10</td>
<td>48 200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>309 000</strong></td>
<td><strong>100</strong></td>
<td><strong>482 000</strong></td>
</tr>
</tbody>
</table>

Source: Regia Autosolubritate and own calculations for 2020

### 2.5 Baseline scenario in 15 years

The amount of generated waste is steadily growing. Business-as-usual for current landfill means no gas capturing and all green house gases will be emitted to the atmosphere (Tab. 2.8). No landfill gas (LFG) capturing leads to an increase of other environmental (gas and leachate emissions) and social (odour, disease) impacts. Due to the absence of protecting liner and a collection system in the landfill, leachate can easily infiltrate into the soil and migrate to surface and groundwater environments. Because groundwater is the main drinking water resource in Moldova, it is clear that migration of leachate to groundwater poses a real risk to human health. Air emissions constitute another considerable impact. Landfill gas contains a high methane concentration and methane is well known as a strong contributor to global warming.

<table>
<thead>
<tr>
<th>Converted to CO₂ equivalents, tonnes CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>LFG emissions</td>
</tr>
<tr>
<td>109.478</td>
</tr>
</tbody>
</table>

Source: Internet data (Danish Project "Landfill Gas Capturing and Flaring at Chisinau landfill, Moldova")
2.6 Description of planned future strategy

There is no collection of landfill gas at the Chisinau landfill. Likewise, there are no specific present or planned national guidelines or regulations, which prescribe the installation of gas handling or its utilisation. Moldova has adopted Climate Change Conventions and ratified the Kyoto Protocol. The first National Communication states that emission reductions should be aimed at. No measurable and time-bound targets have been set so far and no CO₂ reduction technologies have been appointed as preferred or recommended. Neither have relevant requirements for emission reductions from landfills been posed at the national nor at the municipal level. “The landfill gas capture and flaring at Chisinau landfill” project was proposed by the Danish Co-operation for Environment in Eastern Europe in 2004. The predicted reductions in landfill gas emissions are given in Tab. 2.9. The project host Regia Autosolubritate is a private company in charge of MSWM in Chisinau. The Danish-Moldovan co-operation project was aimed at landfill gas extraction, followed by gas burning in an open flare to reduce green house gas emissions. The highest emissions during the project (2005-2018) are expected to be 17.8 million m³ of gas of which 8.9 million m³ of methane. Later during the project, a conversion from gas to electricity generation is foreseen. An additional benefit of the project is the improvement of operational procedures at the landfill, thereby improving the environmental aspects of the day to day operations of the landfill. The expected life time for the LFG recovery pipes is minimum 25 years, for the pumping unit 15-20 years and for the gas combustion unit 15-20 years. The LFG capture and utilisation technology to be implemented is based upon well known technology from west European countries. The project was planned to be started on the 1st of January 2005 but has not been realised yet due to unknown reasons.

An additional plan that has been discussed is the construction of an incineration plant. There has been and still are many discussions going on about this potential solution. At the moment, it is quite difficult for the Moldavian authorities to implement it, due to the high investment cost. At the same time, it has so far proven difficult to manage interests with foreign investors. Until now, there is no decision about the construction and it is uncertain whether there will be any in the future.

Tab. 2.9 Baseline emission foreseen in the Moldovan-Danish co-operation project on LDG capture, project emissions and emission reduction, (thousands m³)

<table>
<thead>
<tr>
<th>LFG emissions</th>
<th>Converted to CO₂ equivalents, tonnes CO₂/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline emissions</td>
<td>109.478</td>
</tr>
<tr>
<td>Project emissions</td>
<td>54.739</td>
</tr>
<tr>
<td>Emissions reduction</td>
<td>54.739</td>
</tr>
</tbody>
</table>

Source: Internet data (Danish Project "Landfill Gas Capturing and Flaring at Chisinau landfill, Moldova")
3. RESEARCH METHODOLOGY

3.1 Solid waste inventory and data collection

As every study, this one with no exceptions started with gathering information. For this, questions were formulated and relevant stakeholders were identified.
- What is the total amount of generated Municipal Solid Waste (MSW) and Production Waste in the Republic of Moldova and Chisinau?
- What are the main sources of waste generation in Chisinau city?
- What is the composition of MSW in fractions of paper, plastic, glass, metal, rubber, textile, organic waste, street waste?
- Current management of MSW? Who is responsible for collection, transportation and disposal?
- Transportation of MSW (distances and fuel consumption)?
- Does the municipality have any projects for building up new treatment facilities?
- The institutions and organisations related to the waste field that were visited, contacted by phone and/or by email have been listed in Tab. 3.1.

<table>
<thead>
<tr>
<th>Tab. 3.1 Contacted Moldovan institutions and organisations related to waste management</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Ministry of Ecology and Natural Resources</td>
</tr>
<tr>
<td>The Regional Environmental Centre</td>
</tr>
<tr>
<td>The Department of Statistics and Sociology of Republic of Moldova</td>
</tr>
<tr>
<td>The Environmental Movement of Moldova</td>
</tr>
<tr>
<td>The Environmental Informational Centre of Republic of Moldova</td>
</tr>
<tr>
<td>The Municipality of Chisinau</td>
</tr>
<tr>
<td>The Central Environmental Agency</td>
</tr>
<tr>
<td>Regia Autosolubritate - a private company responsible for waste collection and disposal in Chisinau city</td>
</tr>
</tbody>
</table>

Source: Own

3.2 Systems analysis of solid waste management

When a complex problem exists, a systems analysis is often of great help. Systems analysis can provide great help, even if it does no more than highlight relevant information or indicate that certain actors offer little hope of bringing about improvement. In most cases, the analysis may even point at a course of action that will bring about the desired changes, a course that can be recognised as the most advantageous and implemented by those with authority to act.

Anything in society or nature may be described as a system consisting of sub-systems and itself acting as a sub-system in a larger context forming a sort of hierarchical structure. A system can be viewed as a hierarchical structure (Fig 3.1) of more and more detailed sub-systems (Gustavsson et al., 1982).

“A systems analysis commonly focuses on a problem arising from interaction among elements in society, enterprises and the environment, considers various responses to this problem and supplies evidence about the consequences” (Miser & Quade, 1985).

“System analysis brings to bear the knowledge and methods of modern science and technology, in combination with concept of social goals and equities, elements of judgement and taste and
appropriate consideration of the large contexts and uncertainties that inevitably attend such problems” (Miser and Quade, 1985).

In the research plan which is the guiding statement for research conducted at the division of Industrial Ecology at the Royal Institute of Technology, environmental system analysis is defined as:” …models and methods for integrated quantification and presentation of materials and energy flows in different subsystems of nature and society and the evaluation of the future sustainability of different alternatives of action” (Industrial Ecology, 1997).

Systems analysis is simply the analysis of systems. Its purpose is generally to help in decision-making and planning of complex systems such as the waste management system. The interaction among elements is done through systems analysis. By understanding the behaviour of the subsystems and the linkage between them, the effects can be estimated. The subsystems and their linkage can be described in some kind of model, a simplified abstraction that could be a computer model, consisting of a mathematical description of the system. The aim of modelling a system is to introduce an increased flexibility in the possibilities to investigate different cases (Björklund, 1998).

**Choice and combinations of tools**

The idea of tools is broad and includes everything from physical tools to computer software to methods and processes. To date, many of the tools to support environmental decisions have been developed with an analytical mode of decision-making in mind. All of them are based on the principle that systematic gathering and analysis of information is the best route to an optimal decision. It is difficult to specify universal criteria for choosing among tools (Dale et al., 1999). There are more or less ten tools with different features and basis that could be combined for Environmental Decision Support.

According to Brattebro (2001), assessment tools can be based on quantitative and qualitative tradition. The qualitative approach is desirable since it is difficult to manage something that is not measured. Among quantitative tools are e.g. Material Flow Analysis, Substance Flow Analysis, Life Cycle Assessment and Life Cycle Costing. The qualitative group is a logical complement to a quantitative approach and includes among others, Interviews, Scenario Analysis (forecasting/backcasting), Panels and Consensus Conferences. A classification cannot always be done in a clear manner since there are qualitative elements within the qualitative tools and vice-versa.
Discussions concerning possibilities of combining different tools have been going on at different levels. Combinations of tools are important in both avoiding problem shifting and compensating for weaknesses in tools (Wrisberg et al., 2002). As mentioned in Eriksson (2002) and Björklund (2000), Life Cycle Assessment (LCA), Material Flow Accounting (MFA), Substance Flow Analysis (SFA) and Life Cycle Costing (LCC) are the major contributors to the method ORWARE.

**Substance Flow Analysis (SFA)**

SFA can be used to trace sources of environmental problems, discover potential future problems, or form a basis for regulations in substance handling. It is based on the thermodynamic law of mass conservation and accounts in physical units the flows of selected materials through a certain area. It is closely related to LCA, in that it is one of the means to provide input data to the LCA. SFA may serve goals such as error check of inventory data, identification of missing flows or hidden leaks in society, identification of problem flows and causes of environmental problems, monitoring, prediction of effectiveness of pollution abatement measures, possible shifting of problems caused by redirected substance flows or screening to identify issues for further investigation with other analytical tools (Björklund, 1998).

**Material Flow Analysis (MFA)**

MFA is used to describe the static situation of different material flows and to handle a large number of physical flows. MFA is a wider concept than SFA and may include, e.g., bulk material flows. Flows such as total solids and polycyclic aromatic hydrocarbons as well as single elements such as chlorine and copper may be followed. In the current ORWARE model, the flow of over 50 parameters can be followed simultaneously (Eriksson et al., 2002). MFA is used to comment on the materials throughput or the materials intensity of national economies, important sectors or large functional systems and therefore concentrates on mass flows. SFA is used to identify the causes of specific pollution problems in the economy and find possibilities for amending or preventing those problems and therefore is concerned with the flows of specific substances. Generally, MFA stops at the border of the environment, while SFA also considers the environmental flows (Bringezu, 1997).

**Life Cycle Analysis (LCA)**

During the last decade, LCA has appeared as a new approach to analyse environmental impacts of waste management. The basic idea of LCA is to evaluate the potential environmental impact associated with a product over its entire life cycle (ISO, 1997). A product may be either a material product or a service with focus on the function provided. LCA fulfils the purpose of identifying, quantifying and assessing the impact of energy and material use related to a product from raw materials acquisition through production, use and disposal, commonly known as “from cradle to grave”. LCA is a tool for comparative assessments, either between different products providing similar functions or between different life cycle stages of a product in an improvement analysis. A waste management system can be described as a service, the function of which is to collect, transport, and treat waste from a certain area in an adequate manner.

**Life Cycle Costing (LCC)**

Many traditional cost-accounting systems lead to incorrect investment decisions concerning environmental costs (Bennett, 1997). LCC is a tool that looks at the entire life cycle of a product, process or activity and calculates the entire life cycle cost, which includes all internal costs plus external costs, incurred throughout the entire life cycle. LCC aims at the analysis of the processes in connection with a given function, like LCA. Environmental impacts in comprehensive LCC can be translated into monetary metrics at three stages. By translating the information to a monetary dimension, it is possible that decision-makers would include environmental concerns in
the investment decision. However, even though LCC might translate environmental information into more familiar units, uncertainties pose special problems concerning cognitive and motivational influences on decisions that are the decision maker’s personal view of reality. This may affect what parameters are considered in the calculation (Ajzen & Fishbein, 1977). Examples are initial interventions as emissions of CO$_2$, “midpoint effects as increasing acidity in water bodies and impacts on endpoints as the fish kill and lose of biodiversity resulting from increased acidity”. LCC uses different costing approaches and techniques that may vary from case to case, depending on where in the impact chain the impacts are assessed (Assefa, 2002). Even if not theoretically accurate, the results from an LCC calculation might provide at least an indication of which strategic decisions should be made (Gluch & Baumann, 2004).

3.3 General description of ORWARE

ORWARE (ORganic WAste REsearch) is a tool for environmental systems analysis of waste management. It is a computer-based model for calculation of substance flows, environmental impacts and costs of waste management. It was first developed for systems analysis of organic waste management, hence the acronym ORWARE but now covers inorganic fractions in municipal waste as well. ORWARE consists of a number of separate sub-models, which may be combined to design a waste management system for e.g. a city, a municipality or a company. A first description of the ORWARE model was given by (Dalemo et al., 1997). All process sub-models in ORWARE calculate the turnover of materials, energy and financial resources in the process, Fig. 3.2.

Processes within the waste management system are e.g. waste collection, anaerobic digestion or landfill disposal. Materials turnover is characterised by the supply of waste materials and process chemicals and by the output of products, secondary wastes, and emissions to air, water and soil. Energy turnover is use of different energy carriers such as electricity, coal, oil or heat, and recovery of e.g. heat, electricity, hydrogen or biogas. The financial turnover is defined as costs and revenues of individual processes. A number of sub-models may be combined to a complete waste management system in any city or municipality (or other system boundary). Such a conceptual ORWARE model of a complete waste management system is shown in Fig. 3.3.
At the top of the conceptual model there are different waste sources, followed by different transport and treatment processes. The solid line encloses the waste management core system, where primary and secondary wastes are treated and different products are formed. With primary waste is understood waste entering a treatment process from a waste source, while secondary waste is generated in a treatment process. Thus source separated organic waste is a primary waste, while incineration slag and fly ash are secondary wastes.

**ORWARE in decision-making**

As it was described before, ORWARE has had a role in decision-making. But the situation can be much better. Therefore, it can be outlined some applications in which the model may give a substantial contribution to the decision-making. The framework for this discussion is taken from Wrisberg (2002, pp 78).

**Strategic planning:** This is the strong card of ORWARE. Here decisions with long term character are made and different options are evaluated. The future studies run by researchers only are still interesting and also construction and evaluation of municipal waste plans.

**Capital investment:** This is a decision to be taken when treatment facilities are to be built. Wrisberg (2002) said: “The necessity of prospective information makes back-casting and scenario analysis adequate approaches for decisions about capital investment.”

In ORWARE, back-casting is not used so far but it has been brought up for discussion within the research team. Scenario analysis and back-casting are two new challenges for ORWARE.

**Design and development:** This is in a traditional meaning the classic product-LCA. Product development is an upstream system to waste management. In ORWARE the impacts for that specific part of the product life cycle can be evaluated. This is of limited value since the “standard” LCA tools are better suited to the task.

**Communication and marketing:** The results from systems analysis can be used by the involved enterprises in marketing.
Operational management: The type of model ORWARE is representing, may not be the most suitable but systems analysis performed by very simple models can be of interest. Just using the material flow analysis part of ORWARE is perhaps a more simple form of systems analysis that is easier to adapt to day-to-day analysis.

Policy/legislation: Systems analysis is useful to map the problem area and maybe to sort small things from large. Systems analysis and ORWARE can also be used for quantification. But systems analysis can only be a small part of the total basis for a decision about new policies and legislation.

3.4 System Boundaries

System boundaries delimit the system under study from its surroundings. It determines what should and what should not be analysed and have a large influence on the result and conclusion of the analysis. For this thesis, the system boundaries are set to fit the cradle to grave perspective of the waste entered. Essentially, there are three dimensions of which system boundaries should be defined; time, space and function. It depends on the scope in an analysis of a certain system. The temporal system varies between different studies and sub-models. Annual averages are used for most of the input data but for the landfill model and the arable land, long-term effects are also included.

The system boundaries in ORWARE are strictly connected to the core function of collecting and treating waste. Depending on the structure of the waste management system, this may also be a geographical or political boundary. Consumption of energy and resources, production of energy, emissions to the air and water and residual effluents are related to the quantity and composition of the material flow to the process. Besides the core function, treatment of a certain amount of waste, additional functions such as district heating, electricity generation, phosphorus (fertiliser) and nitrogen may be delivered from the waste management system (Björklund, 1998).

Time
The period of the analysis must be delimited to define the time span (years, centuries or other) for which inputs and outputs of the system should be included. The ORWARE calculates the impact caused by handling and treating waste generated during one year in a selected area. The emissions mainly occur during that same year but in the case of landfilling, long-term emissions are included. Generally, scenarios are designed to mirror a not too distant future from the present, ten to fifteen years from today (Björklund, 2000).

Space
The geographical boundaries of the analysis may be determined by for instance political boundaries (e.g. a municipality, county or nation) or natural boundaries (e.g. an ecosystem, lake or watershed). In ORWARE, the special boundaries of the core system are the geographical boundaries of the waste collection system. Emissions and resources depletion are, however included regardless of where they occur (upstream systems, core systems or downstream systems).

In Moldova, more than one fifth of the total population and almost 45% of industries are located in Chisinau. Currently, all the waste from the city is disposed of in the only existing landfill, situated 44 km from the city centre. As a geographical system boundary for this thesis was considered the city of Chisinau including the landfill site.

The functional unit
The main function of solid waste management is to treat the solid waste generated within the studied area. Other functions, e.g. providing different kinds of products from waste recovery are
also possible nowadays. Functional units form the basis for impact quantification, meaning that all scenarios must fulfil a number of functions to the same degree. The functional unit should be clearly defined (ISO, 1998) and could be:

- Manage one year’s waste generation from a selected area
- Produce a certain amount of electricity
- Produce a certain amount of phosphorus fertiliser, etc.

In order to achieve a just comparison between the scenarios, functions not present in a certain system have to be compensated for. The compensation of functional units in ORWARE is achieved by expanding the system boundaries to include different so called compensatory processes (Eriksson, 2003). As the system boundary in ORWARE follows an LCA perspective, it should include in principle all processes that are connected to the entire life cycle. This is done by enlarging the core system (the waste management system) to take into account relevant up-stream (e.g. energy generation) and down-stream (e.g. biogas usage) activities and processes. According to Eriksson (2003), up-stream material flows associated with the use of energy carriers in the core system are included in the ORWARE model. In a similar way, down-stream flows associated with the spreading of organic fertilizer from biological treatment may be included in the analysis. Compensatory processes also have up-stream and down-stream processes. Therefore, the conceptual model of the total system in the ORWARE is now enlarged comprises the core system, the compensatory system and their relevant up-stream and down-stream systems, as illustrated in Fig. 3.4.

Fig. 3.4 Conceptual model of the total system in ORWARE

Source: Municipal solid waste management from a system perspective (Eriksson and Frostell, 2001)
3.5 Scenarios

In the waste management system, a scenario is described as a description of the core system, which consists of a treatment method. Scenarios are designed to provide a certain function and then compared for different environmental impact categories and energy consumption. The results are calculated for all parts of the waste management system and compensatory system but may be analyzed from different angles to reveal different interesting aspects of the system (Eriksson, 2003). These scenarios offer a quantitative look ahead and a way to think about today’s choices from the perspective of the future. As such, scenarios can help to free us from the grip of the past and enable us to prepare for a future that will surely be different from today. In the present study, four different scenarios were investigated, considering an improvement in the Chisinau waste management system, by phasing out landfill as the major treatment to biological treatment and incineration. The current situation (Landfill 2005) is compared to three different scenarios established for the year 2020 (Landfill, Landfill + Incineration, Landfill + Incineration + Anaerobic Digestion).

Tab. 3.2 Assumed recycling of waste materials in 2020

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper and carton</td>
<td>20</td>
</tr>
<tr>
<td>Organic waste</td>
<td>25</td>
</tr>
<tr>
<td>Glass</td>
<td>60</td>
</tr>
<tr>
<td>Metals</td>
<td>10</td>
</tr>
<tr>
<td>Plastics</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: Own estimations

In all 2020 scenarios, material recovery is included. Material recovery is nowadays practiced in Chisinau mainly in big industries or better to say, big waste sources, especially when the wastes are not mixed. This waste is not considered in the present thesis, since it is collected by private companies and no data was available. Recycling of waste was considered to be zero in 2005 and was assumed to grow up to figures given in Tab. 3.2 since by that time source separation of waste will certainly be introduced.

Due to a lack of data, a number of assumptions were made based on telephone conversations with Moldovan authorities’ (Tab. 3.3).

Tab. 3.3 Amount of waste in 2004 and estimated amounts in 2020 (tonnes and %)

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>2004</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>tonnes</td>
</tr>
<tr>
<td>Paper and carton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper</td>
<td>40</td>
<td>6 308</td>
</tr>
<tr>
<td>Carton</td>
<td>60</td>
<td>9 461</td>
</tr>
<tr>
<td>Plastic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>40</td>
<td>11 997</td>
</tr>
<tr>
<td>HDPE</td>
<td>60</td>
<td>17 995</td>
</tr>
<tr>
<td>Other waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-combustible</td>
<td>65</td>
<td>9 245</td>
</tr>
<tr>
<td>Combustible</td>
<td>35</td>
<td>4 978</td>
</tr>
</tbody>
</table>

Source: Own estimations
Paper and carton constitute nowadays 5.1% and plastic represent 9.7% of total amount of generated waste. Based on previous assumptions (Tab. 2.7) for 2020, an increase in paper and carton recycling to 11% and plastic to 10% is expected. Category of other waste with 4.5% in 2005 and 10% in 2020 include construction waste with a share of non-combustible 65% and combustible waste 35%.

1. Landfill 2005
The Landfill 2005 scenario serves as a reference of the current waste management system in Chisinau. The total amount of solid waste (309 thousand tonnes) collected by the municipality is disposed of on the landfill. Generated solid waste is discarded without source separation of recyclable materials by households, business, etc.

2. Landfill 2020
In this scenario, the solid waste management works in a similar way to the Landfill 2005. It differs only in the annual amount of solid waste generated within the city, which is projected to be 482 thousands tonnes plus a partial recovery of recyclable materials. A so called ‘business as usual’ scenario is thus formed, enabling a comparison of its impacts to the first scenario. It is also utilized to illustrate some environmental impacts that can be avoided by changing to better options, i.e. the next other two scenarios. Therefore, this second scenario is considered as the future reference case, with which the two last scenarios were compared.

3. Landfill + Incineration in 2020
This scenario was selected in accordance with the current discussion about the future waste management of the city. Incineration was assumed to be the core of waste treatment. Organic waste was included in the portion of waste allocated for incineration. The incineration plant was assumed to be similar to the Högdalen incineration plant in Stockholm since here the organic fraction is not collected separately and is combusted besides other MSW fractions. Bottom ash was assumed to be used as a construction material and fly ash due to its toxicity disposed of to the hazardous waste landfill site (EC Waste Landfill Directive, 1999). The rest of the collected solid waste (non-combustible waste) will still go to the landfill. As a source separation has been introduced, a part of the recyclable materials would be collected separately. A greater separation of recyclable material is not expected, due to a lack of environmental awareness. In the view fact that the incineration plant is located at the edge of the city centre to optimise energy delivery and waste transport, the average waste transport distance is only 11 km.

4. Incineration + Anaerobic Digestion in 2020
This scenario is based on incineration and anaerobic digestion as the two most important treatment technologies forming the core of the waste treatment system. This treatment option provides heat and electricity from incineration and biogas plus compost product from anaerobic digestion. The hazardous landfill is used to dispose of fly ash from incineration. The recycling of materials was assumed to be the same as in the third scenario. A summary of characteristic features of the established scenario is presented in Tab. 3.4.

Functional units taken in consideration in this thesis are:
1. The main function is treatment of certain amount of solid waste generated annually in the city (309 thousands tonnes in 2005 and 482 thousands tonnes by 2020)
2. Production of district heating
3. Production of electricity
4. Production of biogas as a vehicle fuel
5. Production of fertilizer
Tab. 3.4 Summary of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill 2005</td>
<td>There is no source separation and no sorting of recyclable materials; All MSW in a quantity of 309 thousand tonnes is landfilled; There is no landfill gas capture and no energy recovery; Waste is transported an average distance of 44 km.</td>
</tr>
<tr>
<td>Landfill 2020</td>
<td>The same scenario as Landfill 2005, larger waste amount (436000 tonnes); A part of recyclable materials (46000 tonnes) is sorted out; Waste is transported an average distance of 44 km.</td>
</tr>
<tr>
<td>Landfill + Incineration 2020</td>
<td>A part of recyclable materials (46000 tonnes) is sorted out; Incineration of 78% of mixed waste; Heat and electricity are recovered from incineration; The rest of solid waste is landfilled; Only rejected materials from incineration are landfilled; Waste is transported an average distance of 44 km to the landfill and 11 km to the incineration plant.</td>
</tr>
<tr>
<td>Landfill + Incineration + Anaerobic Digestion 2020</td>
<td>A part of recyclable materials (46000 tonnes) is sorted out; Anaerobic Digestion of 25% of organic waste or 14% of total waste; Incineration of 64% of mixed waste; Heat and electricity are recovered from incineration; 100% of biogas from anaerobic digestion is used as a car fuel and the sludge is spread on land; Only rejected materials from incineration are landfilled; Waste is transported an average distance of 44 km to the landfill and 11 km to the incineration plant and to the anaerobic digestion.</td>
</tr>
</tbody>
</table>

Source: Own estimations

Based on the previous assumptions related to the quantity of waste and the recycling rate, the amounts of treated waste in different scenarios were calculated (Tab. 3.5).

Tab. 3.5 Scenarios 2020 and amount of treated waste

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>thous.</td>
<td>2. Landfill</td>
<td>2. Landfill</td>
<td>3. Incineration</td>
<td>4. Anaerobic Digestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tonnes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Paper and carton</td>
<td>11</td>
<td>53</td>
<td>10.7</td>
<td>42.8</td>
<td>10.6</td>
<td>-</td>
</tr>
<tr>
<td>Organic material</td>
<td>55</td>
<td>265.1</td>
<td>-</td>
<td>265.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glass</td>
<td>5</td>
<td>24.1</td>
<td>14.5</td>
<td>9.6</td>
<td>14.5</td>
<td>9.6</td>
</tr>
<tr>
<td>Metals</td>
<td>4</td>
<td>19.3</td>
<td>1.9</td>
<td>17.4</td>
<td>1.9</td>
<td>17.4</td>
</tr>
<tr>
<td>Plastics</td>
<td>10</td>
<td>48.2</td>
<td>19.3</td>
<td>28.9</td>
<td>19.3</td>
<td>-</td>
</tr>
<tr>
<td>Textiles</td>
<td>5</td>
<td>24.1</td>
<td>-</td>
<td>24.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other waste</td>
<td>10</td>
<td>48.2</td>
<td>-</td>
<td>48.2</td>
<td>-</td>
<td>31.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>482</strong></td>
<td><strong>46.3</strong></td>
<td><strong>436.1</strong></td>
<td><strong>46.3</strong></td>
<td><strong>58.3</strong></td>
</tr>
</tbody>
</table>

Source: Own calculations
3.6 Sub-models

The graphical interface of the ORWARE model for Chisinau city that appears in the SIMULINK window is shown in Fig. 3.5. The blocks are the submodels constituting the solid waste management system in this study. The flow of the solid waste was initiated by a number of parameters in the scenarios defined. It implied for instance that in the first and second scenarios, the biological treatment and incineration submodels were not activated in the simulation because all collected solid waste was heading to the landfill system.

![Graphical interface of ORWARE model for Chisinau city](image)

Source: ORWARE model

**Solid waste sources and waste fractions**

Only one source of municipal solid waste was modelled that includes waste from households, industries, offices, markets etc. The source of incoming solid waste is grouped into several fractions such as organic waste, paper and cardboard, glass, metal and plastic. Activities that generate waste are not included, but the model begins when solid waste is collected at the source. According to Eriksson (2003), each fraction is characterized by a set of parameters describing the chemical composition of the waste, including:

Parameters of environmental relevance: heavy metals, NOx, SO2, HCl, PCB, dioxins, PAH, AOX, CH4, CO, CHX, CO2, BOD, COD, NH3/NH4, P, NO2--/NO3-, etc.

Parameters of relevance to process performance: C, H, O, N, P, H2O, energy etc.

Parameters of economic relevance: CH4, N, P etc. (yet economic analysis is not performed)
Parameters that characterize the material recovery: paper, plastic, metals, etc. The amounts of these substances in kilograms per year in every fraction serve the basis for calculating the solid waste flow. The input data for those parameter series, which form the vectors in an ORWARE simulation, were set up based on the Stockholm version of ORWARE model. A certain amount of recyclable fractions were assumed to be sorted out and channelled to the informal collection system. In the biological treatment scenario, a portion of the organic fraction was assumed to be separated.

**Transport**
The transport sub-model comprises different types of vehicle transports. For collection of waste, back-packer and front-loader models were simulated, while to transfer the primary and secondary waste, an ordinary truck and trailer transport was assumed. Data on average load, average speed etc. were used as input in all transport sub-models. The output was total energy consumption, time consumption and costs. Emissions were calculated from the energy consumption. The transport sub-model is further described in Sonesson (1996) and in Sonesson (1998).

**Landfill**
In the landfill sub-model, mixed waste, sludge, ash and slag are modelled separately. Sludge in this particular study refers to resulting sludge from the recycling process and not sewage sludge as in Sweden. The landfill sub-model attempts to include all potential future emissions from the degradation process of primary and secondary wastes, the operation process and the leachate treatment as well. The challenge in modelling landfill emissions lies in the fact that a long period of time of landfill emissions is difficult to compare with instant emissions from other processes in the system. In ORWARE, this dilemma is addressed by separating the future impacts of landfilling into two time periods: surveyable and remaining time. Surveyable time corresponds to the time until the most active processes in the landfill have ended and a pseudo steady state of methane phase is reached for mixed waste and sludge, which is assumed to be in the magnitude of 100 years. In the case of landfilled incineration ash and slag, the surveyable time means the time needed for highly soluble substances such as alkaline salts to leak out to a large extent. Remaining time is the time until all material has been spread out in the environment through gas emissions, leaking and erosion. The remaining time includes the emissions in a kind of worst scenario. The mixed waste landfill, degradation is modelled as completely anaerobic during surveyable time. Proteins, fat, and easily degradable carbohydrates (sugars) are completely converted to CO2 and CH4, 70% of semi-stable carbohydrates, i.e. cellulose etc. is degraded, while lignin and plastic material are not degraded at all. In the simulation, it was assumed that 90% of all nitrogen is emitted as ammonium in water, while 2% of the phosphorus and 0.1 – 0.3 % of all heavy metals are emitted in the leachate (Björklund, 1998).

**Incineration**
The incineration sub-model consists of three parts: pre-treatment, incinerator and air pollution control. The pre-treatment provides baling of all of the incoming solid waste; enabling the possibility to store waste and combust it later. In the incinerator, the solid waste is combusted, resulting in outputs of raw gas, slag and fly ash. The raw gas is led to the air pollution control unit, which is modelled to transfer raw gas components to clean gas (released as air emissions) and moist or stabilized fly ash. Emission factors are calculated from material balances over each process and considered to be: (i) product related, i.e. linearly dependent on the incinerated amount of the substance, (ii) process related, i.e. depend on the amount of waste incinerated, or (iii) threshold related, i.e. parameters under legislative limited value that has to be kept. The air pollution control sub-model is able to remove about 95 – 98% of dioxin, 99.99% of dust and 95% of mercury in the raw gas. The clean gas, however, still contains 100% of NOx, CO and CO2-fossil origin in raw gas. The energy recovered in this sub-model includes heat and electricity.
The combined heat and power (CHP) plant was assumed to be operated at 88% of thermal energy efficiency, of which 22% is power and 78% heat.

**Anaerobic digestion and biogas utilization**
The sub-model for anaerobic digestion is based on a real treatment plant comprising a continuous single stage mixed tank reactor in Uppsala, Sweden and suitable for a thermophiliic or a mesophilic process (Eriksson, 2003). The incoming material is cleared from plastic bags and metals, homogenized and hygienised at 70°C also can be at 130°C prior to the digester. The separation will result in a loss of organic material. After the digestion step, the substrate passes through a heat exchanger and dewatering equipment. The amount of gas generated depends on the composition of different organic compounds e.g. fat, proteins, cellulose, hemi-cellulose, lignin, rapidly degradable carbohydrates and the retention time. The sludge from the digester is separated into a solid and a liquid phase in the dewatering process. The digestion residue is stored in large covered lagoons in solid or liquid phase. Electricity is consumed for mixing, pumping and drying. The sub-model delivers sludge for spreading and biogas to be combusted. Wet sludge is dried completely in the biogas-fired drier before spreading. Produced biogas is used partly for powering this drier, which will result in a loss of biogas energy from the digestion process.

The biogas utilization sub-model comprises possibilities of generating power, engine fuel or hydrogen in a steam reforming process. In this study, the net amount of biogas was utilized for fuelling busses – as described earlier in the scenario – in an attempt to see its potential in delivering this function. It passes through a gas purification step before methane enriched gas is used to fuel busses. Electricity consumption is calculated for this process, as well as emissions from gas purification and gas consumption in busses.

**Recycling**
In ORWARE, there are sub-models for recycling of plastics and cardboard, which are based on specific Swedish plants. The sub-model for plastic recycling represents polyethylene recycling. A certain amount of incoming plastic to the recycling plant is sorted out as reject. The plastic that is recycled gives rise to electricity consumption. The output from the model is emissions to water, waste in the form of sludge and finally plastic granules, which are assumed to replace virgin polyethylene. In the cardboard recycling model, the recycled cardboard needs 15% extra weight to replace virgin cardboard. The cardboard recycling plant gives rise to emissions to water, energy related emissions to air and energy consumption and waste in form of bio-sludge and plastic reject (Eriksson, 2003).

**Spreading of residues**
The spreading sub-model uses dry sludge from anaerobic digestion as input. It is divided into three steps: calculation of spreading areas and transport distances, transport of residues from the treatment plant to the centre of spreading areas and finally the spreading itself. The maximum spreading of residues per hectare is determined from the rest product content of phosphorus and nitrogen. The distance to and the area of each spreading area is used as input data and the model calculates the total distance and energy consumption. Two different spreaders are modelled, one for liquid products and one for solid products. The model determines what kind of spreader is needed depending on the dry matter content of the rest product. The spreader model calculates the emissions from the truck transport and the spreading procedure and also the energy consumption for the vehicles (Eriksson, 2003). As a spreading system is not in place today for Chisinau, an assumption was made for the spreading location. It was not based on the location of arable land available (due to inadequate geographical information) but instead by plausible assumption to simply set up a particular area and distance from the city centre.
Arable land
The chemical processes of nutrient utilization by plants in arable land after spreading of residues are modelled in this sub-model. The model calculates the emissions of nitrogen compared to the use of mineral fertilizer. Thus, relative values are calculated rather than absolute as in the other sub-models. Nitrogen is assumed to exist in three forms: ammonia, nitrate and organically bound. The model gives emissions from mineralization of organically bound nitrogen during the first year after spreading and the long-term effects of mineralization. The emissions of laughing gas (\(\text{N}_2\text{O}\)), nitrate (\(\text{NO}_3^-\)) and ammonia (\(\text{NH}_3\)) depend on the soil condition, the spreading conditions and the climatic region which can be adjusted for the model.

The up-stream and compensatory system
In ORWARE, the energy produced and environmental impact from electricity and district heating generation plants are included as up-stream processes if needed in a waste treatment process, or as a compensatory process if necessary to fulfil a functional unit. The up-stream transport considers the extraction and refining of vehicle fuels, while the core system of this compensatory process deals with direct effects of operating the vehicles. Compensatory production of mineral fertilizer covers production of nitrogen and phosphorus. Cardboard and plastic compensatory processes consider their production from virgin resources (Eriksson, 2003). In this study, the data for the up-stream and compensatory systems were based on Swedish values. The summary of processes and data source is presented in Tab. 3.6.
Environmental Systems Analysis of Municipal Solid Waste Management in Chisinau, Moldova  
Current situation and future perspectives  

<table>
<thead>
<tr>
<th>Sub-model</th>
<th>Primary process</th>
<th>Variable of interest</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste</td>
<td>Initiating waste vectors as one waste stream</td>
<td>Amount of waste</td>
<td>MSW data collection. Regia Autosolubritate</td>
</tr>
<tr>
<td>Collection by municipality</td>
<td>Direct collection system:</td>
<td>Air emissions</td>
<td>MSW data collection. Regia Autosolubritate</td>
</tr>
<tr>
<td></td>
<td>Organic waste</td>
<td>Water emissions, Oil consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rest waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>Transport by ordinary truck</td>
<td>Air emissions</td>
<td>Assumed data. Swedish data</td>
</tr>
<tr>
<td></td>
<td>Reject to incinerization</td>
<td>Water emissions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collected cardboard to recycling plant</td>
<td>Distance route</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collected plastic to recycling plant</td>
<td>Oil consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport by truck and trailers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slag and stabilized ash to landfill</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moist ash to landfill</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reject cardboard to incineration/landfill</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rejected plastic to incineration/landfill</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Informal</td>
<td>Grouping of recyclable materials</td>
<td>Amount of recyclable materials based on group</td>
<td>Assumed data</td>
</tr>
<tr>
<td>collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill</td>
<td>Household waste landfill from waste source</td>
<td>Air emissions</td>
<td>Swedish data</td>
</tr>
<tr>
<td></td>
<td>Degradation of organic, inorganic materials</td>
<td>Water emissions, Oil consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sludge landfill from recyclable plant</td>
<td>Air emissions from trucks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ash landfill from incinerator</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water purification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incineration</td>
<td>Wrapping and sorting</td>
<td>Air emissions</td>
<td>Swedish data</td>
</tr>
<tr>
<td></td>
<td>Slag and raw gas formation</td>
<td>Energy production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air pollution control</td>
<td>Energy consumption</td>
<td></td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>Pre-treatment</td>
<td>Amount of treated organic waste</td>
<td>Swedish data</td>
</tr>
<tr>
<td></td>
<td>Digestion</td>
<td>Biogas production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biogas storage</td>
<td>Energy consumption</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sludge drying</td>
<td>Amount of rejected materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amount of sludge produced</td>
<td>Water emissions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Purification of biogas to vehicle gas</td>
<td>Amount of sludge produced</td>
<td></td>
</tr>
<tr>
<td>Biogas utilisation</td>
<td>Gas consumption in busses</td>
<td>Biogas production</td>
<td>Swedish data</td>
</tr>
<tr>
<td></td>
<td>Transporting and spreading of the residues from anaerobic digestion</td>
<td>Air emissions (from gas purification and consumption in busses)</td>
<td></td>
</tr>
<tr>
<td>Transport and spreading</td>
<td>Calculation of area required for spreading</td>
<td>Air emissions</td>
<td>Swedish data</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Arable land</td>
<td>Utilisation of spread organic materials by plants</td>
<td>Air emissions</td>
<td>Water emissions</td>
</tr>
<tr>
<td>Upstream and compensatory system</td>
<td>External process of electricity and district heating generation, nitrogen and phosphorus production. Cardboard and plastic production and biogas generation</td>
<td>External energy consumption and environmental impact</td>
<td>Swedish data</td>
</tr>
</tbody>
</table>

*Source: Own*

### 3.7 Simulations

The simulations were carried out after (i) the sub-models were connected to each other to form a larger system, (ii) the scenarios were defined and (iii) all necessary parameters input had been specified in the MATLAB files as well as the graphical interface of SIMULINK. All input data are specified. The emissions from the core system, e.g. collection and transport of waste, incineration, landfill, etc. are being summed up and each substance is weighted according to its impact to the air, water and soil environment. Five categories of impact were set up, which included global warming potential, acidification, eutrophication, the effect of photo-oxidant agents of VOC and flows of NOx. A rather similar calculation was applied for the external system, i.e. the effects of upstream and compensatory systems for fulfilling the functional units. Given the same amount of functional unit outputs, the external contribution from the compensatory system can be calculated, which is defined as the difference between the maximum output of functional unit and its production in each scenario. Impacts on air and water were considered for cardboard and plastic production, while for the rest of compensatory systems, only air emissions were considered. The external emissions combined with the ones from the core system were thus forming the total environmental impacts. Energy turnover from the core system covered oil consumption from all collection and transport vehicles, heat and electricity consumed to support the waste treatment processes, produced heat and electricity e.g. from the incineration system and fuel gas generation from anaerobic digestion. The total consumption of primary energy carriers was thus calculated by summing up all energy consumed by the core system and the external system i.e. the up-stream and compensatory systems. The primary energy carriers can also be categorized in term of renewable or non-renewable energy sources, e.g. hydro power, biomass, natural gas, etc.
4. RESULTS
After simulation was performed, all results were combined and transferred to Excel format in tables and graphics to be easily interpreted. The following chapter presents the results and results analysis.

4.1 Waste treatment in each scenario

The waste management system in Chisinau, Moldova in tonnes is illustrated in Fig. 4.1. The bars represent the amounts of primary waste coming into the system, excluding the residues from treatment. The last 3 scenarios handle more waste than the first one since the amount of generated waste will increase by 1.56 times in 15 years from now. The 2020 scenarios represent different treatment methods landfill, incineration and biological treatment. Biological treatment in the 4th scenario is related to anaerobic digestion. The amount of waste is presented in Tab.4.1.

Today in Moldova, there is no material recycling from MSW. It is assumed that the same amount of materials will be recovered in all scenarios in 2020, even though treatment methods are different. Material recycling includes: paper, metal, plastic and glass. However, only the emissions and energy consumption of plastic and cardboard are modelled.

Tab. 4.1 Proportion of total waste treated by different methods in the different scenarios (tonnes per year)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Landfill</th>
<th>Incineration</th>
<th>Biological</th>
<th>Materials recycling</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill 2005</td>
<td>309200</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>309200</td>
</tr>
<tr>
<td>Landfill 2020</td>
<td>436100</td>
<td>0</td>
<td>0</td>
<td>46300</td>
<td>482000</td>
</tr>
<tr>
<td>Lf + Inc 2020</td>
<td>58300</td>
<td>377800</td>
<td>0</td>
<td>46300</td>
<td>482000</td>
</tr>
<tr>
<td>Lf + Inc + Ad 2020</td>
<td>58300</td>
<td>311500</td>
<td>66300</td>
<td>46300</td>
<td>482000</td>
</tr>
</tbody>
</table>

Source: ORWARE results for Chisinau model
4.2 Functional unit output

Functional unit outputs differ for 2005 and 2020 because of different waste generation rates. In the year 2005, represented by the first scenario, the only function fulfilled is waste treatment. Due to the absence of material and energy recovery in 2005, the functional units give no output. The values of outputs for 2020 can be seen in Tab. 4.2.

**Tab. 4.2 Functional units for 2005 and 2020**

<table>
<thead>
<tr>
<th>Functional units</th>
<th>Unit</th>
<th>Output in 2005</th>
<th>Output in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of waste</td>
<td>tonnes</td>
<td>309 200</td>
<td>482 352</td>
</tr>
<tr>
<td>District Heating</td>
<td>MJ</td>
<td>0</td>
<td>1 668 440 245</td>
</tr>
<tr>
<td>Electricity</td>
<td>MJ</td>
<td>0</td>
<td>549 750 999</td>
</tr>
<tr>
<td>Bus Kilometer</td>
<td>km</td>
<td>0</td>
<td>13 779 963</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>kg</td>
<td>0</td>
<td>71 576</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>kg</td>
<td>0</td>
<td>243 578</td>
</tr>
<tr>
<td>Cardboard</td>
<td>kg</td>
<td>0</td>
<td>3 397 436</td>
</tr>
<tr>
<td>Plastic</td>
<td>kg</td>
<td>0</td>
<td>7 717 632</td>
</tr>
</tbody>
</table>

*Source: ORWARE results for Chisinau model*

4.3 Environmental impacts

**Global Warming Potential (GWP)**

![Global Warming Potential (GWP)](image)

The global warming potential is illustrated in Fig. 4.2. The greatest impact with an amount of more than 500 kilo tonnes of CO₂ occurs in the second scenario so called business as usual in 2020. The last two scenarios have an impact three times less than the landfill scenario to global

---

2 Global Warming Potentials (GWP) is a measure of how much a given mass of greenhouse gases is estimated to contribute to global warming
warming 15 years from now. Scenarios 3 and 4 have almost similar GWP impacts. This is since only 25% of the organic waste goes to anaerobic digestion in scenario 4. As is evident from Fig. 4.2 the dominating GWP impact come from landfill and incineration. The effects from recycling, anaerobic digestion and transportation is negligible compared to the effects from incineration and landfilling. The relative contributors to the GWP from the three most important parameters are showing in Tab. 4.3.

**Tab. 4.3 Relative contributions to GWP from CO₂, CH₄ and N₂O**

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Equivalency factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>21</td>
</tr>
<tr>
<td>N₂O</td>
<td>320</td>
</tr>
</tbody>
</table>

*Source: Internet*

The GWP impact is a result of greenhouse gas emissions, mainly as a consequence of methane generation during the biological degradation of organic waste in the landfill. The landfill scenario has no gas collection system and methane produced during surveyable time escapes to the atmosphere. In the case of incineration, the GWP is largely due to combustion of plastics, which creates anthropogenic CO₂ emissions. These emissions cannot be avoided since plastic due to its complexity and high calorific value will not be sorted out before incineration.

Due to the need for compensatory heating and upstream electricity for external systems, the situation will become worse for the landfill 2020 scenario (Fig. 4.3). The GWP grows up to 760 kilotonnes of CO₂ equivalents. By adding impacts from external systems, the relation between scenarios is not changed. Even the last two scenarios have equal impact, only increased in emissions with 40 kilotonnes of CO₂ equivalents. For the incineration scenario, the impact from compensatory petrol was added and for biological treatment the impact from compensatory heating.
Acidification

The largest core system acidification impacts (in contrast to GWP) come from the 4th scenario followed by the 3rd scenario. Emissions from the landfill 2020 scenario with 100 tonnes SO$_2$ equivalents are more than 3 times lower than biological treatment scenario and 2.5 times lower than the incineration scenarios as can be observed in Fig. 4.4.

Fig. 4.4 Acidification from core system (tonnes of SO$_2$-equivalents)
Source: ORWARE results for Chisinau model

Fig. 4.5 Acidification including external system (tonnes of SO$_2$-equivalents)
Source: ORWARE results for Chisinau model

---

3 Acidification is a process whereby air pollution – mainly ammonia, sulphur dioxide and nitrogen oxides – is converted into acid substances.
Acidification is much affected by ammonia, nitrogen oxides and sulphur dioxides that are emitted as air pollution from different treatment processes and transports and converted into acid substances in the atmosphere. In the waste management systems, acidification impacts mainly are caused by incineration, landfilling, collection and transportation. Residue spreading from anaerobic digestion has the second largest impact to acidification after incineration. The impact from material recycling is almost negligible in comparison to other treatment options.

Acidification impacts from the external system (Fig. 4.5) significantly change the order of scenarios. Because of upstream electricity and compensatory petrol the landfill 2020 scenario gives a value of 620 tonnes of SO$_2$ equivalents that is 6 times higher than the core system. Compensatory petrol increases the impact by 120 tonnes of SO$_2$ equivalents in the incineration scenario, placing it on the second lowest place with respect to acidifying emissions. Together with the external system, the biological treatment scenario has the lowest acidification impact. Since it produces fuel for busses and at the same time generates electricity and heat, there is no need for compensatory petrol and energy.

**Eutrophication**

As for GWP the landfill scenario is the main contributor to eutrophication impact with an amount of 5800 tonnes of NO$_2$-equivalents per year (Fig. 4.6). The incineration scenario has the lowest impact that is 50% less than the landfill scenario. The impact from the landfill is so high that in the incineration scenario the emission from the landfill has the same value as emissions from incineration even though only 12% of waste is landfilled. In the biological treatment scenario, emissions from residue spreading are added to those from the incineration and the landfill. Transportation of waste has less impact but still is considerable. For this impact category, plastic recycling has a small impact in comparison to previous ones.

![Eutrophication from core system (tonnes of NO$_2$-equivalents)](image)

*Source: ORWARE results for Chisinau model*

---

4 Eutrophication is the fertilisation of an aquatic system by addition of nutrients, primarily phosphorus and nitrogen that stimulate blooms of algae.
Emissions of nitrogen (mostly in the form of ammonia and NOx) are identified as the major cause of this effect. A relatively insignificant contribution comes from a small amount of phosphorus.

![Graph showing environmental impacts](image)

**Fig. 4.7 Eutrophication including external system (tonnes of NO₂-equivalents)**

*Source: ORWARE results for Chisinau model*

The order between the 3rd and the 4th scenario is changed after including impacts from upstream and compensatory systems (Fig. 4.7). The biological treatment scenario has the lowest impact where the external system contributes with a very small impact from compensatory heating. Because of compensatory petrol, the incineration scenario has increased to 3500 tonnes of NO₂-equivalents and has the second lowest emissions. The landfill 2020 scenario has the highest impact as for the core system. It increases the impact by 30% due to compensatory petrol, heating and upstream electricity.

**Photo-oxidant VOC**

This is one of the two impact categories connected to the formation of ozone. Mainly CH₄ and volatile organic gases from the landfill processes and CO from incineration cause photo-oxidant formation and are calculated in ethene-equivalents. As for global warming potentials and eutrophication, the landfill scenario dominates the impact of photo-oxidant VOC (Fig. 4.8). The emission amount corresponds to 250 tonnes of ethene-equivalents. The incineration and biological treatment scenarios have almost the same impact equivalents approximately 40 tonnes of ethene. Even though only 12% of the waste is landfilled in the incineration and biological treatment scenarios, the landfill has 5 times higher photo-oxidant VOC impact than incineration. Other treatment options have a negligible impact, except a small impact coming from biogas utilisation.

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5 Photo-oxidant VOC is a measure of the photo-oxidant formation which derives from volatile organic compounds emissions, causing destruction of tropospheric ozone
When the photo-oxidant VOC impact from external systems are added (Fig. 4.9), the relation between scenarios remain the same. Upstream and compensatory systems main contribution come from the need for compensatory petrol, heating and upstream electricity. The impact from the landfill increases to 310 tonnes of ethene-equivalents, an increase with 60 tonnes compared to the core system. Compensatory heating and electricity for the biological scenario contribute less in photo-oxidant VOC impact than compensatory petrol for the incineration scenario.
Even though the biological scenario has the lowest impact, the difference between the 3rd and the 4th scenario is very small. It contributes with an average of 55 tonnes ethene-equivalents that is more than 5 times less than the landfill scenario.

**Photo-oxidant NO\textsubscript{x}\textsuperscript{6}**

NO\textsubscript{x} is partly responsible for a series of problems, including acidification and increased concentration of photo-oxidant in the atmosphere. That way the acidification and photo-oxidant NO\textsubscript{x} impacts show similarities (Fig. 4.10).

![Graph showing emission from core system (tonnes of ethene-equivalents)](chart)

Fig. 4.10 Photo-oxidant NO\textsubscript{x} from core system (tonnes of ethene-equivalents)

Source: ORWARE results for Chisinau model

The lowest impact emission comes from the landfill scenario with an amount of 13 tonnes of ethene-equivalents. The incineration and biological treatment scenarios have the highest impact with an amount of 65 tonnes of ethene-equivalents. Emissions of nitrogen oxides (NO and NO\textsubscript{2}) arise primarily from the reaction of nitrogen and oxygen during the combustion of fossil fuels and biomass. In Fig. 4.11 it is clearly illustrated that impact occurs mainly from incineration, followed by waste collection and biogas utilization. Both for acidification (Fig. 4.5) and photo-oxidant NO\textsubscript{x} (Fig. 4.11), the order between scenarios is drastically changed by adding external systems. High emissions with an amount of 150 tonnes of ethene-equivalents from the landfill scenario are a result from compensatory petrol, heating and upstream electricity. The incineration scenario has the same high impact from compensatory petrol and has the second lowest impact. Biological treatment has the lowest emissions for this impact category. The emissions from the 4th scenario correspond to 90 tonnes of ethene-equivalents.

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\textsuperscript{6} Photo-oxidant NO\textsubscript{x} is the photo-oxidant formation which derives from NO\textsubscript{x} compounds reaction, causing destruction of tropospheric ozone
Fig. 4.11 Photo-oxidant NOx including external system (tonnes of ethene-equivalents)
Source: ORWARE results for Chisinau model

Total environmental impacts
All core system environmental impacts from the different scenarios are summarised and
normalised in Fig. 4.12. The landfill 2005 scenario was excluded from this comparison, since it is
not of interest for future planning.

Values were normalized against highest value within each impact category

Fig. 4.12 Environmental impact of core system
Source: ORWARE results for Chisinau model

Three out of five impact categories demonstrate that the landfill 2020 scenario may be considered
the worst, causing the highest environmental impacts. Incineration and biological treatment show
nearly the same impacts from the core system. Biological treatment has a higher acidification impact (23%) and eutrophication (5%) than the incineration scenario. For photo-oxidant VOC impacts, both the incineration and biological treatment scenarios reduce impact by 80% compared to the landfill 2020 scenario. For photo-oxidant NOx, the situation is opposite; here the landfill scenario shows 4 times lower impact from the core system compared to the 3rd and the 4th scenarios.

By adding the external system the situation has changed Fig. 4.13. Five out of five environmental impacts demonstrate that the landfill 2020 scenario has the highest environmental impacts. The landfill scenario therefore may be considered the least preferable waste management system regarding overall environmental impacts. The lowest impact is achieved for the biological treatment scenario, followed by the incineration scenario. These two scenarios may be considered as representing improved future waste management, since they are capable of decreasing the emissions. The main reduction of emissions of the incineration and biological treatment scenario is seen for photo-oxidant VOC followed by GWP and eutrophication impact categories. The incineration and biological treatment scenarios have almost the same acidification and photo-oxidant NOx impacts. The impacts reduction for different environmental impact categories varies from 35 to 80% when a transfer from landfilling to the biological treatment scenario is introduced.

Fig. 4.13 Environmental impact of total system
Source: ORWARE results for Chisinau model
4.4 Energy Turnover

The energy consumption and production for different scenarios in this study was calculated for transport fuel (waste transportation), electricity and heat. The model takes into account the use of energy sources as coal, natural gas, oil, biomass, hydropower and nuclear energy. At the moment Moldova does not use biomass or nuclear energy. For energy turnover calculations, the ORWARE Stockholm model was used, that calculates an average national mix for both heat and electricity production from different sources.

<table>
<thead>
<tr>
<th>Energy in the WMS <a href="Internal">TJ</a></th>
<th>Landfill 2005</th>
<th>Landfill 2020</th>
<th>Lf + Inc 2020</th>
<th>Lf + Inc + Ad 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Consumption</td>
<td>-33</td>
<td>-58</td>
<td>-49</td>
<td>-50</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>0</td>
<td>-55</td>
<td>-157</td>
<td>-172</td>
</tr>
<tr>
<td>Heat Consumption</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-22</td>
</tr>
<tr>
<td>Fuel gas production</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Electricity production</td>
<td>0</td>
<td>0</td>
<td>550</td>
<td>495</td>
</tr>
<tr>
<td>Heat Production</td>
<td>0</td>
<td>0</td>
<td>1668</td>
<td>1503</td>
</tr>
</tbody>
</table>

*Source: ORWARE results for Chisinau model*

In the scenario 2005, only oil is used for waste transportation to the landfill. For all 2020 scenarios, energy consumption is added for transportation activities and material recycling. Since the incineration and biological treatment scenarios are more complex systems, they lead to more transport and energy use. The incinerator is placed at the boundary of the city centre in order to optimise infrastructure for heat and electricity distribution and waste transport. The use of oil for waste transportation is almost the same for all 2020 scenarios (Tab. 4.4). Due to an increased systems complexity, the electricity consumption for the 3rd and 4th scenarios is 3 times higher than for the landfill 2020 scenario.

*Fig. 4.14 Energy balance for the waste management system [TJ (10^12J)]*

*Source: ORWARE results for Chisinau model*
The biological treatment scenario consumes an additional amount of 22 TJ of heat. Waste is incinerated in both the 3rd and 4th scenarios and produces an average of 500 TJ of electricity and 1500 TJ of heat. In Fig. 4.14, the energy turnover is shown for the four simulated scenarios. The incineration scenario produces over ten times more energy than it uses, while the biological treatment scenario produces over eight times more energy than it uses. As a result of anaerobic digestion, biogas for busses is produced. The amount of energy produced is 31 TJ per year, contributing to nearly 14 million bus transport km.

4.5 Materials recovery

At the moment, there is no material recovery in Moldova. It was assumed that by 2020 the material recovery will be introduced and the same level of material recycling was assumed for all future scenarios (see Tab. 3.2). The simulated model calculates only the amount of recycled cardboard in the form of virgin cardboard substituted and recycled plastic in the form of HDPE granules. The amount of recycled cardboard will constitute 3400 tonnes per year and the amount of recycled plastic will be 7700 tonnes per year. It was found that the environmental impact from recycling is quite small. There is a small acidification and photo-oxidant impacts from plastic recycling. The impact from cardboard recycling is not visible in any impact categories and it is negligible in comparison with impacts from other systems.
5. DISCUSSION

The thesis provides technical and environmental information on solid waste management in Chisinau, Moldova. The study covers the whole waste stream since the aim was to find the total impact for different treatment methods. The MSW flow in 2020 has been analysed in three different scenarios; landfill, incineration and incineration plus biological treatment. The analysis has provided the possibility of a quantitative assessment of different environmental impacts, energy potentials and how some materials can be recycled. From the analysis, it is obvious that traditional landfilling of mixed household waste is not a good treatment option. However, the landfill 2020 scenario was included to have a clear picture of what should be expected and how bad the situation can be in comparison with other treatment options. The study shows that decision makers have to set goals to avoid a so called business as usual situation and to focus on more sustainable treatment methods. The results presented are influenced by many factors. They depend on system boundaries, specific parameters, the model construction and how suitable the assumptions made for Chisinau were. Lack of data and a low accessibility to existing data might have affected the accuracy of the simulations performed. One important issue is that the ORWARE model has been developed for Sweden that has different geographic and climatic conditions from Moldova.

5.1 Environmental impacts

The study does not include a justification of the importance of different impact categories among themselves. One impact category at a time was considered to make comparisons between different treatment options. As mentioned before, landfilling is the least preferable choice with focus on environmental issues. GWP, acidification and photo-oxidant formation from VOC are very much affected by the operation and maintenance procedures at landfills. There is no doubt today that landfilling causes many problems in surrounding areas. Due to inadequate operation, many people complain about odour and health problems related to bad air and water. The simulations performed cannot show such impacts. The development level of a country influences the waste treatment methods used. At the present time, landfilling is the most common waste treatment method not only in Moldova but also in all former Soviet Union countries. This happened due to the reason that landfill taxes were and are very low. Since Moldova has signed the Kyoto protocol to reduce carbon dioxide emissions, measures should be taken without delay. In the national discussion, incineration and biological treatment have been considered but have not yet been implemented. This is a pity, since landfilling is not a treatment method but rather postponing the handling of a problem, while causing different types of impacts. Here, as always, financial factors stay in front of environmental issues. It was assumed that if a project should start, it has to be of economical interest. Therefore, the incineration (3rd) scenario was chosen due to electricity and heat production and the ash can be used as a construction material. From an environmental point of view, it was found that the combustion process has a considerable potential to reduce most of the environmental impacts, except NOx emissions. At the same time, the ORWARE simulations for the entire system resulted in lower environmental impacts if a certain amount of electricity and heat is produced by conventional systems. That is because formation of photo-oxidant NOx is lower in an incinerator. It should be noted that the incinerator was simulated to function as incinerator from Stockholm with efficient process control and has a strict air control system. It has very low NOx emissions compared to other incinerators from Europe. Thus, the simulation figures may give a too positive picture for a number of released gases. More than that, upstream and compensatory systems are likely to be different. One step forward is biological treatment (4th)
scenario that is performed through anaerobic digestion of organic waste and also has incineration as a treatment method for the rest of the waste. The anaerobic digestion technology is proven to be one of the best available technologies for organic solid waste. As mentioned before, the biogas will be used as a fuel for city busses. That will certainly improve the air quality in Chisinau. In view of the fact that only 25% of organic waste is biologically treated in the 4th scenario, there is a slight difference of GWP photo-oxidant NOx and VOC impacts between the 3rd and 4th scenarios. But by adding external systems, the impacts from the biological treatment scenario give the lowest values. Due to lower environmental impacts than the landfill scenario, both for the incineration and biological treatment scenario may be considered as future improved waste management options.

5.2 Energy and materials recovery

Moldova has no natural resources and any alternative energy is most welcome. By using alternative sources, Moldova may start to reduce, little by little, the national dependence on imported energy and raw materials. Here, energy from waste is an interesting alternative. As an example, heat recovery from waste incineration should be very interesting, since Chisinau has a winter temperature that is an average by 4°C lower than that in Stockholm. More than that, 40% of the Moldovan industry is located in Chisinau and as it is well known, industry demands always heat and electricity. Unfortunately, there is no material recovery from MSW in Moldova today. There are local actors that recycle industrial waste but no one has focused on material recovery from MSW. Moldova has quite a fast economic growth and the presence of paper, plastic, glass and metals increases while organic waste decreases in percentage. There will be some time before Eastern European countries will reach the recycling level of Western European countries. In a country like Moldova, first of all, there is a need to work with social aspects of development. Later, other issues such as more sophisticated waste management, using full cost accounting and extended producer responsibility, might be introduced. Recycling should focus on efficient use of recycled material, energy conservation and environmental protection. In the model, presence of a good infrastructure for waste management and a well-informed population was assumed, something that may not be in Moldova. Therefore, the quality of recycled material in Chisinau might be lower.
6. RECOMMENDATIONS

The Model: There were many complications with data gathering. First of all, the institutions and organisations responsible for waste management should be well organised and have a suitable distribution of responsibilities. After all, the collected information provided only a general picture of MSW flow in Chisinau. When it comes to ORWARE application, there was insufficient data; therefore assumptions had to be made to simulate the model. Many parameters included in the ORWARE, simulations presented here, were therefore assumed to follow Swedish figures. Due to differences in geographic and climatic conditions, the same waste will perform differently in different places. That way, the studied area must be investigated and characterised first. It is essential to collect as much as possible valid data to avoid assumptions. The local data should give a detailed waste characterisation and waste sources mapping. More accurate waste data would result in better decision-making. Another concern is the development of the recycling sub-models such as glass, metal and paper in the ORWARE model. It would be valuable to achieve the whole picture of the environmental impacts from recycling. In order to include all costs in the systems analysis, the system boundaries should be enlarged.

Waste Management: Based on the simulation results, the biological treatment scenario using incineration and anaerobic digestion is the best simulated waste treatment option from an environmental point of view. The incineration scenario may be seen as a good future waste handling option too since it might significantly decrease the environmental impacts compared to the landfill scenario.

Firstly, the decision-makers’ focus should be on incinerating the municipal solid waste and gradually to increase public awareness in order to promote recycling. Material recycling has an economic, environmental and social advantage in addition to its benefits of reducing the quantities of waste to be landfilled. Therefore, based on Swedish experience, an extended producer’s responsibility should be introduced. If producers will be in charge to recycle their products or materials, there is a good chance that they will reduce the products complexity and will increase the use of recycled materials. With time, besides an increase in materials recycling, organic waste will be sorted out too with an increased producers’ responsibility. When enough organic waste will be recycled, a biological treatment facility will be built. Since an anaerobic digester facility normally has a smaller scale than an incinerator plant, several organic treatment facilities will have to be built with time. By developing an infrastructure of anaerobic digestion plants, the organic waste transport distances will be reduced and perhaps more organic waste can be sorted out. A successful implementation of a new waste management program has, however, to be done incrementally, taking into consideration social acceptability.

Environmental Information and Public Participation: Public participation and environmental awareness are important issues in improving the local waste management system. Unfortunately, it takes a long time to make people aware of the necessity to improve the waste management system and to increase their participation. Here, pilot programs, supported with education programs, are of importance. The pilot program could be started in small residential areas, before being extended to the entire city. If combined with a strong education and publicity program, the pilot program can help people become more environmentally alert. The potential users of recycled materials have to be informed about the solid waste management system and where it is possible to obtain those materials. Another suggestion is to extend the environmental information centre currently in operation in Chisinau. The centre should work in close cooperation with environmental organisations and institutions and all environmental information should be provided to the public. Such a mechanism would result in a faster increase of the local environmental awareness and improve public participation.
7. CONCLUSIONS

Due to a lack of time, a cost analysis was not included in this report. Social impacts such as human health were not evaluated neither. In this study, I have tried to apply systems analysis by using the ORWARE model. This resulted in broad analysis of (i) identifying the linkage between the solid waste stream and surroundings and (ii) pointing out the entire magnitude of environmental consequences associated to the present and a number of future waste management options. The current waste management in Moldova (landfilling) causes serious environmental problems. An increasing waste generation will result in increasing environmental problems. The study results show that by changing the waste management system, there will be an essential decrease of environmental impacts. Three out of five impact categories give lower emissions results for the incineration and biological treatment scenarios. The incineration scenario has a reduction of global warming potential with 65% and photo-oxidant VOC with 80%, while biological treatment with a combination of incineration and anaerobic digestion results in even lower emissions. Five out of five results show lower emissions for the incineration and biological treatment scenarios by including the external systems. The biological treatment scenario releases the lowest emissions in providing the same function. Such a waste treatment system with a combination of incineration and anaerobic digestion would supply the city with heat and electricity and biogas for buses. As a consequence, the air quality in the city will improve. Nevertheless, despite it was assumed that not more than 25% of the organic waste will be separated in 15 years from now; biological treatment combined with incineration was the best waste treatment scenario. Being the dominant fraction, the organic waste should be seen as of key importance for an effective waste management in Chisinau. An efficient organic waste source separation should therefore be developed. If more organic waste will be separated and treated biologically, the impact will be further reduced. Besides the organic fraction, recycling of different materials should be improved. At the moment, the separation system has not been developed yet. The simulation results show that environmental impacts from recycling of plastic and carton are almost negligible compared to other treatment options. The municipality of Chisinau should start to implement an effective source separation of waste as soon as possible. As mentioned before, it is also very important to increase public environmental awareness, since this factor influences the quality of separated waste and their treatment. The solid waste management in Moldova should be regarded in a broader perspective. A number of parallel measures should be taken that will avoid or minimize impacts from waste and waste management. Any possibilities to energy and material recovery should be regarded as potential alternative sources and investigated in more detail. These waste programs and policies have to be realistic, effective and integrated with other systems.
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