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MSc Program
Environmental Technology & International Affairs

Demand for Final Sinks of Selected Substances in Countries of Different Economic Development - Analyse for Carbon, Nitrogen and Mercury in three cities of the world

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 5 June 2013

Affidavit

I, **BOURSIER SYLVAIN**, hereby declare

1. that I am the sole author of the present Master's Thesis, "DEMAND FOR FINAL SINKS OF SELECTED SUBSTANCES IN COUNTRIES OF DIFFERENT ECONOMIC DEVELOPMENT", 115 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The anthropogenic influence on the Earth's ecosystems has never been as important as today. Natural cycles of elements are disturbed especially in big cities of the world. Depending on the level of consumption and the environmental protections that are in place, cities emit more or less substances that are then diluted in the available natural sinks. The goal of the thesis was to assess and compare the emissions of carbon, nitrogen and mercury in the atmosphere, hydrosphere, lithosphere and in landfill for three cities of the world with different level of development. As this is a complex task, the purpose is to find in each case a rough estimation of quantities emitted per year, then to calculate necessary dilution factors that allow comparison between the three cities. The total emissions level for Vienna, Santo Domingo and Bamako could be determined but sometimes with high approximations. The main results from the comparison of the necessary dilution factors are that the emissions of a developed city, here Vienna, are in general more easily diluted by the available sinks and therefore put less pressure on the local ecosystem. Bamako, as a weakly developed city, exerts more pressure and Santo Domingo as an intermediate developing city exerts even more than the others. This is mainly due to an interdependence between pollution control and the amount of used resources. In the end, this simplified research verified the assumption that a developed city with high environmental standards has a lower impact on the local environment.

Acknowledgements

I would like to take this opportunity to express my gratitude to my supervisor Johann Fellner who guided me in the right direction with precious pieces of advice, constant feedback on my work and enthusiasm through this year.

Moreover, I would like to thank my parents, my girlfriend, my ETIA colleagues and my friends for their inestimable support and help throughout this master programme.

Table of Contents

List of Abbreviations/Acronyms/Chemical Formula

ASGM	Artisanal and Small scale Gold Mining
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
CSO	Combined Sewer Overflows
EMEP	European Monitoring and Evaluation Programme
GDP (PPP)	Gross Domestic Product at Purchasing Power Parity
GHG	Greenhouse Gas
GIE	Groupement d'Intérêt Economique or Intercompany management syndicate
HC	Hydrocarbon
HM	Heavy Metal
Hg	Mercury
LDC	Least Developed Countries
MBT	Mechanical-Biological Treatment
MEA	Multilateral Environmental Agreement
MSW	Municipal Solid Waste
N/A	Not Available
NMVOC	Non-Methane Volatile Organic Compound
N_2	Nitrogen
NH_4^+	Ammonium
NH3	Ammonia
N2O	Nitrous Oxide / Laughing Gas
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NO_2^-	Nitrite
NO_3^-	Nitrate
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutant
SFA	Substance Flow Analysis
SIDS	Small Island Developing States
SLCP	Short-Lived Climate Pollutants
TOC	Total Organic Carbon
UN	United Nations
UNEP	United Nations Environmental Programme

UN-HABITAT	United Nations Human Settlements Programme
UN-OHRLLS	United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and the Small Island Developing States
USD	United States Dollar
WEEE	Waste Electrical and Electronic Equipment
WWTP	Waste Water Treatment Plant

1. Introduction

In the current globalised world, the use of resources has never been so important. Human beings exploit the planet surface and ground to develop their economy and consume more and more resources. However, this increasing consumption puts a growing pressure on the planet. Resources are extracted, often transformed, used or consumed and eventually disposed of or emitted. This process is unfortunately not a closed cycle because generally resources are not disposed in their original state and at their original place. This creates a disequilibrium in the system of the planet that could cause irreversible alterations in the future. Climate change is today the best example of this issue. Fossil carbon, contained in the lithosphere and planet crust, is now released in the atmosphere and modifies the planet's natural greenhouse effect.

Even if most of these disruptions in the system have no visible effect yet, it is important to understand them and to assess the proportion they have. Therefore, it becomes relevant to analyse the stress that is put on the sinks that receive the substances consumed by mankind.

As the Earth is a highly complex system made of hundreds of thousands of chemical compounds that interact in a wide range of meteorological and geographical settings, it is relevant to limit the scope of research to precise areas and to a restricted amount of elements. In addition, with the high disparity of development that can be found on the globe, performing a comparison of the substances released by different places in the world would allow to understand their degree of implication on the sink demand and more generally on the disturbance of the system. The results could then help to decide the best policy to follow for a less disrupted future.

In the end, the research realised in this thesis is performed on three distinct chemical elements, i.e. carbon, nitrogen and mercury, and three types of cities of the world that have a different level of development.

1.1. Hypotheses and Research Question

1.1.1. Hypotheses

The comparison of three cities, with different developmental growth, will give an idea on which model would be more appropriate to minimise the impacts on the sinks in the future. Different levels of development imply that the amount of goods consumed will also change. So the first hypothesis is that emissions of carbon, nitrogen and mercury are higher in more developed cities because of the higher level of consumption.

It has also been observed that the environmental protection of a specific site was very often linked to the level of wealth. In fact, after having covered their basic needs, human beings start to take care of the surrounding environment. Therefore, the second hypothesis is that the more developed a city is, the higher environmental standards it has.

Thus, the most developed city analysed is assumed to use more resources that are, after utilisation, released in the available sinks. This higher amount of emissions directly affects the concentration of the substance in the sink that has then a reduced capacity of absorption. But, the most developed city is assumed, at the same time, to minimise the release of harmful substances in the environment via pollution control for example. On the contrary, the least developed one is assumed to consume less but to care less about its reemitted substances.

1.1.2. Research Questions

After having defined the two hypotheses in the former section, the goal of the thesis is to verify whether these assumptions are true. Therefore, the research questions are the following:

- What are the demands of sinks in a city with a high consumption of resources and developed emissions control?
- What are the demands of sinks in a city with a medium consumption of resources and partly developed emissions control?
- What are the demands of sinks in a city with a low consumption of resources and low developed emissions control?

- In which city are the sinks demands the least impacting for the environment?

In other words, it is attempted to prove a common assumption in the Western World that it is better for the human beings and the planet environment to live in a developed world that cleans its environment.

1.2. Structure of the Thesis

In order to answer the question of this thesis, there is first an introductory chapter covering general background information about the substances chosen and the types of city covered for the research. In the same chapter, a brief state of the art presents the current differences of knowledge and information available according to the elements and to the cities.

In the following section, the methodology used to find out the level of emissions and to lead the research is described. There is also a section covering the different sources of data that have been used.

After these two theoretical chapters, the results found are presented. First of all, the emissions for each element and each city are given. Secondly, the necessary dilution factor for each sink is calculated and a comparison between the cities is done. Thirdly, the assumptions that had to be made and the difficulty to assess the margin of errors are explained.

After a presentation of the results, there is a summary made and some discussions covering the strengths and difficulties of the thesis and its limits. The last chapter gives a conclusion on the research. The potential applications of the findings is analysed and the future possible directions of the topic are summarised.

2. State of the art

2.1. What is a Sink?

The scientific definition of a sink can describe two different things. On the one hand, a sink can be a transformation process. For instance, an incinerator that transforms a chemical compound in other substances is the final sink for this compound. On the other hand, in case of chemical elements, a sink is a big reservoir that accumulates substances and that also has, in most cases, a way to discharge the accumulated substances.

The main environmental sinks known are the sediments, the oceans and the atmosphere. So when a substance is released, it ends up in a sink for a certain amount of time. This period of time usually determines whether the sink is considered as final or temporary. A reservoir that keeps a substance for at least 10000 years is considered as final. For instance, in atmospheric chemistry, chemical compounds released in the atmosphere can have a lifetime of several decades such as nitrous oxide (N_2O) or of only a few hours like nitric oxide (NO). In fact, it may undergo a chemical transformation and be transported in the upper layers of the atmosphere. Or it may be washed away by the rain and therefore is moved to the ground. Once on the globe's surface, the substance may be absorbed by a plant, be transported by run-off to oceans or stay in the ground and therefore become part of the sink called lithosphere.

The capacity of the sinks depends very much on the type of substances and, among others, on the meteorological and chemical conditions. The main sink for carbon is not the same as the main sink for nitrogen. As seen in the table 2.1, carbon is essentially stored in sediments, whereas nitrogen can mainly be found in the atmosphere in the form N_2. It can also happen that sinks become saturated. It means that their capacity of absorption for a substance reduces. For example, oceans absorption of carbon dioxide (CO_2) has already started to decrease (Sabine et al., 2004). In that case, the carbon cycle is disturbed and this could imply a modification of the climate.

Table 2.1 Reservoirs for Carbon and Nitrogen (Brasseur et al., 1999)

Table 5.1a
Reservoir Masses in the Global Biogeochemical Cycles of Carbon, Nitrogen, Phosphorus, Sulfur, and Oxygen

Reservoir	*Element* (10^{15} g of element)				
	C	N	P	S	O
Atmosphere	760	3,950,000	0.00003	0.003	1,216,000
Ocean	38,400[a]	570[b]	80[c]	1,248,000[d]	4100[e]
Land biota	600	10	3	2.5	800
Marine biota	3	0.5	0.07	0.1	4.2
Soil organic matter	1600	190	5	95	850
Sedimentary rocks	78,000,000	999,600	4,030,000	12,160,000	1,250,000,000

[a]Dissolved inorganic carbon. [b] NO_3^-. [c]PO_4^{3-}. [d]SO_4^{2-}. [e]Dissolved O_2.
From Mackenzie, 1997.

2.2. City Pollution and its Sinks

2.2.1. Specificities of Cities

The system considered in this study is limited to the borders of the city. Cities constitute a very specific place on Earth that has been particularly created for human beings. Therefore, it has some specific characteristics that have to be mentioned in order to understand their emissions to the different sinks available.

First, cities generally have a higher population density. A larger population on a limited area increases the concentration of solid waste, waste water and off-gas per square meter (m^2).

Second, the high density of population increases the traffic into the city. In fact, the proportion of cars may be smaller but cities are equipped with public transportation systems. So, concentration of pollutants due to traffic is usually higher.

Thirdly, the limited amount of space is generally another incentive to restrict the area dedicated to agricultural and industrial activities or to energy production. Moreover, as these activities may generate visual, olfactory or noise pollution, they tend to be outside the legal borders of cities. It is only after the production process that final goods are imported into the city.

2.2.2. Sink of Cities

In cities, three main sources for the emissions of carbon, nitrogen and mercury can be identified. The sources have different sinks.

First, waste water, which comes from households, industries and water run-offs from rain or from agriculture. It represents the main waste of household. This water, depending on the local specificities, seeps into the lithosphere or is released in the hydrosphere, i.e. river, lake, sea, ocean or groundwater.

Second, non-liquid waste generated by households, industries and agriculture. Waste are generally collected and gathered at some places to be reused, treated, recycled, incinerated, disposed or sent outside of the city. The action performed on waste determines in which sink and at which proportion substances end up. In that case, all the sinks can be concerned namely the lithosphere, the atmosphere, landfills or waste can be sent out of the system, if it is for example hazardous.

Third, chemical reactions such as the combustion process, the respiration of human beings and plants and the photosynthesis also emits substances in sinks. The atmosphere is in that case the most important sink that is involved.

In the end, as seen in the figure 2.1, sinks of the cities are the hydrosphere, the atmosphere, the lithosphere and landfill sites. A flow of substances is directly recycled or reused and another one leaves the system.

Landfills and even the atmosphere could be considered as temporary sinks because some of substances that are released there spend a reduced amount of time before being reemitted. However, in order to simplify the analysis, this will not be the case in this thesis.

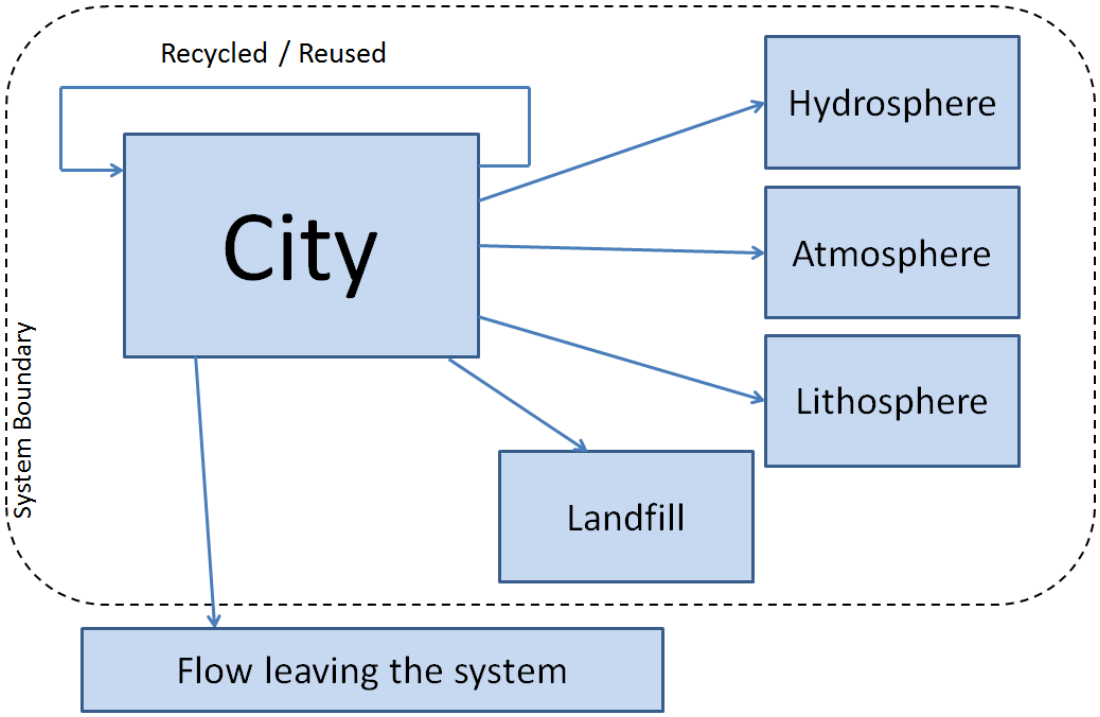

Figure 2.1 City sinks

2.3. The Three Elements Selected

Everything on Earth is composed of more than 100 different chemical elements. These elements, all listed in the periodic table of Mendeleyev, can be found in different proportions. The three elements chosen, i.e. carbon, nitrogen and mercury have a strong link with anthropogenic activities in cities and also to human health.

2.3.1. Carbon

Even if carbon represents only 0,025% of the Earth's crust, it is the element with the highest number of compounds (Encyclopædia Britannica, 2011) and it plays an essential role for all living organisms. It is involved in the respiration process, with the CO_2 as a product of the chemical reaction, in the food chain, with the numerous organic compounds and in the combustion process[1]. Therefore, carbon is closely related to the development of mankind.

Most of the carbon is stored in the sediments of the planet's crust as calcium carbonate ($CaCO_3^-$); however, a part of it circulates between the different systems of

[1] The Element carbon reacts with the element oxygen (O_2) to give CO_2 and to release energy.

the planet (i.e. atmosphere, oceans, soils and living organisms). This natural carbon cycle has been disturbed ever since the use of fossil fuels by human beings. The fossil carbon stored in the Earth's crust has been released after combustion in the atmosphere and is one of the causes of climate change. The current carbon cycle is presented in figure 2.2. Climate change is expected to have large consequences on the future of the planet and represents for the past two decades one of the main topics discussed at the international level.

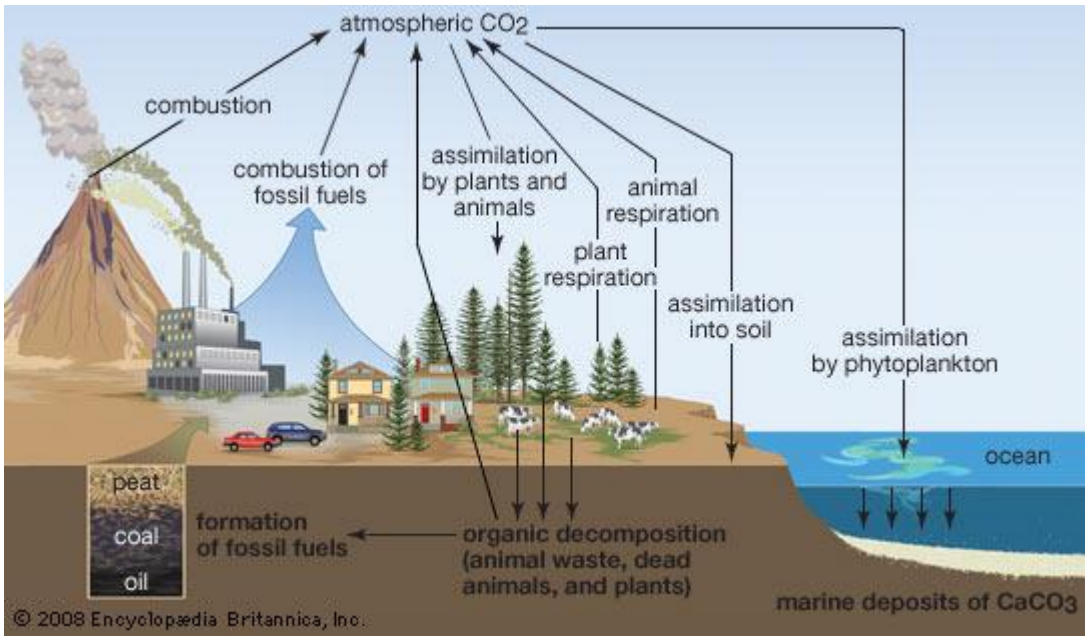

Figure 2.2 The Carbon Cycle (Encyclopædia Britannica, 2012)

In addition, some carbon compounds can represent a risk for human beings. The main gases released during the combustion CO_2 and carbon monoxide (CO) can cause suffocation in a closed environment. Other inorganic and organic compounds, e.g. hydrogen cyanide, fluorine, and bromine are toxic or can affect the nervous system (Encyclopædia Britannica, 2011).

Finally, the predominant role of carbon in human beings' life and in its future justifies the choice of the element for this study.

2.3.2. Nitrogen

As for carbon, nitrogen has played an important role in the recent development of societies. Indeed, in the beginning of the 20th century, the Haber-Bosch process allowed to artificially control the nitrogen fixation. Largely available in the air, nitrogen gas could now be transformed, in large proportion into ammonia, a

chemical compound that could be used as a nutrient by living organisms. This chemical process contributed largely to the development of intensive agriculture and is one of the main reasons for the modification of the nitrogen cycle.

Another important factor is, like for carbon, the development of the combustion process. Fossil fuels contain a certain amount of nitrogen. When they are burnt, nitrogen molecules bonds to the oxygen atom and becomes nitrogen oxides[2] (NOx) gases. In addition to this fuel NOx formed, the high temperature stimulates the generation of thermal NO by splitting the N_2 contained in the air that is then combined with atoms of oxygen.

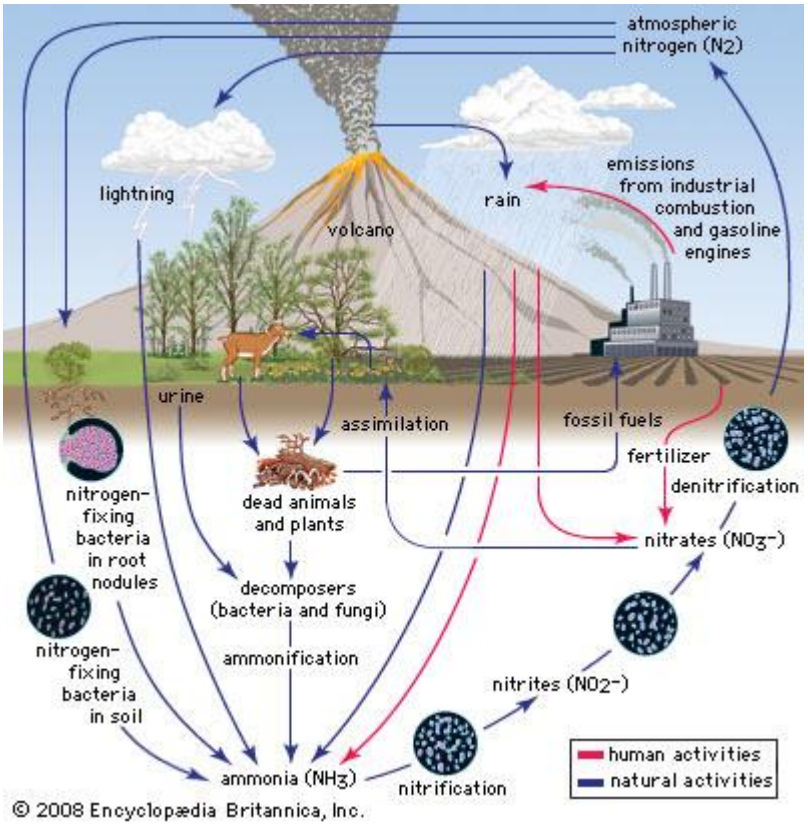

Figure 2.3 The Nitrogen Cycle (Encyclopædia Britannica, 2008)

These two anthropogenic actions, represented by red arrows on figure 2.3, disturbed the natural nitrogen cycle and contribute to two types of pollution. The nitrogen oxides pollute the atmosphere and can cause lung problems to human beings. Today, it is the main pollutant generated by vehicles. Nitrogen oxides are also precursors of secondary aerosols that intensify the greenhouse effect.

[2] NOx is the sum of NO and NO_2. They are grouped under NOx because NO is usually transformed in NO_2 after some time.

Furthermore, a part of the nitrogen used in agriculture as a fertiliser ends up in nearby water bodies and pollutes in several ways. Indeed, nitrite and ammonia are toxic for fish, nitrate (NO_3^-) is harmful for drinking water and ammonium takes up the oxygen necessary for the living organisms. In addition, sometimes the nitrogen is transformed to N_2O, which is one of the main contributors of global warming.

In the end, nitrogen plays an important role in the human society, on the one hand as a nutrient for agriculture and on the other hand as a serious pollutant for the biota and for humans.

2.3.3. Mercury

Mercury, or quicksilver, is an elemental metal with the exclusive property to be found at liquid state at standard temperature and pressure conditions. It has other interesting characteristics, such as a high conductivity or a natural water-imperviousness that makes it useful for specific human activities. Its compounds have been used since several centuries in medical, meteorological and mining fields.

However, mercury is a heavy metal (HM) and can be particularly dangerous for human health. Some of its compounds are poisonous after inhalation, ingestion or contact by humans and animals. A biomagnification[3] of methylmercury in the aquatic food chain also takes place and eventually reaches harmful concentration at the end of the food chain.

With the increase of anthropogenic activities on the planet, mercury, which is naturally found in the Earth's crust, has been largely extracted, used and released in the natural sinks over the last centuries. This extracted mercury does not sediment easily and tends to be naturally recirculated among the hydrosphere, the atmosphere, the lithosphere and living organisms. It has been estimated that between 60% and 70% of the mercury in recirculation comes from past emissions (United Nations Environment Programme, 2013: i). This enhanced mercury cycle constitutes a growing threat for living organisms especially on a long-term scale and in January 2013, an international agreement has been signed to limit the use of mercury (Kinver, 2013).

[3] Accumulation of a substance in living organisms due to successive ingestions by predators in the food chain

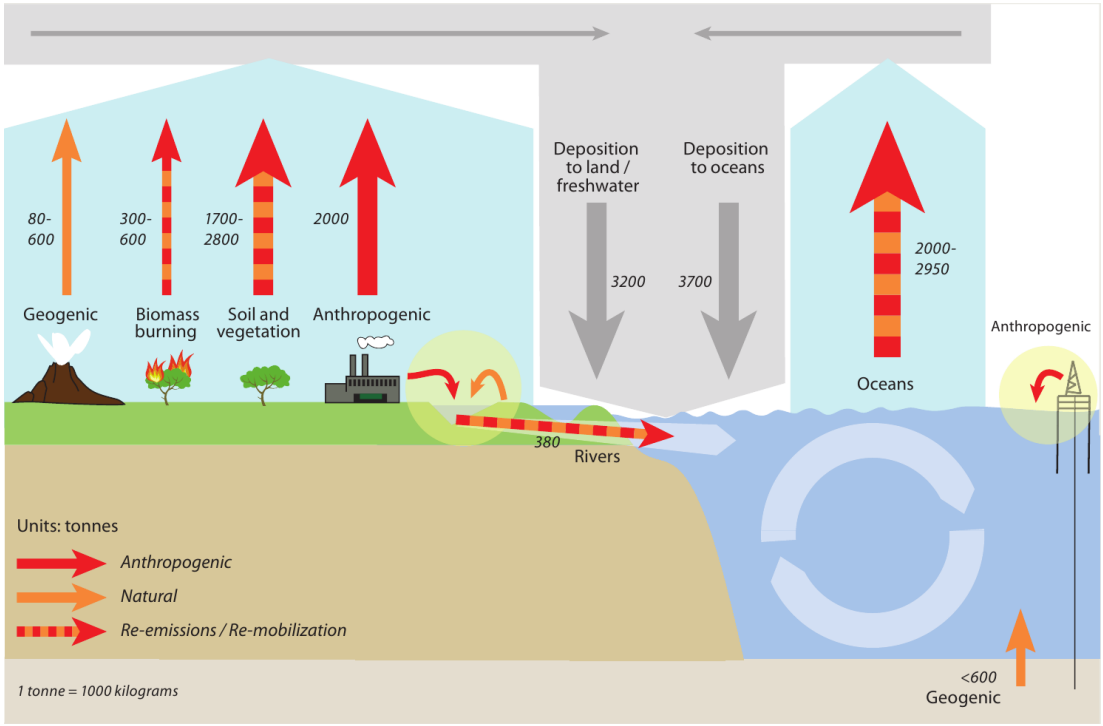

Figure 2.4 The Mercury Cycle (United Nations Environment Programme, 2013: 5)

As for carbon and nitrogen, mercury is an element that is useful for human beings but that presents some serious risks that need to be better understood and monitored.

2.4. The Three Types of Cities Selected

Cities of the world can be very diverse. In order to have a first estimation of cities emissions, three types of cities, with different levels of development, have been selected. Due to a probable lack of information in a designated city, the research scope has been extended to types of city. In fact, one main city per type is selected and when the relevant information cannot be found, data from relatively similar cities of the same region are taken to complete the study.

2.4.1. A Developed European City

Today, Europe is one of the leaders in the world for its economic situation. It has a high consumption for energy and goods; and the amount of waste generated is important. It is about 70 tonnes of waste per capita per year. Approximately half of this waste comes from excavated soil (Fellner, 2013).

Nevertheless, Europe is very concerned by environmental issues. It regularly sets new internal policies to protect its environment and the European Union is among the most active party to implement multilateral environmental agreements (MEA). Within the European countries, the development level of environmental technology shows disparities, but in regards to the rest of the world, it can be considered as rather homogenous.

In terms of climate, Europe is located in the mid-latitudes and thus has a temperate climate with four distinct seasons. Both the temperatures and the amount of precipitation vary along the year.

The capital of Austria, Vienna, has been selected as the main city for the study. Vienna is located on the plains of Austria along the Danube river and is spread over an area of 414,87 km². It had 1 731 236 inhabitants in 2012 (Section Statistics Vienna, 2012). So the density of population was 4172 inhabitants per km². Vienna is among the leader for environmental protection and uses advanced technologies for its treatment of waste water and waste incineration. It is also considered by some international surveys as the city with the world's best quality of living.

2.4.2. A Developing Caribbean City

The developing countries can be divided in different groups. Some improve their economic situation and some other still struggle to develop. This trend is reflected by the GDP. In the Caribbean region, there are strong disparities of wealth between the sovereign states and the dependent territories. However, most of them have a GDP (PPP) per capita above $9000 (Central Intelligence Agency, 2012). While the region has low resources to exploit, it has developed in part due to tourism. So tourism brings foreign capital but also extra waste that has to be dealt with on a limited amount of space. In fact, there are 4,5 million visitors per year and around 10% of the waste in the Eastern Caribbean is generated by tourists (Caribbean Recycling Foundation (CRF), 2003).

As tourism is essential for this region, the preservation of natural habitats and landscapes has to be taken into account. This means that even if they have limited means, Caribbean countries cannot neglect environmental issues. With the rising problem of climate change, these states are also among the first affected by the modification of the predicted climate. The rise of the sea level, the coral bleaching phenomenon and the increase of extreme disasters could affect them. Therefore,

they formed the group of the SIDS to increase their weight during international negotiations.

Regarding the climate, it is characterised by hot temperatures and regular precipitations during the whole year. There is a more humid season, from May to November, often called the hurricane season when there are risks of tropical storms.

The capital of Dominican Republic, Santo Domingo, has been chosen as the main city for the study. Indeed, it is one of the few cities of the region that has developed steadily its economy and that has reached the size of a metropolis. It is located on the south of the island on the shore of the Caribbean Sea. The metropolis has been divided in municipalities. The four urban municipalities are the National District, Santo Domingo East, SD West and SD North. As it can be seen on figure 2.5, the last three also have rural areas (non-orange coloured part). For this work, only urban areas are considered, therefore after calculations based on the census of 2010 (Oficina Nacional de Estadística, 2012a), the urban area of Santo Domingo is considered to be approximately 421 km². The urban population of Santo Domingo was 2 581 827 in 2010. So the density of population was 6133 inhabitants per km².

Figure 2.5 Municipal Division of Santo Domingo (Oficina Nacional de Estadística, 2009)

In addition, it is important to notice that Dominican Republic is one of the Caribbean countries that is making the effort to take care of its environment. It has a plan to reduce its CO_2 emission by two million tonnes in 2030 (DiaroDigitalRD, 2013) and

recently announced its intention to join the programme to reduce short-lived climate pollutants (SLCP) (allAfrica, 2012).

2.4.3. City in a Sub-Saharan Country Weakly Developed

Among the developing countries, the least developed countries (LDC) are the ones that are the least advanced according to a set of economic and social indicators. There are currently 34 of these countries located in Africa (UN-OHRLLS, 2012). With problems to cover the population basic needs, these countries do not consider the development of environmental protections, which could reduce their emissions of carbon, nitrogen and mercury, a priority. However, they try to achieve the Millennium Development Goals set by the United Nations (UN). One of these goals is to ensure environmental sustainability. Others goals can also partly be achieved thanks to environmental measures. For example, to reduce child mortality or diseases, a minimum level of waste management is required.

There is per se no Sub-Saharan climate. Depending on the distance to the Sahara and to the equator, the climate varies between a desert and a tropical one. So the climate depends on the latitude and also on the local water resources available. Nevertheless, in most cities, there is a wetter and a dryer season. Temperatures are usually quite high, i.e. more than 20°C, throughout the year.

The capital of Mali, Bamako, has been chosen for the case study. Bamako is located in the south west of Mali and lies along the Niger River. This is the first highly populated city along the third largest African river. Its population was estimated in 2010 to 1,809 million (Ministère de l'environnement et de l'assainissement, 2010: 9). With an area of 267 km² (District de Bamako, 2010), the density of population was 6776 inhabitants per km² in 2010. The climate in Bamako is Sahelian. It has a dry and a wet season with strong distinctions and receives between 200 and 510 mm of precipitation per year (Ministère de l'environnement et de l'assainissement, 2010: 108). Regarding environmental protection, Bamako has problems to keep its standards. Indeed, the population has multiplied by a factor of 1,8 between 1998 and 2009. The website of City Mayors estimated in 2006 that Bamako was the sixth fastest growing in the world and the first one in Africa with an annual growth of 4,45% (2006). Thus, Bamako is relevant choice for the study because it represents an extreme case regarding environmental pressures in developing countries.

Due to a strained political context, very few up-to-date pieces of information were found. In fact, in January 2012, a movement of rebellion started in the northern part of the country and in March, an attempt of military coup occurred in Bamako. This situation probably blocked the normal activity of the city. A proof of this decline in activity can be seen with the tourism industry (Office Malien du Tourisme et de l'Hôtellerie, 2013).

2.4.4. Common Aspects

The three main cities chosen have, despite of the difference of development level, some characteristics in common. They are all capitals of their country. This is where the government seats and it can be assumed that additional efforts are made to show a good image of the city, partly through the use of environmental measures.

The three cities have also the same range of population. They are not megalopolises but their size ensures that they have most of the characteristics described in the section 2.2.1.

Another common factor is the strong attraction for the city. In the case of Vienna and Santo Domingo, there are highly frequented by tourists. As explained in the former section, Bamako, with its fast growing rate, is attractive for the Malian population. Regarding tourism that grew steadily in the last decade, most people arrive in the capital to visit the country. Thus, for the three cities, in addition to the local population, there is a significant additional amount of waste and emissions generated by visitors.

Both Vienna and Bamako are situated along a major river which constitutes the main sink for water emissions. Santo Domingo has the Ozama River but its influence is not as strong. Therefore, the Caribbean Sea is the main sink for releases into the hydrosphere.

2.5. Literature Review

Research about concentrations of substances in soil, water, air and landfill has been performed for the past decades. These studies have usually been conducted after people started noticing increasing pollution. As a consequence, they were only performed when worrying thresholds were reached. Today, there is a better

understanding of the effects of carbon, nitrogen and mercury compounds on human beings and ecosystems. And measurements are now performed on a more regular basis. Still, as research costs money, in developing countries this systemic approach is not applied yet. This also means that there are strong disparities in the amount of literature available among cities and substances. The next paragraph presents the literature found for the cities and some of the substances and sinks analysed.

2.5.1. Vienna

The range of literature that can be found about the city of Vienna is broad. First of all, the Austrian government and the Federal State of Vienna provide regular reports about the environment. Some reports cover the whole environmental field, while others focus on one topic. For example in the water area, documentation exists about drinkable water, metals in groundwater, water quality of the Danube, and common river pollutants.

Furthermore, as part of the European Union, Austria, like all other Member States, must respect pollution limits. In order to fulfil its obligation, measurements to monitor the concentration of substances in the atmosphere and water bodies are often performed. Measuring stations for air pollution operate continuously all over the country and annual reports are available. These data are then gathered at the European level and are made fully accessible online through platforms such as the emission database of EMEP [4]. This database has been developed for the Convention on Long-range Transboundary Air Pollution and provides emissions information all over Europe. A grid divides Europe in squares of 50 km per 50 km and allows having a rather accurate estimation of emissions for a city such as Vienna.

In addition to those documents and data, additional information can be found in company reports. Enterprises dealing with environmental activities provide regular summary of activities. The Waste Water Treatment Plant (WWTP), the energy and waste companies in Vienna are also working on research programmes with the

[4] The website address to access the EMEP database is: http://www.ceip.at/webdab-emission-database

Natural Resources and Life Sciences (BOKU) and with the Technical Universities (TU).

In the end, information on emissions of carbon, nitrogen and mercury for Vienna or more generally for Austria is available. Therefore, there was no need to collect missing information from neighbouring cities in Europe. Then, the difficulty is more to find the relevant and exploitable piece information in reports that are generally long and numerous.

2.5.2. Bamako and Santo Domingo

Emissions data for Santo Domingo and Bamako are quite rare. Unlike Vienna, hardly any report is officially published and most data delivered by governmental institutions are on a national scale. Nonetheless, there are pieces of information about the organisation of the city that help to understand how waste or water is handled.

Another source of information is the reports and surveys from international organisations. For example, the United Nations Human Settlements Programme (UN-HABITAT), which takes care of human settlements programme, publishes regular reports about cities of the world, their waste management, their water sanitation. As measurements or analyses are performed sporadically, data can become quickly obsolete especially in the case of Bamako and an actualisation is required.

In addition, research papers also cover the lack of official information. Usually very specific, they provide precise data. However, it is rare that they fit exactly to the need of the thesis, so they have, in such cases, to be adapted.

2.5.3. Mercury

The toxic effect of mercury has been known for a long time. However, unlike lead, it is still used during the production of some substances like polyvinyl chloride (PVC) used in plastics, and is still part of products such as dental amalgams or electric switches. The main reason is the cost. It is often cheaper than its substitutes. With the increasing quantity of mercury in natural sinks, it became relevant to decide on a reduction of mercury use. Denmark was one of the first countries to place a ban on mercury. The United Nations Environmental Programme (UNEP) led the

international negotiations during several years and finally, in January 2013, countries reached an agreement to decrease their use of mercury.

Before this successful outcome, several studies had been performed in order to better understand the mercury cycle. Today, measurements have been taken and models have been developed in order to assess on a global scale the mercury concentrations and its sources. For example, some countries such as Dominican Republic or Burkina Faso made an inventory of all their mercury sources and the related sinks. Sources are today well known and only the use of mercury in Artisanal and Small Scale Gold Mining (ASGM) activities is hard to evaluate. Even if the knowledge on the mercury cycle increased greatly, there are still major uncertainties subsisting. For example, the first major report describing mercury in aquatic sources was published in 2011 (Keenan et al., 2011). Additionally, chemical reactions involving mercury, in both air and water environments, are still not fully understood and further research needs to be done.

Furthermore, mercury is often separated in the literature from the other heavy metals. This is probably because of its liquid state at normal surface temperature. Papers that attempt to determine HM concentrations usually do not include mercury. That results in less available local data. In many scientific publications, measurements are performed when some pollution has been noticed and when its origin could be assessed.

In the end, mercury knowledge has recently grown and allows for correct evaluation of its related risks. Nevertheless, the picture given by the literature is for the moment slightly too global and is still incomplete.

2.5.4. Greenhouse Gases

A part of the gases containing carbon and nitrogen are in the list of important GHG. These gases that have an effect on the natural greenhouse effect in the atmosphere have started to constitute an issue when the risk of a climate change has been assessed. The first important meeting dealing with this topic took place in Rio in 1992. A few years later in 1997, the Kyoto Protocol was signed and for the first time the GHG emissions would be monitored to legally ensure the application of the treaty. Thus, it has represented a good incentive to increase the state of the art on GHG emissions. More than a decade later, these emissions are regularly assessed and calculated all over the world. Thus, the knowledge regarding the amount of gas

released for each source is wide. The difficulty in assessing emissions of carbon and nitrogen is to know precisely all the different sources in a city. Actually, cities are very complex systems where GHG are emitted from a large range of sources in number and in types.

However, the non-GHG containing carbon and nitrogen also have to be considered. For example, information about traffic pollution gases is also needed. Indeed, exhaust fumes contain NO, NO_2, ammonia (NH_3) and hydrocarbons (HC) that are not GHG. In this case, literature is also consequent but the problem to assess the number and the strength of the sources still remains. In developed countries, this information is generally available, whereas, in developing countries, it can be harder to find up-to-date data.

In the end, the state of the art for GHG and other air pollutants is broad but the difficulty is to accurately determine the numerous sources.

2.5.5. Waste

Waste management can be very advanced like in Vienna or basic like in Bamako. As written in the section 2.5.1, waste companies in Vienna provide quite complete information. The technologies, which are developed there, are then sold to other countries. It explains why also reports or brochures can be found in English. For instance, the data available can be about the amount of waste received, its type, its composition and even the transfer coefficient of substances in each sink. The hard part is to understand the flow of waste because it can be burnt, recycled, reused, landfilled or sent outside of the city.

As for Bamako and Santo Domingo, the situation is not as clear. Usually, information about waste composition is available. In terms of waste treatment, research papers or international reports describe the waste management with words but often lack usable data. Therefore, it is necessary to use information from other cities and to use rough estimation of emissions.

2.5.6. The Hydrosphere

Reports or studies that cover the water environments for the three cities can be found. Nevertheless, information regarding emissions is sporadic. In fact, in that field, the level of analysis is done at higher level than the city. The management for rivers

is made for the entire basin. For groundwater, it is the whole area and data for the Caribbean Sea cover much more than the region of Santo Domingo. Therefore, information found is also influenced by other parameters that have to be taken into account.

Concerning the research of carbon releases into the hydrosphere, only organic carbon is considered. In fact, inorganic carbon is harder to deal with, especially when it comes to restricted area like a river. The most important chemical reactions between carbon dioxide, carbonate and bicarbonate take place due to CO_2 emissions, but its exact influence is rather hard to determine.

Like mercury, measurements of concentrations in developing countries are often performed when pollution has been detected. Analyses are performed on the disturbance of the ecosystem. A typical example is the level of fish intoxication. Indeed, fish are consumed by human beings and could constitute a source of diseases.

Another relevant piece of information that is needed to evaluate the necessary dilution factor is the amount of incoming water that depends on the amount of precipitation. This value is generally known for agricultural purpose or to assess the flooding risk. Santo Domingo, which is regularly affected by tropical storms, has a good knowledge on this topic. Regarding Vienna, the Danube river basin, as one of the most important in Europe, and which involves 12 countries, has also been deeply studied. The same type of research has been done on the Niger River basin but it is not yet as complete.

In the end, information about the hydrosphere is available, but precise figures are sometimes missing because of the lack of water management on a larger scale.

3. Methodology & Used Data

3.1. Defining and Understanding the System

The first obligatory step to assess emissions of substances in a city is to define the area covered by the system and to acquire a minimum understanding of it.

For this thesis, the limits of the system are the official borders of the city. This choice is debatable because of the evident amount of goods that is imported into the system. Nonetheless, considering for example the agricultural emissions of the fields used to grow the food consumed in a city would make the study even more complex than it already is.

Furthermore, a minimum knowledge of the city's activities is necessary to correctly estimate how emissions and sinks are connected. For instance, the sinks concerned by waste depend highly on the applied treatment. A WWTP reduces releases in the water sinks but increases them in the atmosphere. The sludge produced becomes a waste that can be used to generate energy but it may also be incinerated, spread on agricultural fields or directly landfilled. For instance, in Austria, sludge cannot be used anymore for these last two actions and are often incinerated. Thus, it is essential to know about the existence of a WWTP and the characteristics of the cleaning process. In the same way, a waste incinerator produces relatively much more flue gases than waste water. So the atmosphere is in that case more used than the hydrosphere. If instead of being incinerated, the same waste would be landfilled, emissions would be higher in the lithosphere and the hydrosphere, especially if leachates[5] are not properly managed. Therefore, an overview of the substances sources and their flows in the system is necessary before considering the emissions.

To summarise, the first task in the estimation process is to have a sufficient understanding of the system. The goal of the thesis is to give a rough estimation of emissions. Therefore, each source is analysed to determine if it is relevant enough for this study.

[5] Leachate is the liquid product emitted by landfills after water infiltration, usually coming from the rain.

3.2. Determining Emissions

After having understood the system, the research for emissions can start. There are several ways to determine the amount of carbon, nitrogen and mercury emitted into the sinks; and depending on the method chosen, results may be slightly different. Nevertheless, due to the difficulty to find precise data, it is necessary to employ this range of alternatives to obtain estimations. They are basically two types of direct information that can be utilised. In case, nothing can be found, there are four secondary ways to get data.

First, the easiest way to assess the release of a substance is to compare the incoming and outgoing concentrations of a sink, for example, a river flowing in the city. This method is efficient but is not the most accurate. In the case of a river, the flow is fluctuating during the year so the accuracy of the mean average depends on the number and the repetition of the measurements taken. Determining the incoming or original concentration can also be difficult. Moreover this method does not take into account the removing processes that affect negatively the concentration.

A second approach is to make an inventory of all important sources of substances emissions and for each of them obtain the relevant figures. The idea is to analyse the very last link of the chain before the element is released to the sinks. For example, the WWTP is, in the case of Vienna, the last stage before waste water is being released into the Danube. However, this is just the normal path. Some water coming from the Combined Sewer Overflows (CSO) tank and from water run-offs also reaches the river without any treatment. Then, it is necessary to assess whether this secondary source of emissions is enough influent to be considered. Thus, using this evaluation method implies that some sources can be forgotten or that their degree of influence wrongly evaluated.

In case data cannot be found to apply the two former methods, there are other ways to estimate concentration of substances.

To start with, if the emissions are not known at the end of the Substance Flow Analysis (SFA), it is possible to have a look at the previous link in the flow. For instance, if the amount of water that ends up in the hydrosphere is not known, the water consumed by the agricultural, industrial and private sectors can be used. In that case, the transfer coefficients for each sink must be known and the amount of

precipitation has also to be taken into account. Therefore, this indirect assessment is possible but usually requires more pieces of information that are then combined.

Furthermore, a bigger scale of analysis can help to determine emissions of substances. Working on a regional or national level is also a way to access to data. The easiest technique to use this type of data is to multiply it by the ratio between the population living in the city analysed and the country population. The estimation can also be slightly more advanced. When the information is divided into sectors, figures for agricultural and industrial activities can be adapted to the specific city environment generally less developed in these fields.

As mentioned already, another approach to find data is to use the one coming from neighbouring countries sharing similar characteristics. The margin of error is higher in that case but within the framework of this thesis, it is acceptable.

The last resort is to use side information found in the literature that describes a situation or type of management with words and no figures. For example, in the case of African cities, some research papers explain what is done with the waste. Then the hard task is to transform these pieces of information into realistic figures.

To summarise, there are several methods that can be used to determine the amount of substances emitted into the sinks. Some are more accurate but they also all have drawbacks. As the goal of the thesis is to have a global picture, the most important is to find information that could be exploited and to clearly explain the degree of estimation that is used.

3.3. Guideline Followed for the Research

In order to conduct the work, a guideline has been followed. It has been decided to start with the most complex system of the three cities. The European developed city, Vienna, is considered as more complex because the treatments performed to waste or waste water are multiple and make use of a wide range of technology. The advantage of starting with an elaborated system is that once understood, simpler systems can be easily and quickly analysed. Thus, the research of numerical values started with Vienna. Another positive aspect for this choice is that the evaluation of the relevant sources becomes easier. As explained in the second chapter, data for emissions and concentrations were found in reports, internet database and research papers.

Finding values for emissions or output concentration is not enough. In order to perform comparisons, input or geogenic concentration of the place must be known. This information is necessary to either compare it with the output concentration or to determine the necessary dilution factor. For instance, mercury is found naturally in soils. Having the concentration of mercury in a city soil is not enough to know the quantity emitted by the city. The geogenic concentration has to be removed from it first.

Once general emissions for a substance have been found, the necessary dilution factor is calculated. In fact, the natural dilution of a substance in a sink depends very much on the type of sink. For this thesis, the dilution is considered in an easy way. A certain amount of substance is emitted. In order to reach a target concentration, for instance that is not harmful for mankind, a volume to dilute the emissions is needed. Once the theoretical volume needed is found, it is compared with the volume of the sink available. For example, 10 kg of mercury is emitted per year in a river and the concentration of mercury should not be above 1 ng/m^3. Then, the volume of mercury needed to reach this concentration can be simply calculated and is, in that case, 10^{13} m^3. If the river has an annual flow of 10^{14} m^3, one tenth of the river flow is required to dilute the mercury emitted. But if the river has only a 10^{12} m^3 flow, then the volume required to dilute the element to 1 ng/m^3 is 10 times the existing volume. The formula used for the calculation and more explanations about the necessary dilution factor can be found in chapter 6.

Finally, once the necessary dilution factors determined, they can be compared between the three cities and the result are analysed.

3.4. Utilisation of Data

As explained in the literature review chapter, most of the figures could be found in reports and research papers. However, the dates of publication of these data vary and some of them are more than 15 years old. Exploiting these figures as they are would not make much sense because the cities' evolution was quite noticeable. So, it is in some cases needed to actualise figures to obtain more realistic and comparable results. As the amount of data to deal with is rather high, the actualisation is performed in a simple way by considering the evolution of the population and the development of the city.

Additionally, an actualisation of figures means that margins of errors should also be updated. As most of the sources of information are reports, these margins are very often missing. As the goal of this thesis is to have a rough estimation of the emissions, margins of errors are not indispensable. However, when they are available, they are always taken into consideration by the author during the calculations performed.

In the end, with the wide range of information sources, a thorough overhaul is needed to get exploitable results. Due to time constraints and the large amount of data to be found, only a general estimation is performed with available data from the literature after having been adapted and actualised to the system analysed.

4. Results: Emissions of Substances

The results of the research are presented in two distinct chapters. This chapter deals with emissions and original concentrations of the three substances. Results found are organised per city and per sink. When both emissions and concentrations could be found, emissions are presented first.

4.1. Vienna

Vienna is the most complex system but also the one with the highest number of information available. In some cases, emissions for one substance could be assessed in different ways. Despite of this, some information have not been found probably due to a lack of time and to the language barrier.

Depending on the sink analysed, the amount of sources varies greatly. It can however be noticed that the waste treatment is somehow always involved in the flow.

4.1.1. Atmosphere

Emissions in the atmosphere happen in Vienna via different processes. It very often involves combustion from vehicles, households, agriculture, industries such as incineration plants or chemical treatments like the biological cleaning that takes place at the WWTP. As illustrated in the diagram below, urban emissions can be often seen in addition to a regional background concentration. On top of that, urban

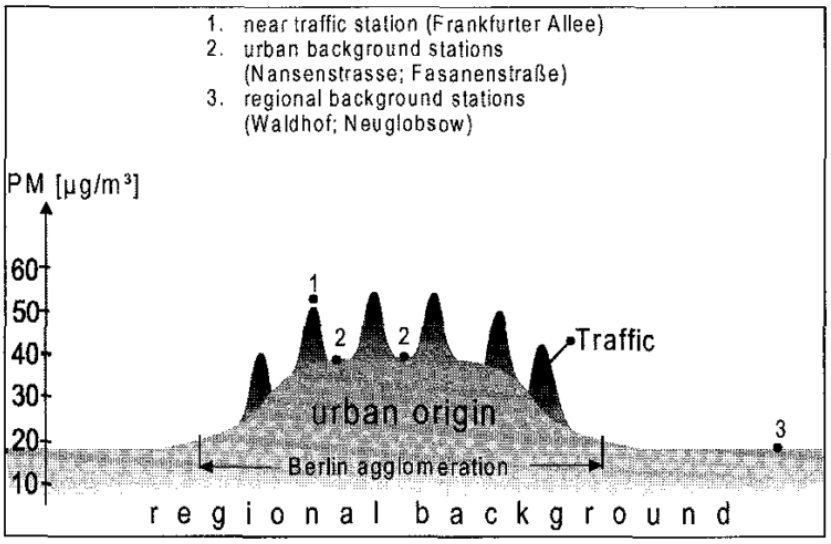

Figure 4.1 Particulate Matter in Berlin (Lenschow et al., 2001)

traffic, which is highly variable in time and space, is added.

4.1.1.1. Carbon

In the literature, carbon compounds released in the atmosphere are usually divided in a few distinct categories with different level of relevance.

The first category covers the gases contributing to the greenhouse effect. The main ones are CO_2, methane (CH_4), Non-Methane Volatile Organic Compounds (NMVOCs) and Fluorinated gases or F-Gases[6]. The emissions for the city of Vienna were estimated in 2010 to be: 9244 Gg[7] of CO_2, 4706 tonnes of CH_4, 17 Gg of NMVOC and 293 Gg CO_2 equivalent (CO_2eq) of F-Gases. The three biggest sectors for carbon dioxide were energy with 38,4%, traffic with 36,5% and domestic use with 18,4% (Anderl et al., 2012).

In addition to the GHG, gases containing carbon are numerous. The main others, which are often analysed, are CO, HC and the Persistent Organic Pollutants (POPs).

For some of these gases, the EMEP database is a useful source of information. As explained in the section 2.5.1, information about emissions is given for individual squares of 2500 km². For Vienna, as shown on figure 4.2 below, there is one square covering approximately 90% of the city area. The rest of the surface is part of the state of Lower Austria. In order to approximate correctly only the emissions for Vienna, a simple ratio calculation is made. Above, the amount of NMVOC estimated was 16,97 Gg. The same year, NMVOCs emissions for the section n° 76 51 in the EMEP system was 21,8 Gg. According to these two figures, emissions of Vienna represent then 77,7% of the total. As approximately 10% of Vienna's area is missing in the section n° 76 51 and as the surrounding areas of Vienna have a relatively low amount of emissions compared to the capital, this ratio is considered plausible and is used in the following pages each time an information is taken out of the EMEP database.

Table 4.1 presents the emissions for Vienna and the average for the surrounding area in 2010 for CO, NMVOCs and three categories of POPs.

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[6] There are 3 types of F-Gases: HFCs (HydroFluoroCarbons), PFCs(PerFluoroCarbons) and SF6 (Sulfur hexaFluoride) and only HFCs and PFCs contain carbon.
[7] Gigagramme = 10^9 g or 1000 tonnes

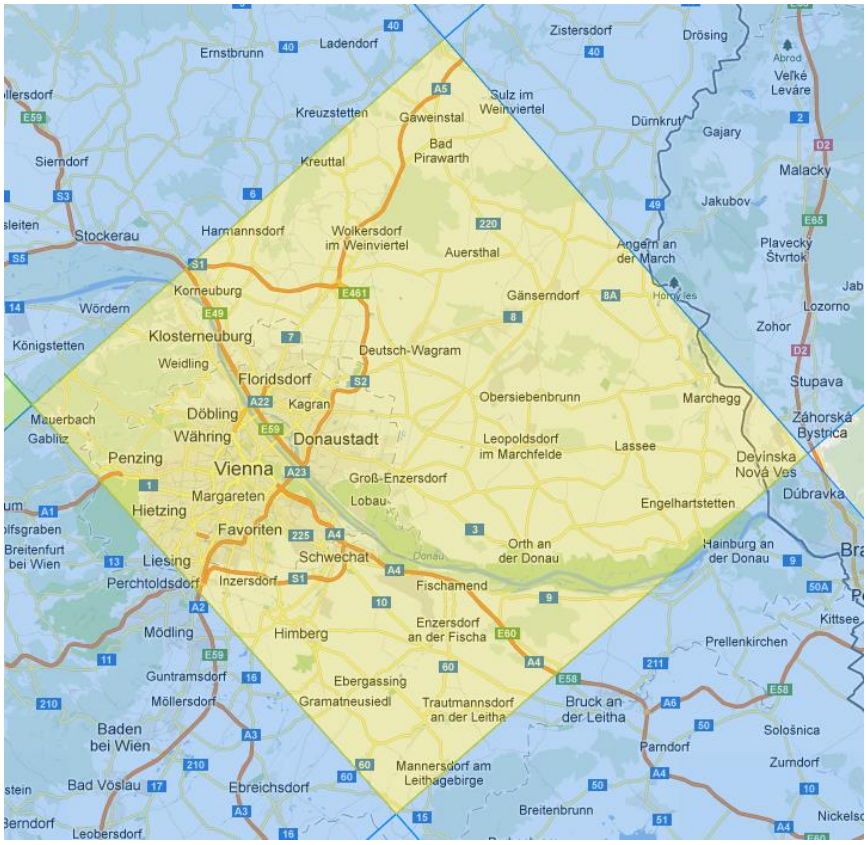

Figure 4.2 EMEP Grid with section n°76 51 covering most of Vienna

Table 4.1 Emissions of CO, NMVOCs and POPs in the Viennese region in 2010

Compounds	CO in Gg	NMVOC in Gg	PCDD/PCDF (dioxins/ furans) in g I-Teq	PAHs in tonnes	HCB C6Cl6 in kg
Around Vienna	11,2	2,6	0,74	0,17	0,79
Section 76 51	67	21,8	3,9	0,71	3,6
Total Vienna	**52**	**17**	3,1	0,55	2,8

Others studies such as the ones from Augustyn et al. (2012) or from Spangl and Nagl (2011: 73) are also focusing on some specific compounds like benzene or benzo[a]pyrene that are in the lists of POPs or NMVOCs. However, this thesis does not cover them because of their relative low concentration. In fact, as we can see in the table above, the sum of PAHs emitted represents 0,001% of the amount of CO released.

The atmosphere is a particular sink because even on a short-term scale, e.g. a year, a part of the carbon compounds that are released in the air are stored by the vegetation. In 2011, the emission storage by forested areas in Austria were

estimated to 3542 Gg of CO_2, and 0,01 Gg of CH_4 (Anderl et al., 2013). Vienna with 414,87 km² represents 0,49% of the country. However, it has a higher degree of sealing. It has 43,9% of its surface sealed compared to 31,9% for Austria (Umweltbundesamt GmbH, 2011). By considering these two parameters, it can be said that Viennese forests stored approximately 14,4 Gg of CO_2, and 0,04 tonnes of CH_4 in 2011.

In the end, the emissions in Vienna for the element carbon can be found in table 4.2 below.

Table 4.2 Carbon Emissions in the atmosphere in Vienna in 2010

In tonnes	CO2 (M:44,01)	CH4 (M:16,05)	CO (M:28,01)	NMVOCs	F-Gases	POPs
Emitted	9 244 000	4 706	52 075	16 973	293 000 in CO2 eq.	<10
Stored	14 440	0,04	n/a	n/a	n/a	n/a
Total	9 229 560	4 706	52 075	16 973	293 000	<10
Amount of C	2 308 831	3 521	22 329	10 900	Not Estimated	
Total Carbon Emitted		**2350 Gg of C**				

In order to calculate the amount of carbon for each compound, the molar mass has to be used. For instance with carbon dioxide, the chemical reaction is the following $C + O_2 <-> CO_2$. One mole of CO_2 has a weight of 12,01 + 2 x 16 = 48,01 g. So 9230 Gg of CO_2 is equivalent to 192 242 Mmol. The ratio is stoichiometric so the amount of moles of carbon is the same. The total mass of carbon emitted is therefore 192242,45 x 12,01 = 2309 Gg of C.

Regarding the carbon content of NMVOCs, a global mean has been calculated with a list of 62 compounds. The average carbon content used is 64,2%. The British government used a value of 71,4% in one of its report[8]. As for F-gases, the estimation given is rather difficult to extrapolate because it is given in CO_2eq and the factor of transformation used in the report varies between 140 and 23 900 (Anderl et al., 2012: 190). With such a big factor of transformation and the lack of information

[8] http://uk-air.defra.gov.uk/reports/cat07/0703280959_Review_of_Stored_Carbon_2005_NIR_Issue1_v1.3.1_cd4561jw.pdf

on the carbon content of the fluorinated gases, it seems reasonable to consider the emissions source as minor and not to estimate it. However, it does not mean that this emitted amount of F-gases does not have a harmful effect on ecosystems and human beings.

4.1.1.2. Nitrogen

Depending on the source, the nitrogen compounds emitted are different. For nitrogen dioxide (NO_2), 60% of the emissions derive from traffic (Municipal Department for Environmental Protection – MA 22, 2007: 62). NO_2 is generally emitted as NO during a combustion process, but quickly transforms into NO_2. Concentrations in Vienna are rather heterogeneous (Umweltbundesamt GmbH, 2010: 39): the last five years, the mean concentration in Vienna has remained more or less constant and in 2011, it was 31 µg/m^3 (Augustyn et al., 2012; Magistrat der Stadt Wien - Wiener Umweltschutzabteilung - MA22, 2011: 9). In terms of amount emitted, it has been evaluated at 21,1 Gg in 2010 (Anderl et al., 2012)

The two other main nitrogen gases emitted are NH_3 and the N_2O. In 2010, still according to Anderl et al. (2012), 544 tonnes of N_2O were released into the atmosphere in Vienna and 395 t of NH_3.

As for carbon compounds, N_2O is partly stored by Vienna green areas. In 2011, 0,16 Gg was stored in Austria. By applying the same calculation with the relative area and sealed surface of the Vienna, the N_2O stored is estimated to 0,64 t.

The deposition rate of nitrogen should also be considered. Indeed, once in the atmosphere, nitrogen particles can still be deposited by hydrometeors[9]. The EMEP database provides information for oxidised and reduced nitrogen that are deposited under both wet and dry conditions. The total reduced nitrogen deposition rate is 625 mgN/m² and the oxidised one is 506 mgN/m² per year. So the total deposition is 1131 mgN/m². With an area of 414,87 km², the amount of deposited nitrogen is 469 tonnes.

Now that emissions and removal of nitrogen compounds from the atmosphere are known, it is possible to calculate the total value. Results of calculation are shown in table 4.3.

[9] A product (as fog, rain, or hail) formed by the condensation of atmospheric water vapour (Merriam-Webster Dictionary and Thesaurus, 2012)

Table 4.3 Nitrogen Emission in the air in Vienna in 2010

In tonnes	NO_2 (M:46,01)	NH_3 (M:17,04)	N_2O (M:44,02)
Emitted	21 100	395	544
Stored	n/a	n/a	0,64
Total	21 100	395	543
Amount of N	6 425	325	173
Annual N Deposition	469		
Total Nitrogen Emitted	**6,45 Gg**		

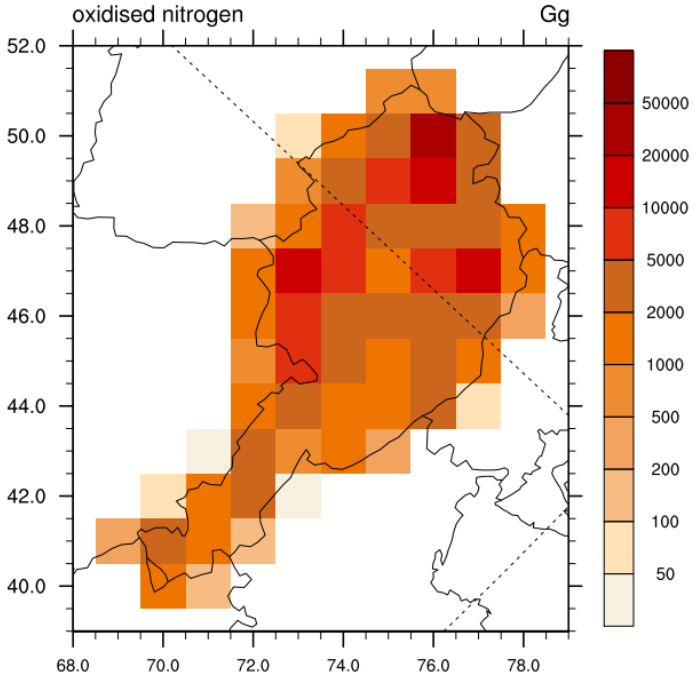

Figure 4.3 Emissions of oxidised N in Austria in 2010 (Gauss et al., 2012: 10)

In terms of concentrations, the EMEP database provides the concentration of NO_2, NH_3, NH_4^+, HNO_3 and NO_3^-. In total, the concentration of nitrogen in Vienna in 2010 was 16 µgN/m^3 and the average concentration around the city was 11,5 µgN/m^3. The figure above illustrates this difference of emissions and therefore, level of concentration between Vienna and the rest of the country. Vienna, located in the darker square of the map, has the highest emissions of oxidised nitrogen of the country.

4.1.1.3. Mercury

Without strong mercury emitters from the industrial sector, most of the sources from the city are coming from goods such as medical instruments, electrical switches, bulbs or dental amalgams. Therefore, most of these products ends up at the end of

their lifetime in the waste management process and are either specifically handled or incinerated. As shown in the diagram below, most of the incinerated mercury (Hg) ends up in the filter cake and the fly ashes[10] which are then treated and landfilled in an appropriate place.

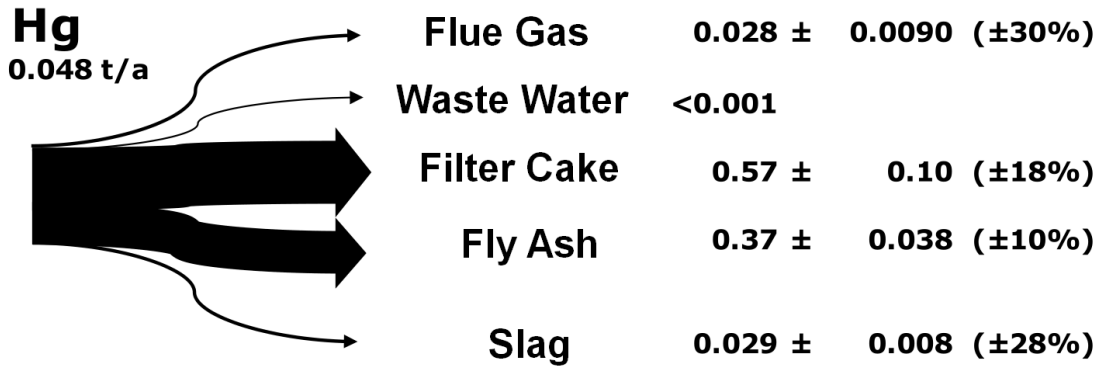

Figure 4.4 Mercury Transfer Coefficients at Spittelau Incinerator (Rolland et al., 2011: 24)

In figures, the emissions in Spittelau were less than 1 µg/m^3 in 2004 and in 2005 (Ableidinger et al., 2007: 132). According to the EMEP Database in 2010, the mercury emissions in the atmosphere were for Vienna 93 kg. The concentration was 1,73 ng/m^3 which was 0,3 ng/m^3 more than the surrounding areas.

In order to assess the real emission of the city, the mercury deposition has to be removed. Still according to the EMEP, the annual deposition rate was estimated at 17,2 g/km² in the region of Vienna. So the total deposition was 7,1 kg/yr. for Vienna and in the end, the real amount of emissions is 86 kg.

During the research phase, an interesting question came up. Should the crematorium be considered an important emitter of mercury? In fact, mercury contained in human bodies, especially the one from dental amalgams, is released during the incineration process. A mercury report in Denmark determined in 2001 that 1200 kg/yr. were used for dental amalgams (Skårup et al., 2003: 17). With a population of 5,359 million, it means an average of 0,22 g of mercury per capita. In 2011, 3608 people were incinerated in Vienna (Dezernat Statistik Wien, 2012a: 173) so approximately 808 g of mercury could be released. According to figure 4.4, only 2,8% of Hg goes into the air so 22,6 g could potentially go into the atmosphere.

[10] In an incinerator, the filter cake and fly ashes are both products from the cleaning process of the flue gas.

However, in Austria, emissions' restriction for crematoria, namely 0,5 mg/m^3, is ten times higher than the one for incinerators (Municipal Department for Environmental Protection – MA 22, 2007: 64). So, it can be assumed that the cleaning system in crematoria is not as efficient. Even if 100% of the mercury would be release in the atmosphere, this would represent 808 g or 1% of what is emitted for the whole city. For a city like Vienna, 1% of the emissions are not negligible but crematoria cannot be considered as an important emitter. Nevertheless, if all the funerals of Vienna would use the cremation process, the potential amount of mercury would be multiplied by four.

4.1.2. Hydrosphere

The waste water system in Vienna has been designed to ensure that all sorts of water that can be collected are treated in the only WWTP of the city. This would mean that releases of carbon, nitrogen and mercury in water bodies take place in one location for the whole city. However, in reality this is impossible. First, there are natural water run-offs like the ones generated by the rain that end up directly into the flows of surface water. Second, infiltration takes place and reaches the groundwater. According to Zessner, between 0,5 and 1% of sewers waste water seeps into groundwater (2013). Third, in spite of the CSO tank, overflows of the sewer system happen from time to time. Leitner estimated that amount to 37,5 cubic hectometres (hm^3)[11] per year (2013), which corresponds to 17% of the total of waste water arriving to the WWTP. Lastly, it should be mentioned that ten tonnes of solid waste is removed every day from the sewer system (Ensorgungsbetrieben Simmering, 2010). So a certain amount of the elements analysed are removed from that path.

The Danube is the main river flowing through Vienna. The other flows are all eventually mixing with the Danube. The Petersbach and Liesingbach in the south of Vienna flow into the river Schwechat that mixes with the Danube a few kilometres after the city borders. The river Mauerbach in the 14th district flows into the Wienfluss which flows into the DonauKanal. The DonauKanal which is a deviation from the river Danube flows back into Danube.

Regarding groundwater, there are two aquifers that are located partly under the city: Marchfeld in the north east and the "südliches Wiener Becken" in the south west.

[11] One cubic hectometre is equal to 1 million or 10^6 m^3

The total amount of aquifer stock is approximately 100 hm^3 (Stadt Wien – MA 31 Wiener Wasserwerke, 2003). More than 96% of the drinkable water in Vienna is coming from the Styrian region and is brought via two aqueducts. The total of amount of drinkable water brought every year represents 142 hm^3 (Wiener Wasser (Magistratsabteilung 31), 2012).

Vienna has some agricultural fields. One concern of the federal and national institutions is the pollution of pesticides and herbicides such as atrazin and desethylatrazin in water bodies. Most of these products contain carbon and nitrogen elements. In fact, the concentration of the sum of 53 products has been estimated by the author and is about 2,37 µg/l. This concentration is too low to be relevant in regards to the total amount of carbon and nitrogen emitted by the city. Therefore, as for POPs in air emission, they are not considered in this study.

4.1.2.1. Carbon

The WWTP is essential to remove the carbon contained in waste water before it reaches the Danube. In 2012, the removal rate of organic carbon was 93,4% (Ebswien hauptkläranlage Ges.m.b.H, 2013). With an effluent concentration of 12 mg/l and approximately 200 hm^3 released from the WWTP (Zessner, 2013), the carbon annually emitted in the Danube was approximately 2400 tonnes. This is the main emission point of carbon for the river, nevertheless, the amount of carbon spillover should also be added. By having a conservative approach, figures for sewage water can be deducted from the WWTP ones. With 2400 tonnes not removed from cleaned water, the amount of carbon arriving from the sewers is 36,4 Gg. However 17% were already lost in spillover and approximately 0,75% in groundwater. So the amount of carbon in the sewers was 44,1 Gg. Assuming that all the carbon, 17% of the carbon contained in the waste water that spillover is an upper limit of the system. However, as mentioned before, probable other losses are not taken into account for the calculation. Thus, it means that 7488 tonnes were directly sent into the Danube due to spillover. By adding the two flows, the total amount of carbon released in the Danube is about 10 000 tonnes.

Regarding groundwater, 330 tonnes of carbon from the sewer system are released in the lithosphere. Depending on the porosity and properties of soils, the share of carbon reaching the groundwater varies. It can be estimated that 20% finally reaches groundwater, so approximately 66 tonnes.

In terms of concentration, measures are regularly taken in the Danube, groundwater and sources for drinkable water to ensure a good quality. Firstly, by using the H2O database provided by the Austrian minister of life[12], the concentrations of carbon in the Danube before Vienna, i.e. in Nußdorf and after Vienna, i.e. Wildungsmauer located 25km after Vienna, can be used to assess the impact of the city on the river. The average concentrations between 2009 and 2012 are found in table 4.4. Secondly, as groundwater concentrations were varying quite significantly in the whole area, only the measurements taken within the city limits of the Marchfeld groundwater were considered. The results can also be seen in table 4.4. Thirdly, regarding drinkable water, the concentration of Total Organic Carbon (TOC) is available on the state website. The measurements performed in November 2012 are given per source (Wiener Wasser (Magistratsabteilung 31), 2012).

Table 4.4 Concentrations in Vienna Water bodies in 2012

DANUBE	Nußdorf	Wildungsmauer	Difference
TOC (C) mg/l	2,57	2,44	-0,13
GROUNDWATER	2009-2011	2012	(Mean 2012 - Dec 2011)
DOC (C) mg/l	1,0	0,975	-0,16
TOC (found with DOC/TOC ratio)~81%	1,23	1,2	-0,2
Source of **DRINKING WATER**	I.HQL	II.HQL	Wasserwerk Lobau	Wasserwerk Moosbrunn
m^3 per day	169 500	206 500	7 500	5 500
TOC in mg/l	0,79	1	0,9	0,55
Amount of Carbon in kg/yr.	**48 875**	**761 262**	**2463**	**1104**

According to table 4.4, the total amount of carbon brought annually in Vienna via drinkable water is 813 tonnes. By assuming that only the carbon contained into the waste water reaches groundwater, it can be said that the total amount of carbon released in the hydrosphere by the city of Vienna is 9888 + 66 – 813 = 9200 tonnes. However, this number has been reached by doing strong assumptions.

The decrease in concentration that can be noticed in both groundwater and the Danube shows that the influence of the city on the water bodies is not consequent. The graphs below show the evolution of the concentration in the last 4 years. The

[12] The website address of the database is: http://wisa.lebensministerium.at/h2o

first diagram shows the very close relationship between the incoming and outgoing concentration. This is a sign that the city emissions do not constitute a big change for the river.

Figure 4.6 shows that the carbon in the groundwater decreased slightly in 2012 but the annual average is close to the previous years. Therefore, the releases of carbon in groundwater seem to be relatively low. One of the explanations could be that Vienna's emissions do not significantly affect groundwater.

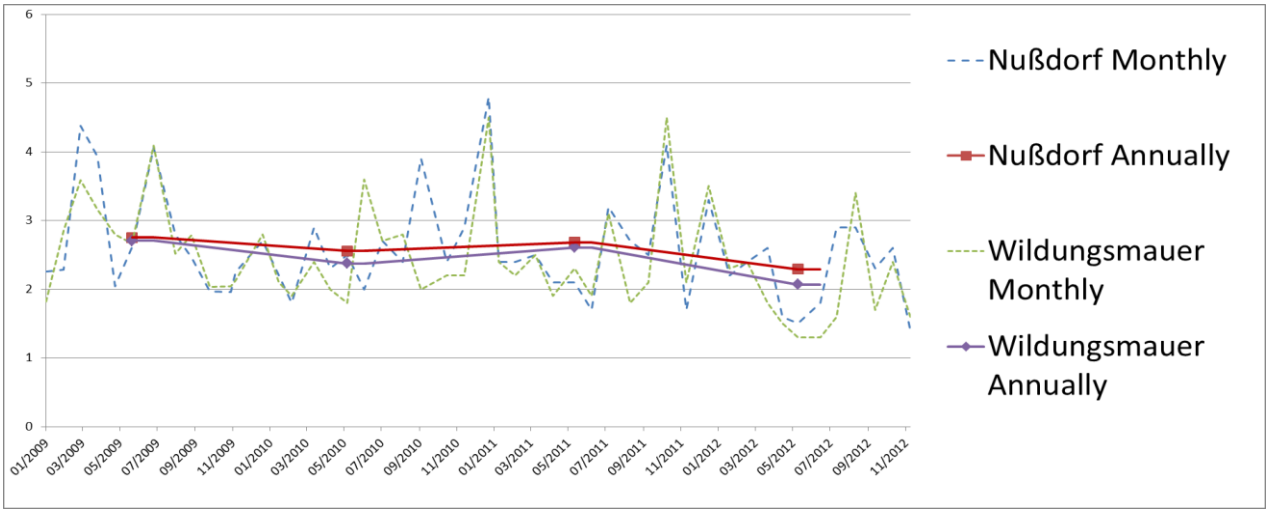

Figure 4.6 TOC in mg/l for the Danube before and after Vienna for 2009-2012

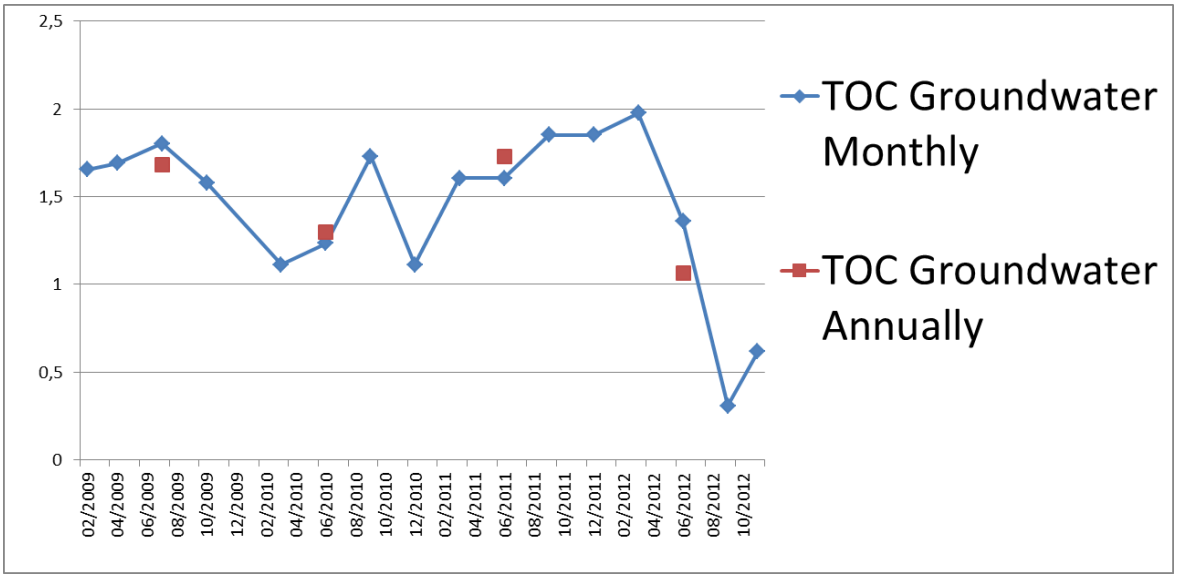

Figure 4.5 TOC in mg/l for Marchfeld groundwater

4.1.2.2. Nitrogen

The method applied to determine carbon emissions based on the WWTP values can also be used for nitrogen. In 2012, nitrogen removal was 84,4% (Ebswien hauptkläranlage Ges.m.b.H, 2013). The typical effluent concentration of N is 10 mgN/l, which means that 2000 tonnes of N are released by the plant in the Danube, that 10 821 tonnes arrive at the WWTP. It also means that there are 13 131 tonnes of N reaching the sewer system. The amount of nitrogen that spills from the sewers is therefore 2228 tonnes, 98,5 tonnes infiltrate the soil and 49,3 tonnes reach groundwater.

Another source of nitrogen for water bodies is agriculture. The total area used in Vienna for agriculture was 22 465 ha in 2010 (Dezernat Statistik Wien, 2012b: 210) and the excess of nitrogen due to agriculture is, according to Schilling et al., 26 kg N/ha per year (2012: 31). So, there are 586 tonnes of N in Vienna that end up either in the lithosphere, water bodies or that are evaporated. On average, 17% of N in arable soils of Western Countries evaporates (Cameron et al., 2013: 148). The rest is considered to be equally shared between losses in the hydrosphere and the accumulation in the ground. Therefore, 42% of agricultural nitrogen or 245 tonnes enter the hydrosphere. It estimated that an equal share reaches the Danube and the aquifer.

For drinkable water, concentrations of three nitrogen compounds are given and can be seen in table 4.5 below (Wiener Wasser (Magistratsabteilung 31), 2012).

In total, the nitrogen brought in Vienna via drinking water is 391 kg. In the end, nitrogen emitted in Vienna is 2000 + 2228 + 49 + 243 – 391 = 4130 tonnes.

Table 4.5 Nitrogen content for Vienna drinkable sources

Source	I.HQL	II.HQL	Wasserwerk Lobau	Wasserwerk Moosbrunn
NH_4^+ mg/l (M:17,05)	<0,01	<0,01	<0,01	<0,01
NO_2^- mg/l (M:46,01)	<0,008	<0,008	<0,008	<0,008
NO_3^- mg/l (M:62,01)	5,4	3,3	2,8	17
Total N in mg/l with maximum values	1,23	0,76	0,64	3,85
m^3 per day	169 500	206 500	7 500	5 500
Amount of N in kg per yr.	**208**	**157**	**4,8**	**21**

In terms of concentration, the H2O database gives information about for nitrogen compounds: ammonium, ammonia, nitrite, and nitrate. Therefore, the concentration of nitrogen found is the addition of these 4 substances. The table below gives the concentrations of nitrogen in the Danube before and after Vienna and the diagram shows the evolution of this concentration in the last 4 years. As for carbon, it can be said that the concentrations in the two sites are very close.

Table 4.6 Danube nitrogen concentrations before and after Vienna in mg/l

Average 2009-2012	Nußdorf	Wildungsmauer	Difference
Total N mg/l	2,071	2,09	0,015

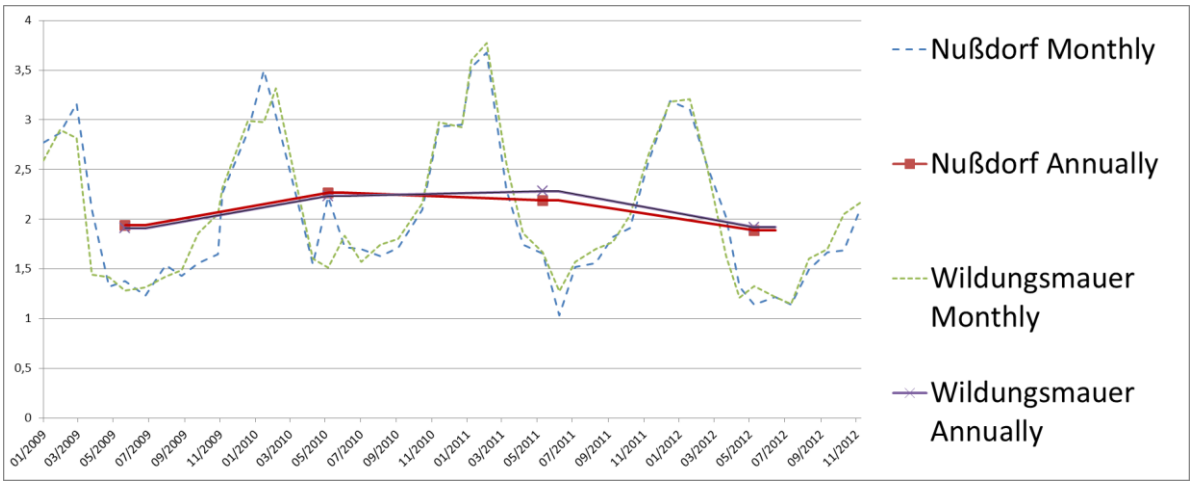

Figure 4.7 Figure 4.7 Danube Nitrogen Concentration in mg/l for 2009-2012

Additionally, Vienna officially has one lake, it is the Alte Donau. The nitrogen concentration was 19,6 µg/l in 2012. Regarding groundwater, the same method than for carbon has been used and the total nitrogen concentration was 46,5 mg/l. In comparison, during an interview, Kral specified that the natural concentration of nitrogen for groundwater is approximately 20 mg/l (Kral, 2013). So this means that the contribution of the city activities more than doubled the geogenic concentration since it exists.

The evolution of the groundwater and lake concentrations is shown on figure 4.7 and 4.8 below. It can be seen that the concentration remains relatively constant over the years. As for carbon, the concentration of the sink is affected in the same way every year and one reason could be that the influence of the emissions is relatively low.

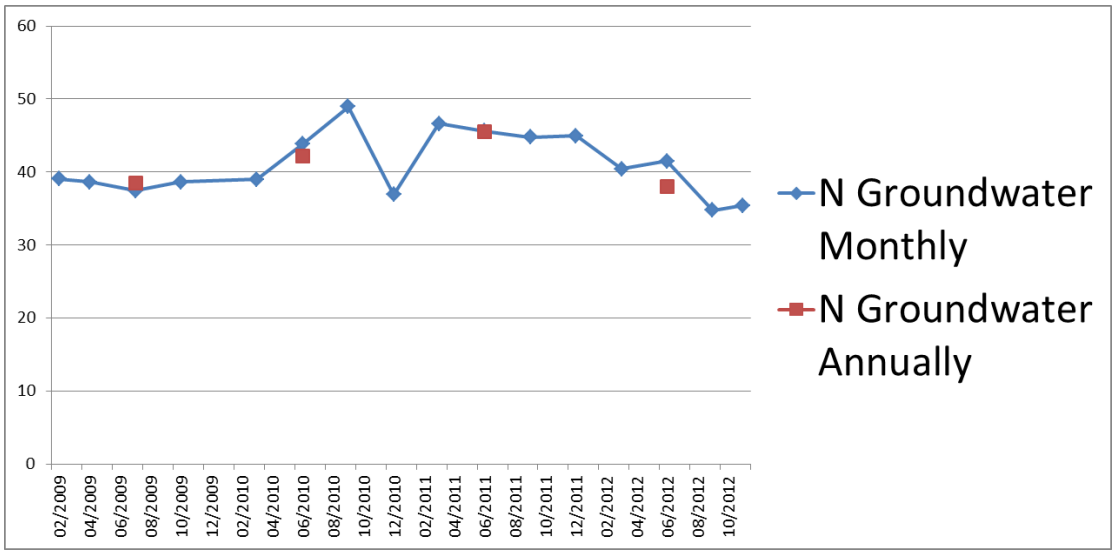

Figure 4.8 Groundwater Nitrogen Concentration in mg/l for 2009-2012

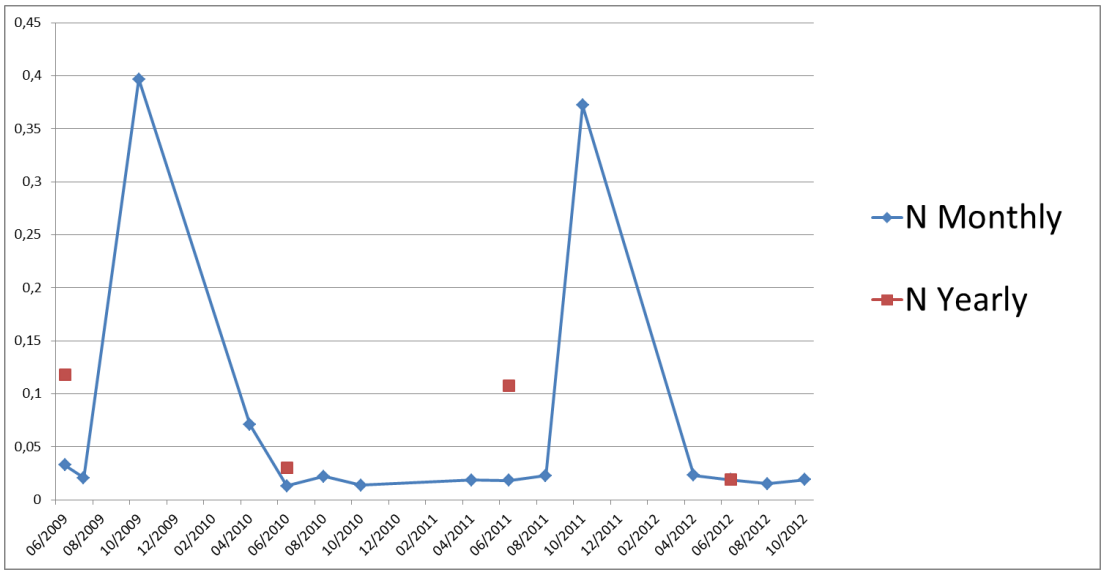

Figure 4.9 Alte Donau Nitrogen Concentration in mg/l for 2009-2012

4.1.2.3. Mercury

Mercury emissions in water are supposedly small because, according to Kroiss et al. (2008), around 17% of the mercury that reaches at the WWTP is transferred to the sludge. They evaluated that the yearly emissions of mercury in the effluent was approximately 10 kg.

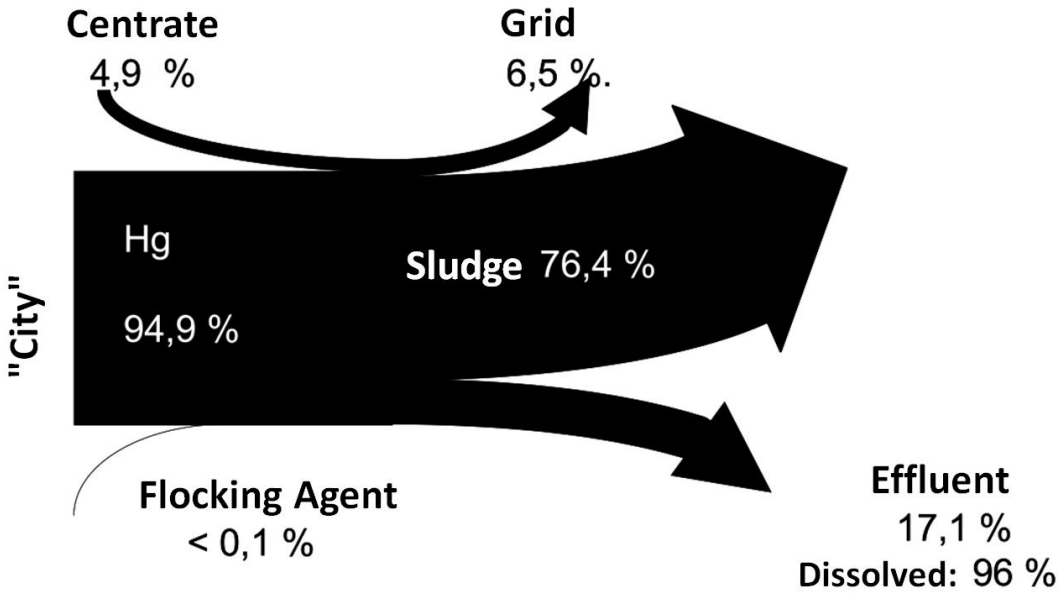

Figure 4.10 Transfer Coefficient of Hg at Vienna WWTP (Kroiss et al., 2008)

In order to know the amount of mercury released by spillovers, the same type of calculation as for carbon and nitrogen is performed. Thus, 59 kg of Hg go through the WWTP, 56 kg are in the sewer system. With 17% lost in spillovers and 0,75% lost in groundwater, there are 11 kg reaches directly the Danube, and 500 g infiltrate the soil. In total, the mercury that reaches the Danube is 22 kg.

In terms of concentration, the H2O database gives a concentration of 70 ng/l in the Danube for both sites: Nußdorf and Wildungsmauer.

According to a report from the Umweltbundesamt GmbH (2012), the concentration of mercury in Viennese groundwater is pretty similar to the rest of the country. The maximum value allowed of 0,2 µg/l is not reached (Wemhöner et al., 2012: 41–43).

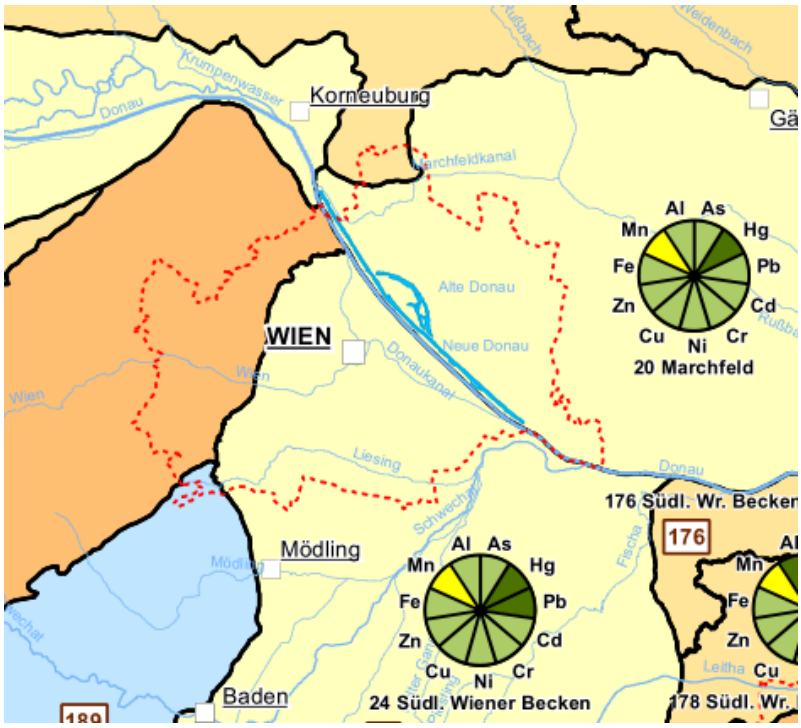

Figure 4.11 Mercury in Vienna Groundwater (Umweltbundesamt GmbH, Geologische Bundesanstalt, BMLFUW, 2012)

Regarding drinkable water, the limit is set to 1,0 µg/l and has never been reached in 2005, 2006, 2007 all over Austria (Bundesministerium für Gesundheit, 2009: 29–31).

In the end, the amount of mercury released in the Danube is 22 kg. As the concentration measured in the two sites is the same, these emissions do not seem to affect the concentration of mercury in the Danube. A small calculation can verify this assessment. With an average flow of 1723 m^3/s, the annual volume of water available is 48,27 km^3. So the concentration of the mercury emitted by the city of Vienna is 0,45 ng/l. With a concentration of 70 ng/l in the Danube, the mercury emitted represents only 0,6% of the total. Thus, the extra amount of mercury brought by Vienna emissions is too small to affect the average concentration of the Danube River.

4.1.3. Lithosphere

In comparison to air or water emissions, the amount of available information for soils is low. In fact, more elements are extracted from the ground than being put there. The main products from anthropogenic activities stored in the ground are waste and they are usually sent to landfills. In this thesis, landfill is dealt as a different sink. Therefore, releases of carbon, nitrogen and mercury in soils mainly happen after

deposition of non-sealed surface or via water infiltration. When water seeps, it is filtrated and some compounds are kept into the ground. In any case, it is complicated to get clear estimations of the proportion of substances that remains in the ground because the element can be reemitted in the air, washed away by water or even consumed or assimilated by living organisms. What happens exactly depends, among other things, on the type of soil, e.g. its porosity, the possible chemical reactants available, the weather conditions or the characteristics of the biota. In the end, information that has been found concerns the deposition rate of elements, the concentration of elements but there was no monitoring over several years like for the atmosphere or the hydrosphere.

As previously mentioned the degree of surface sealed in Vienna was 43,9% in 2011 (Umweltbundesamt GmbH, 2011). This means that direct deposition of chemical compounds on soils only takes place over unsealed areas, which represent about 233 km². When deposition happens on sealed places, compounds are either reemitted in the air or are washed away with water run-offs. In some case, these run-offs infiltrate the ground and part of the substances stays there. Annex I is a map of Vienna showing the different types of land use in the city. It can be seen that unsealed areas are located mostly on the outskirts of the city.

In addition, the brownfields, places formerly used for commercial or industrial activities and that have been closed, are not covered in this work. However, they have not been cleaned properly and what is considered as the normal ground still pollutes soil and aquifer. In Vienna, there are numerous such areas and they have started to be cleaned. In 2011, it was estimated that there were 23 contaminated sites with 13 under decontamination and 90 suspected contaminated sites (Granzin and Valtl, 2013: 36; Lebensministerium, 2011b: 407). The type of emission depends on the site and pollution is generally localised (Granzin and Valtl, 2013). Moreover it could be considered as a “secondary” source. In fact, the emissions do not depend on the present anthropogenic activities and comparing on a yearly period this type of emissions between cities of the world is not exactly the purpose of the thesis. In any case, a thorough analysis would require more time and thus it is not covered in this work.

4.1.3.1. Carbon

Concerning carbon, it has been decided as for the hydrosphere to only consider organic carbon. Carbon emissions in Vienna’s lithosphere mostly happen during

water seeping from waste water, water run-offs and leachates. In fact, the advanced waste management does not theoretically allow any releases from direct waste disposal. Leachates are considered to be negligible especially because their carbon content is really low. Infiltration of water run-offs via the ground is really hard to estimate and no information has been found. So only, the amount of carbon coming from waste water could be evaluated. In the section 4.1.2.1, it has been evaluated that 330 tonnes of carbon were released. The share of this amount that remains into the ground is around 80%, or in terms of weight 264 tonnes of carbon (Fellner, 2013).

In 2007, Spiegel et al. (2007: 49) performed a study in Fuchsenbigl located 20 km in the East of Vienna in Lower Austria. The organic carbon content was 1,2% in the first 30 cm. This means that in one 1 kg of soil, there were 12 g of organic carbon.

Another study about POPs has been led in forests and grasslands. The closest site to Vienna is 30 km in the South East. Most of the POPs are found in very low concentration of a few µg/kg and sometimes ng/kg. Therefore, their influence in terms of total carbon content is low. In addition to POPs, the research states that the concentration of hydrocarbons is lower than 100 mg/kg in dry substance. Again, it seems to be too low to be considered because it would represents only 0,01% of the total organic content (Freudenschuß et al., 2008).

4.1.3.2. Nitrogen

In order to determine the health of soil, some Austrian reports such as the one from Zechmeister et al. (2005), use the analyse of mosses. However, the knowledge required to draw conclusions about soil concentration is too broad for the scope of this study.

As explained in the section 4.1.1.2, the total deposition rate of nitrogen is in the region of Vienna 1131 mgN/m². The non-sealed surface represents 56% or 233 km². Therefore, the amount of nitrogen that can theoretically be stored in the soil is 263 tonnes per year. Fellner estimated that 20% of the N is not washed away by water (2013). So there are 53 tonnes of N remaining in the ground after deposition.

Nitrogen released due to excess use of fertilisers in agriculture is another nitrogen quantity that can be estimated. The calculation has already been presented in the section 4.1.2.2 and the amount of nitrogen that stays in the lithosphere is estimated

to be 244 tonnes. In addition, the amount of nitrogen lost in sewage system has also been estimated earlier and represents 49 tonnes.

Two other sources are missing from this figure: landfill leachates and pollution from brownfields. Leachates from the landfill of Vienna are collected and then treated at the WWTP so it is assumed that this value is negligible compared to the other sources of emissions. Concerning brownfields, as explained already they are not considered in this study.

To summarise, there are approximately 346 tonnes of nitrogen deposited or released in Viennese soils per year.

The same study in Fuchsenbigl gives for nitrogen a content of 0,16% in the first 30cm. So for 1 kg of soil, there is 1,6 g of N (Spiegel et al., 2007).

4.1.3.3. Mercury

For mercury, values for deposition in urban areas were found in the EMEP database and correspond for Vienna to 18,6 g/km² per year. With a non-sealed surface of 233 km², the deposition of mercury on the ground surface is 4,3 kg. In addition, 0,5 kg of Hg infiltrates the soils from waste water in sewers (see section 4.1.2.3). According to Fellner, most of the mercury compounds remains in soils, thus, they are approximately 4,6 kg of mercury that can stay into the Viennese soil (2013).

According to Kral, mercury geogenic concentration in soil is 0,3 mg/kg (2013).

4.1.4. Landfill

With an advanced waste management system, Vienna constitutes a good example of what has to be done to significantly reduce the quantity of landfilled waste. There is one landfill in Vienna and since 2009, it is not allowed to receive any untreated waste[13]. Contact with the surrounding ground is prevented by two successive walls and leachates are collected and sent to the WWTP to be cleaned. The CH_4 naturally produced by the landfill is collected and used to produce electricity. About 200 Gg of waste are landfilled annually and approximately 100 Gg tonnes of former landfilled waste is dug annually to be treated with modern techniques before being landfilled again. This action reduces the volume of waste already stored and removes some

[13] See Annex III to know more about the evolution of MSW management in Austria.

previous pollution (Magistratsabteilung 48, 2013). Another interest of excavating waste from the past is to exploit valuable elements that had been landfilled. With the increase of metal prices, copper for example, it becomes rentable to perform urban mining activities.

There are two interesting reason for treating waste before landfilling. It reduces the volume of waste and valuable substances are extracted or used instead of being buried. Therefore, organic compounds can be burnt, nitrogen elements are used as nutrients and recycled mercury avoids importation of mined mercury. These actions depend greatly on the price of the treatment process. Vienna, which is a relatively rich and clean city, can be considered as advanced in these treatments and therefore, it can be expected that the amount of carbon, nitrogen and mercury landfilled is low.

Waste treatment in Vienna is very complex and sophisticated. For example, households alone are generating 900 Gg of waste and in theory, none of it is directly disposed. Within the city, a wide-range of waste treatment plants can be found: thermal treatment plant and physico-chemical treatments plants, shredder plants for scrap metals, treatment plants for construction and demolition waste, composting facilities, biogas plants, plant that sorts recyclable and recoverable product. It is still missing a mechanical-biological treatment plant (MBT) and plants to recycle waste. Regarding the incineration, only municipal solid waste (MSW), bulky waste and sewage sludge are burnt. This means that not every type of waste can be treated in Vienna. When it is the case, waste is considered in this thesis as exported. For instance, 1900 tonnes of household's hazardous waste and 11 230 tonnes of waste electrical and electronic equipment (WEEE) are treated in Vienna before either being further processed, landfilled once sent outside of the city (Lebensministerium, 2011).

Similarly, the landfill in Vienna only takes the waste of incineration plants, the street cleaning and the residual treated waste (Magistrat der Stadt Wien - MA 48 - Abfallwirtschaft Straßenreinigung und Fuhrpark, 2012: 13). Therefore, wastes such as construction material or hazardous substances are sent outside the city to be disposed in adapted landfills.

The landfilled waste is naturally emitting compounds in the atmosphere, the hydrosphere and the lithosphere. Theoretically, there should not be any uncontrolled losses. This means that the controlled emissions of CH_4, CO_2 or N_2O in the

atmosphere and of leachate in the lithosphere should be the only emissions happening. In reality, it is impossible to ensure a 100% degree of impermeability. So emissions in the other sinks, even in reduced quantity, still exist. As a consequence, to estimate the quantity of elements stored in the landfill, both the controlled and the uncontrolled losses have to be known. In the case of Vienna, a system with a double wall prevents the groundwater to be affected and leachates are collected. In order to simplify the analysis, it is assumed that 100% of the leachates are collected.

4.1.4.1. Carbon

In order to estimate the carbon content in the landfill, the information given by the incineration plant is used. In fact according to Rolland et al., the average concentration of carbon in waste incinerated from 2009 to 2010 was 230 g/kg (2011). The same authors assessed the transfer coefficients for carbon. They can be found in the diagram below.

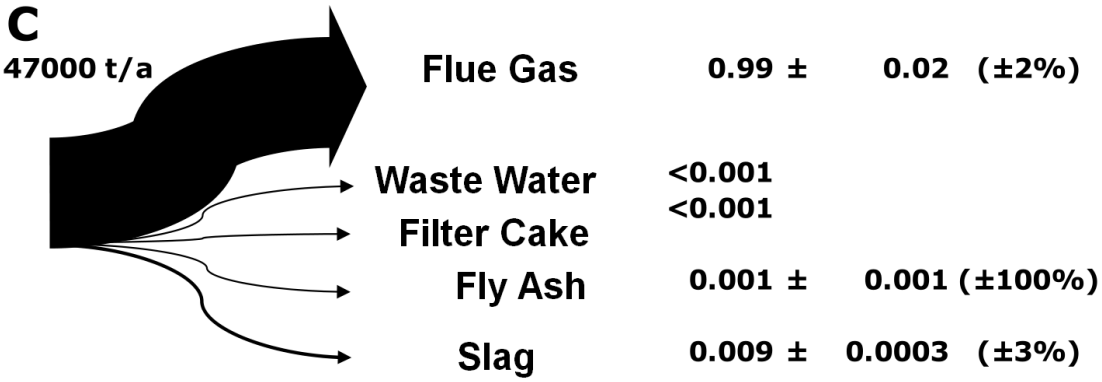

Figure 4.12 Transfer Coefficient for C in Spittelau incinerator (Rolland et al., 2011: 24)

The amount of waste incinerated was 578 Gg[14] in 2009 (Lebensministerium, 2011a: 41). As the fly ash and the slag end up in the landfill, 1% of the carbon contained in the waste incinerated is stored in the landfill. In mass, it represents 1330 tonnes of carbon. However, not only incinerated waste is sent to the landfill. According to the same report, the total quantity of waste sent there was 185 Gg in 2008 and 97% of it was from the incineration waste. By assuming the same carbon content in the 3% left, the total amount of carbon arriving at the landfill is 1372 tonnes of carbon. The carbon in a landfill is for 46% emitted via gas, i.e. CO_2 and CH_4, in the atmosphere

[14] Sum of 541 Gg of residual and 31 Gg of bulky waste and 5,7 Gg of residues from sorting.

and for the 54% left stored in the landfill (Fellner, 2013). Therefore, the amount of carbon stored annually in Vienna's landfill is 741 tonnes.

To conclude, with a simplified calculation, the amount of carbon stored in landfill has been assessed. It is a relatively low number, however the maximal concentration of TOC for the waste sent there should be 5% maximum (Lebensministerium, 2011a: 115). This estimation does not take into account the huge reservoir of carbon already there and coming from past waste. This explains why some landfill gases are still captured. To be complete, the carbon that goes out the landfill via leachates should be removed. As it represents only 0,3%, the total amount of carbon stored is almost similar. It is 739 tonnes.

4.1.4.2. Nitrogen

As for carbon, the amount of nitrogen ending in the landfill is reduced because of the waste thermal and biological treatments. Their function is to recover the nutrients instead of landfilling them. Once in the landfill, nitrogen can be emitted in the atmosphere as N_2O. According to Fellner (Fellner, 2013), these emissions take place at the very beginning of the disposal and in the last phase of gas production. Also, N_2O landfill emissions represent 3 to 4% of GHG emissions. In the case of Vienna, the numerous treatments probably strongly reduce this proportion.

Nitrogen was not included in the study of Rolland et al. about the incinerator however the usual concentration of the waste sent to incineration is 5 gN/kg and the transfer coefficient are assumed to be the same than for carbon (Fellner, 2013). In fact, during combustion, most of the nitrogen is transformed in NOx and with a DeNOx transformed back into N_2 before being released into the atmosphere. With 578,2 Gg of waste incinerated, the amount of nitrogen contained in fly ash and slag is 29 tonnes that reach the landfill. A 0,46% share of these 30 tonnes are emitted as N_2O landfill and 36% of the total is washed away with leachates. Thus, 64% of nitrogen, or 19 tonnes, stay in the landfill.

4.1.4.3. Mercury

Rolland et al. evaluated the concentration of mercury to be 0,25 mg/kg for the year 2009 and 2010. They also determined the transfer coefficients of mercury during the incineration process. As seen on the diagram below, 37% goes to fly ash and 3% to slag (2011).

By using the same calculation method than for carbon, the amount of mercury that arrives to the landfill can be estimated to 59,5 kg per year. This is a relatively small amount that shows that waste is treated before it reaches the disposal step. From this amount, a small proportion, i.e. less than 5%, is probably lost in leachates and in the air. By considering 5% of loss, it means that 56,5 kg are stocked in the landfill. The corresponding concentration is 0,32 µg per kg.

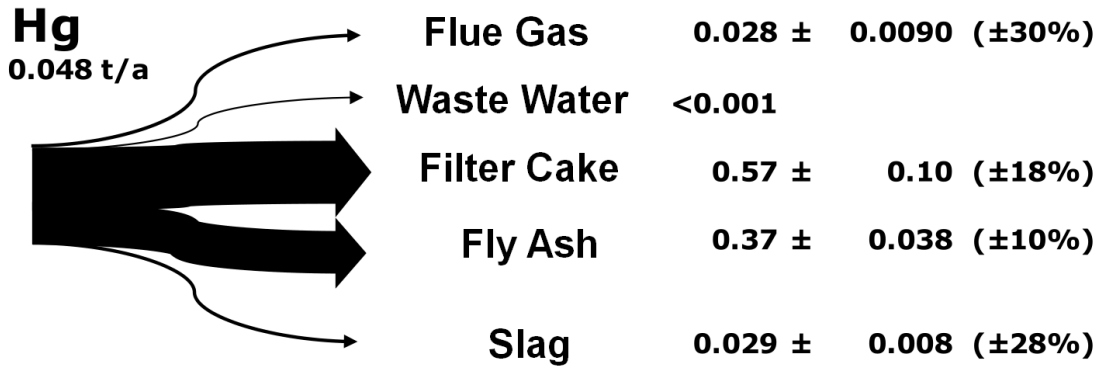

Figure 4.13 Transfer Coefficient for Hg in Spittelau incinerator (Rolland et al., 2011: 24)

4.1.5. Sent Outside

As explained in the former sections, not all the waste can be treated or landfilled in Vienna, therefore it is sent outside of the system boundary defined in this thesis. Before being sent, this waste is usually treated. All the information about the flow of elements sent outside Vienna have been found in the waste management report of the Lebensministerium (2011a).

Firstly, the amount of exported material that has been sorted before being recovered is 455 Gg/yr. As there is no plant available in Vienna for this activity, it is an outgoing flow. From this flow, the amount of recyclable waste collected from households is available: 130 Gg of paper pressure, 27 Gg of glass, 2,3 Gg of metals and 26 tonnes of textiles. The Research Centre of Waste and Resource Management

assessed the proportion of elements such as carbon and nitrogen for an extended range of waste types. By using this table, it can be said that out of this 159 Gg of recoverable waste from households, there are 56 Gg of carbon and 408 tonnes of nitrogen. Regarding the 296 Gg left, as no detail is given about the content, it is very hard to assess the amount of carbon, nitrogen and mercury sent.

Secondly, hazardous waste is regularly sent out of Austria to be treated further or landfilled. In 2009, 215 Gg of diverse hazardous waste were sent to foreign countries. Contaminated ash, slag, oil and sludge are some examples of what is exported[15]. As for recyclable waste, an estimation of carbon and nitrogen could be made by using the table of conversion. The estimation can be done on 86,5% of the hazardous waste. By extrapolation, the amount of carbon found was 40 Gg and 629 tonnes for nitrogen. By using the population ratio[16], it can be said that the exports of carbon via hazardous waste in 2009 for the city of Vienna was 8 Gg and 129 tonnes of nitrogen.

Regarding other types of waste, some pieces of information are given but this is not sufficient to perform estimations. The types of waste concerned are for example animal fat products, asbestos, fats and oil frying, gas discharge lamp, fat glass and glass packaging, end-of-life vehicles. With regard to the last category, it is known that 250 000 vehicles were removed in 2009 from the market and only 91 200 were treated. Therefore, 158 800 vehicles were exported. For Vienna, this represents proportionally 18 645 vehicles.

To summarise, some information are known about the flows of waste that are exported. However, the assessment of element content is hard. By considering only the exportation of hazardous waste and of recoverable waste from households, 64 Gg of carbon and 537 tonnes of nitrogen were sent outside Vienna in 2009.

[15] See the Annex II for more details about the list
[16] In 2011, Austria had 8 420 900 inhabitants and 1 721 573 of them were living in Vienna (Statistik Austria, 2013: 40). Thus, the population ratio is 20,5%.

4.2. Santo Domingo

Santo Domingo, the capital of the Dominican Republic, is the main city of the country. However, with the limited space, agricultural and industrial activities and population development also take place at the outskirts of the city in the provinces of San Cristobal and Santo Domingo. Information found was sometimes covering only the capital city and other times the whole metropolis. In this work, only the main city is covered. However, an exception is made for the landfill and the main harbour that are both located a few kilometres outside the city. In fact, there are both important emitters of the elements analysed and excluding them would give irrelevant results.

The values found for mercury emissions in Santo Domingo are all based on a national report from 2010. It assessed the amount of mercury emitted by sources and their sinks in 2008 and 2009 (Direccíon de calidad ambiental, 2010). As it concerns the whole country, an adaptation of the values has been performed. The estimations for each sector depend on the relevance on the information regarding Santo Domingo. For example, the mercury estimated to be used in gold mining activity has been simply removed from the calculations. The values for goods containing mercury were adapted to the population of Santo Domingo. And the fixed sources of mercury, such as plants, were considered depending on their location in the country. For instance, the two refineries located in Santo Domingo's harbour have been considered, whereas industries located in the second city of the country have been removed. The details for the type of calculation made can be found in the table below.

Table 4.7 Type of calculation performed for each source of mercury in Santo Domingo

Source	Calculation	Details
Sum of used fuels	Per population	Fuels: biomass, fossil fuels, natural gas
Refinery activities	Per site	Two sites located close to Santo Domingo
Production of lime	Per site	Located close to Santo Domingo
Goods	Per population	Thermometers, light bulb, batteries, laboratory equipment, use for religious rituals
Incineration of hazardous and medical waste	Per site	Located in Santo Domingo
Landfill emissions	Per site	Landfill in Santo Domingo

Waste water	Per population	
Crematoria & Graveyard	Per population	

The report also covers production of metal, i.e. gold and ferronickel (FeNi) and of cement. However, these sites do not concern directly Santo Domingo so the related numbers have not been used. As the report was the first evaluation ever made in the Dominican Republic, some information was lacking. However, the document analysed and estimated most of the relevant sources.

4.2.1. Atmosphere

Santo Domingo is located along the shore of the Caribbean Sea and strong winds are cleaning the city air. But even if pollutants concentrations are relatively low, emissions of carbon, nitrogen and mercury are significant. A good proportion of the information following is coming from a report from the ministry of environment and natural resources (Ministerio de Medio Ambiente y Recursos Naturales, 2010).

4.2.1.1. Carbon

The most recent information found about carbon compounds emissions were GHG releases in the country for the year 2000: -392 Gg of CO_2, 231 Gg of CH_4, 7970 Gg of CO, 140 Gg of NMVOCs. The sectors of energy, industry, transport, agriculture and others are covered and the carbon storage from living organisms is already included. In comparison to the emissions of 1994, the amount of CH_4 increased slightly, it was 216 Gg in 1994. However, the figure given does not include the carbon storage. Compared to methane, emissions of CO and NMVOCs have been multiplied, they were respectively 462 Gg and 76 Gg (Secretaría de Estado de Medio Ambiente y Recursos Naturales, 2002). It is difficult to determine whether this large increase is only due to the development of activity, which means at the same time an increase of pollution; or whether the evaluation method had also been improved between the two measurements. This example shows that an update of the figures to the present decade will present strong uncertainties.

In 2000, the population of the country was 8 553 739 inhabitants and 9 659 054 in 2009, so the increase in nine years was of 12,9%. Additionally, the proportion of Dominicans living in Santo Domingo was 26,7% in 2009.

In order to calculate the total amount of carbon released, it is first required to estimate the CO_2 emissions. In fact, the net emissions given above cannot be used directly. With the development of the population, it is unlikely that the emissions storage also increased by 12,9%. It is more realistic to keep this amount of storage constant. So first, based on the emissions of 1994 that were 8370 Gg for a population of 7 746 719 inhabitants, it can be said that the CO_2 emissions in 2000 were 9242 Gg and the carbon sequestration 9634 Gg. Therefore, emissions of GHG in 2009 were approximately the following:

Table 4.8 Emissions of carbon in Santo Domingo per gas in 2000 and 2009

Net GHG Emissions in Gg	CO_2 (M:44,01)	CH_4 (M:16,05)	CO (M:28,01)	NMVOCs 64,22%
2000	-392	231	7970	140
2009	802	261	9000	158
Amount of C	219	195	3859	102
Total Carbon Emitted in Dominican Republic			4375 Gg of C	
Total Carbon Emitted in Santo Domingo			**1169 Gg of C**	

The average carbon content used for NMVOCs is the same than the one used for Vienna: 64,2%. It can be noticed that the amount of CO emitted is important. This is explained by the high number of old cars imported from developed countries that are not equipped with catalytic converters.

In addition to these gases, ozone depleting agents also contribute to the amount of released carbon. The values in 2011 for the whole country were for 2,8 kg of Chlorofluorocarbon (CFC), 65 kg of HFC, and 94 kg of methylbromide (CH_3Br) (Ministerio de Medio Ambiente y Recursos Naturales, 2012b: 44). However, these amounts are relatively insignificant and are rather difficult to estimate for CFC and HFC. For example, 94 kg of CH_3Br represents for Santo Domingo $3{,}17 \times 10^{-6}$ Gg of carbon. Therefore, ozone depleting substances are not considered in this thesis.

Regarding air concentration, only figures for CO have been found. According to the report from the ministry, in 2002, the mean ratio of CO in the air was 2 ppm which corresponds to a concentration of 2,3 mg/m^3 at 20°C and 1 atm (Ministerio de Medio Ambiente y Recursos Naturales, 2010: 119).

A report from Bogdal et al. (2013) on the concentration of POPs in the world gives the following values for the Caribbean region: PCBs 1-3 pg/m^3, DDTs 1-5 pg/m^3, PCDDs/PCDFs 74 fg WHO98 TEQ/m^3, dl-PCBs 1–248 fg WHO98 TEQ/m^3. As for the ozone depleting substances above, concentrations in pg or less are not significant enough to be considered in the calculation.

In the end, the updated calculation performed estimates that 1170 Gg of carbon were emitted in 2009 in Santo Domingo. Nevertheless, the uncertainty level is quite high.

4.2.1.2. Nitrogen

Nitrogen emissions in the air are mostly caused by NOx, N_2O and NH_3 gases. Only information about the NO_2 and N_2O has been found. The lack of NH_3 could be explained by the little proportion of catalytic converters used for vehicles (Ministerio de Medio Ambiente y Recursos Naturales, 2010: 119). Indeed, this pollution control system releases NH_3. The other reason is the reduced amount of agricultural fields in the urban areas of Santo Domingo.

In 2000, the amount of N_2O released in Dominican Republic was 9,8 Gg and the amount of NO_2 was 93 Gg. As for CO and NMVOCs, the comparison with the figures from 1994 shows a strong increase. Emissions were respectively 2,5 Gg and 77 Gg at that time. The actualisation of the values for 2009 gives the following figures: 11 Gg of N_2O and 105 Gg of NO_2 which makes 36 Gg of N for the whole country and 9,5 Gg of N for Santo Domingo.

Moreover, the same study found an average NO_2 concentration of 13 ppb or 24,9 µg/m^3 at 20°C.

4.2.1.3. Mercury

As explained in the introduction of this section, the mercury calculation has been adapted to the characteristics of the city. The emissions in the atmosphere for Santo Domingo are found in the table below and represent in total 182 kg.

Table 4.9 Emissions of mercury per type of source in Santo Domingo in 2008

	Sum of used fuels	Refinery activities	Lime production	Goods	Incineration of hazardous & medical waste	Total emissions
Hg in kg	48	66	0,4	4,3	63	**182**

4.2.2. Hydrosphere

The Dominican Republic receives a good amount of precipitation. Nevertheless, with its high density, Santo Domingo cannot sustain itself. In 2005, 82,3 m^3 of water were used per person which means a volume of 212,4 hm^3 only to cover the population needs. Therefore, water sources are the rivers flowing in the region, the regional aquifers and aqueducts bringing water from other regions.

The metropolis is located in the region of the river basin Ozama – Nizao and the average precipitation for the year 2007-2011 was 1913 mm (Oficina Nacional de Estadística, 2012b: 31). The aquifer located under the city has a depth of 50,5 m and a volume of flow of 0,03 m^3/s (Ministerio de Medio Ambiente y Recursos Naturales, 2012a). In 2011 for the whole province of Santo Domingo, the repartition between the three sources was the following: 94 hm^3 of groundwater, 132 hm^3 brought to the city via aqueducts and 286 hm^3 from surface waters (Oficina Nacional del Estadística, 2013). This allows more than 90% of the urban population to have access to drinking water.

The report published by the ministry for the environment points out that the sea water of Santo Domingo is quite polluted. It has a low oxygen concentration, 5 mg/l, and contains consequent amount of fine particles and coliform bacteria. However, no data regarding carbon or nitrogen concentration is provided. The report also indicates that the number of study covering the water quality topic is low (2010: 150).

In 2011, the waste water produced by the urban population of Santo Domingo province was 437 hm^3. Out of it, only 9,4% was collected and 3.1% or 10,5 hm^3 was treated (Oficina Nacional del Estadística, 2013). A big proportion of the waste water is released into the sea and contributes to the bad quality of the water described in the previous paragraph.

4.2.2.1. Carbon

The main source of carbon for the hydrosphere is the waste water. The amount of waste water is known. However, no value regarding its carbon content could be found. In order to still obtain a comparable value, the carbon concentration in Vienna is used. In fact, even if they have a different level of development, there are both quite populated metropolises with some common characteristics. In the section 4.1.2.1, it has been calculated that 36 364 tonnes of carbon arrives at the WWTP of

Vienna. With a population of 1 731 236 inhabitants, the amount of carbon emitted per capita per year is 21 kg. By using an equivalent ratio for Santo Domingo, it makes 54 230 tonnes of C contained in waste water. In 2010, 3,1% of the waste water was treated (Oficina Nacional del Estadística, 2013). By using the estimation figures from Baker et al., it would mean that 1681 tonnes would receive a treatment that removes approximately 80% of the carbon[17]. This means that 52 885 tonnes of carbon were not removed from waste water.

According to the ministry of environment, a lot of efforts still have to be made on the water sanitation (Ministerio de Medio Ambiente y Recursos Naturales, 2010). Thus, it is highly probable that not all the waste water is released in surface water bodies. Thus, it is assumed that 5%, or 2644 tonnes, of the carbon seeps into the ground, and 20% of it, 529 tonnes, reaches the groundwater (Fellner, 2013). This means that 50 241 tonnes of carbon from waste water end up in the rivers and the Caribbean Sea.

In addition to waste water, carbon is also released in the hydrosphere via water infiltration into the lithosphere that ends up in groundwater. As there was no direct information that could be exploited, an estimation of the emissions by municipal solid waste has been made. This estimation will also be used in the lithosphere and landfill sections. In fact, some pieces of information found in different papers allow estimating roughly the emissions of carbon from MSW.

First, it is required to know the composition of MSW in order to determine the nitrogen and carbon content. The studies from Garraway (Garraway, 2002), from the Caribbean Recycling Foundation (2003) gives the waste composition of three Caribbean islands. The carbon content for each category has been found in the table already used in the section 4.1.5. Calculations can be found in the table below.

The average daily generation of MSW per households has been estimated by Espinal and Niver for Santo Domingo between 2,67 and 5 kg (2004). As the figure needs to be actualised, 4 kg is considered as a relevant estimation.

[17] Vienna with a state-of-art WWTP reaches 93,4% of removal.

Table 4.10 Santo Domingo's composition of MSW and its carbon content

Component	St. Kitts & Nevis in %	Trinidad & Tobago in %	Puerto Rico in %	Mean for Santo Domingo in %	Carbon content In g/kg	Carbon Generated In g/kg
Organics	27,4	26,7	25	26,4	375	98,9
Paper	20,5	19,7	26	22,1	425	93,9
Glass	8,1	10,5	12	10,2	0,2	0,02
Metals	8,8	10,4	12	10,4	0	0
Plastics	23,2	19,9	9	17,4	771	134
Textiles	7,4	7,3	0	4,9	770	377
Others	4,8	5,3	16	8,7	0	0
Total	100,2	99,8	100	100		**364**

A recent report on households (Oficina Nacional de Estadística, 2010) gives the proportion of households that dumps its waste illegally. The number of households concerned is 21 700 which represents 2,92% of the total. By multiplying the carbon generated per kg of waste, the amount of waste and the number of households, direct emissions of carbon from MSW to water bodies represent annually 11 544 tonnes. But only 20% of this amount reaches groundwater. So the amount emitted in groundwater by MSW is 2309 tonnes.

The waste landfilled also potentially releases carbon in water via leaching. Usually, 0,3% of the carbon brought to the landfill goes into the leachate and 20% of the carbon contained in the leachate reaches groundwater. Therefore, out of the 625 Gg brought to the landfill (see section 4.2.4), 375 tonnes of carbon are reaching the water bodies.

In the end, the total amount of carbon from MSW and other types of landfilled waste that ends up in the hydrosphere is 50241 + 529 + 2309 + 375 = 53 454 tonnes. As the carbon content from Vienna waste water has been used, this estimation is highly approximated but it gives an idea of the total amount of carbon released in the hydrosphere.

4.2.2.2. Nitrogen

According to Baker et al., sewage water in the Caribbean contains, on average, 3,9 kg of nitrogen emitted per capita annually (2010). For Santo Domingo, this would

correspond to an emission of 10,1 Gg of nitrogen. This figure is probably too high for a city because nitrogen from the use of fertiliser is reduced.

The estimation with MSW performed for carbon in the previous section can also be performed. The table presents the results:

Table 4.11 Santo Domingo's composition of MSW and its nitrogen content

Component	Mean for Santo Domingo in %	Nitrogen content In g/kg	Nitrogen Generated In g/kg
Organics	26,4	117	3,1
Paper	22,1	3,1	0,68
Glass	10,2	0,3	0,03
Metals	10,4	0	0
Plastics	17,4	5,5	0,96
Textiles	4,9	1	0,049
Others	8,7	0	0
Total	100		**4,81**

After multiplying the nitrogen content of waste with the amount of waste and the number of households, the direct nitrogen emissions from MSW released in water bodies are estimated at 124 tonnes. Furthermore, the amount of nitrogen, which is deposited on sealed surface, is taken away by precipitation and ends up in waste water. Approximately 55% of the 421 km² are sealed and on average 2 kg of N are deposited annually per hectare. Therefore, it represents 46 tonnes that is added to waste water. Thus, 171 tonnes from MSW and from deposition are released in the waste water.

The amount found above is very different from the estimation of Baker et al. In fact, the waste water and the waste from industry surely contribute importantly to the emissions of nitrogen in sewage water. In 2010, 3,1% of the waste water was treated (Oficina Nacional del Estadística, 2013). By using the estimation figure from Baker et al., it would mean that 312 tonnes would receive a treatment that removes approximately 70% of the nitrogen[18]. Thus, still 9851 tonnes of nitrogen is released

[18] Vienna with a state-of-art WWTP reaches 84,4% of removal.

in the hydrosphere from the waste water. Due to the medium quality of the water management in Santo Domingo, it is highly probable that not all the waste water is released in surface water bodies. Thus it is assumed that 5%, or 493 tonnes, of the nitrogen seep into the ground and half of it, 246 tonnes, reaches the groundwater.

The other possibility for nitrogen to reach water bodies is via infiltration in the ground. Three different sources have been identified. Firstly, 50% of the nitrogen of the illegally disposed MSW reaches groundwater. In the case of Santo Domingo, it represents 15 tonnes of nitrogen. Table 4.12 in the lithosphere section gives some extra information about the method used to find this number. Second, the landfill leachates contain nitrogen. Nitrogen amount in landfill waste constitutes 8236 tonnes (see section 4.2.4). On a short-term, 37,5% of it is taken away by the leachates and half of this amount ends up in groundwater. Therefore, 1544 tonnes of nitrogen coming from the landfill end up in the hydrosphere. Thirdly, groundwater receives also nitrogen after deposition. Half of the amount deposited on unsealed surfaces remains in the ground, so 19 tonnes (for more details, see the section 4.2.3.2). The quantity of nitrogen reaching the hydrosphere via infiltration is then 1825 tonnes.

In the end, the total amount by combining the two sources makes 10,9 Gg. This figure is based on strong assumptions and relies mostly on the estimation from a study covering the whole Caribbean.

Regarding concentrations, in 2000, a study was performed on a river basin in the north west of the country. The location is not particularly affected by anthropogenic activities and the measurements found can be considered as the natural concentrations in water. The average concentration of ammonia was 0,85 mg/l and 0,1 mg/l for nitrate (Soldner et al., 2004: 867). In total, it represents a concentration of 0,72 mg/l for nitrogen.

4.2.2.3. Mercury

In terms of emissions, the total amount for Santo Domingo is 395 kg. Details of the influence from the different sources are in the table below.

Table 4.12 Mercury Emissions in water bodies in Santo Domingo

	Refinery activities	Goods	Waste Water	Total emissions
Hg in kg	3,7	8,7	383	395

As for nitrogen, 5% of the waste water is estimated to seep into the ground and most of it remains there.

In addition to these direct releases, 5% of the mercury stored in the lithosphere reaches the groundwater, which makes an additional 27 kg.

In the end, the total mercury released in the hydrosphere is 403 kg.

The national report on mercury estimated that the concentration in waste water was between 0,5 and 10 µg per litre (Direccíon de calidad ambiental, 2010: 50).

4.2.3. Lithosphere

Emissions of carbon, nitrogen and mercury for Santo Domingo are not easy to assess. In fact, most of the solid waste generated goes to landfill and the amount of agricultural fields is limited. Thus, releases of elements in soils happen during infiltration of waste water into the ground, air deposition, illegal dumping, and brownfields.

4.2.3.1. Carbon

The carbon emissions in the lithosphere are coming from waste water infiltration, illegal and legal disposal of waste.

Regarding waste water, as explained in the former section, 5% of the carbon in waste is assumed to reach the ground and 80% of it stays there. It represents in terms of mass 2812 tonnes.

As for waste, the calculation method based on MSW used in the former section is used again to estimate the amount of released carbon in soils. In fact, the study of households' behaviour also points out that some of the waste probably ends up in soils. Three categories, namely burnt waste, dumped waste to the yard and others are considered. Regarding the first one, as seen in the section 4.1.4, only 1% of the carbon contained in the incinerated waste stays into the solid products of the combustion. The results are shown in table 4.13 below.

Table 4.13 Carbon and Nitrogen released in soil

	Burn the waste	Dump into the yard	Other	Total
Number of households	13 022	8 300	13 273	34 595
Waste in tonnes per year	19 012	12 118	19 379	50 509
Share of Carbon in tonnes	69	4 415	7 060	**11 544**
Share of Nitrogen in tonnes	0,9	58,3	93,2	**152**

Therefore, 11 544 tonnes of carbon coming from MSW are directly discharged into the soil. Out of this amount, Fellner (2013) estimated that 80% remains into the soil and 20% ends up in groundwater. So, 9235 tonnes of carbon from MSW stay in the ground. No specific information was found for industry and tourism activities or regarding air deposition and pollution from brownfields.

With regard to landfilling activities, only 0,3% of the carbon landfilled is found in the leachates and 80% of it goes to the ground. So 0,24% of 625 Gg of landfilled carbon makes 1444 tonnes of carbon.

As brownfields and deposition influences can be considered as minor, the only source not evaluated is the industrial illegally dumped. Castillo Tió (2001) assessed that 5,6% of the waste landfilled in Santo Domingo was industrial which represents 6,4% of the MSW landfilled. By assuming that the ratio of illegal dumping is the same for MSW and for industrial waste and that the carbon content is similar in the two types of waste, it represented an additional 591 tonnes of carbon.

The total amount of carbon that could be estimated with a rather high uncertainty was 13 385 tonnes of carbon.

Carbon concentration was measured in four sites in the Dominican tropical forest. The organic matter concentration was estimated to be 13,9% (Hernández et al., 2007: 38). This ratio can be considered as the original concentration in the Dominican soils. Additionally, in 1998, Sbritz et al. (1998) assessed the amount of chlorinated hydrocarbons in the near shore sediments. As for POPs released in the atmosphere, these pollutants such as DDTs, chlordanes or PCBs were found in very small concentration, i.e. in ng/g, and are thus not relevant for this thesis.

4.2.3.2. Nitrogen

By using the same calculations than for carbon, released nitrogen into ground for MSW is estimated to 152 tonnes (see table 4.13). Only half of it remains into the sink soil, so it makes 76 tonnes.

In terms of deposition of N, Martinelli et al. (2006) used data from different studies to estimate the yearly wet deposition in Latin America and the Caribbean between 1 and 3 kg per hectare. The share of sealed surfaces for Santo Domingo could not be found. As Vienna has a sealing rate of 43,9% for a lower density of population, it can be expected that the sealed surfaces of the urban part of Santo Domingo represents at least 55% of the city. With a deposition rate of 2 kg, the deposition of N would be at least 38 tonnes. Half of this amount would remain in the ground, so 19 tonnes.

Nitrogen amount in landfill waste constitutes 8,25 Gg. On a short-term, 37,5% of it is taken away by the leachates which represents 3092 tonnes of nitrogen. Half of this amount ends up in groundwater and half remains in the soil. Therefore, 1546 tonnes of nitrogen coming from the landfill end up in the soil.

Regarding nitrogen contained in waste water that infiltrates the ground, the value estimated in the section 4.2.2.2 was 246 tonnes.

The total emission estimated represents 1887 tonnes. Emissions of brownfields are not considered in this thesis.

In terms of concentration, Hernández et al. also assessed the nitrogen concentration found in Dominican forests and it represented 0,7% (2007: 38). This can be considered as the normal concentration found in Dominican soils.

4.2.3.3. Mercury

Emissions of mercury in Santo Domingo's soils are found in the table below. However, the report does not make the difference between landfill and soil. As most of the waste ends up in the Duquesa landfill, only a limited amount of mercury is supposed to end up in soils. Additionally, the mercury that is landfilled is considered to entirely remain there.

To determine the emissions to the lithosphere, the ratio of households used for carbon and nitrogen estimations can be used and 7% of the waste ends up in soil. Therefore, the estimated emission of mercury to soils is 548 kg. However, 5%, or 27 kg are estimated to ends up in the groundwater.

Table 4.14 Mercury emissions in soil and in landfill

Quantities in kg	Sum of used fuels	Refinery activities	Goods	Waste Treatment	Crematoria & Graveyard	Total emissions
Q in soil	0	0	104	7 555	33	7 692
Q for waste	6,5	3,7	30	42	0	83
Sink soil (7%)	0,5	0,3	9	536	2,4	**548**
Sink landfill (93%)	6,0	3,4	125	7062	31	**7227**

Regarding the value for waste treatment, which is by far the most important value, the approximation is high due to a factor of 10 between the maximum and minimum possible. In fact, it is considered that there are between 1 and 10 g of mercury per tonne of waste.

In addition to this amount, 10% of the mercury contained into the waste water seeps into the ground and 95% remains there (see section 4.2.2.3). It makes an additional 20 kg of Hg stored in the ground. In total, the mercury that remains in the lithosphere is approximately 541 kg.

In terms of concentration, a coastal sediments analysis in Santo Domingo was performed in 1998. The average concentration was 486 ng/g (Sbriz et al., 1998). This was the highest concentration of the 11 sites analysed. The lowest in comparison had an average of 116 ng/g and was found on a small island, Saona, used as a natural reserve. This can be considered as a representative value for natural concentration in soils. The average concentration for the Caribbean region had also been assessed by Guzmán and Garcia in 2002 and was 71 ng/g, so slightly below the one in Saona (2002).

4.2.4. Landfill

Duquesa landfill is the only official landfill for the metropolis of Santo Domingo. It received approximately 4200 tonnes of waste per day or 1,53 Tg annually in 2001 (Castillo Tió, 2001: 99). The value actualised to the population of 2009 makes 1,73 Tg. Castillo Tió also gives the ratio of the different source of waste: 85,7% of MSW, 1,2% of street cleaning, 7,1% of commercial and institutional waste and 5,6% of industrial waste.

A mechanical sorting is performed to separate paper, plastic bottles, metal, glass and all sorts of objects that can be reused or recycled (Ayuntamiento del Distrito Nacional, 2013). However, no precise data on the amount of recoverables could be found. With 600 scavengers, a 1% recycling rate represents 70 kg per person and seems to be a plausible assumption. The landfill has a liner and the dumping is supposedly controlled however pollution problems are noticed (Ministerio de Medio Ambiente y Recursos Naturales, 2010). Furthermore, no reliable data about the leachates could be found.

4.2.4.1. Carbon

As 85,7% of the waste disposed is coming from MSW, the carbon sent to the landfill can be estimated by using the method used in the water and soil section. According to table 4.10, 1 kg of MSW contains 364 g of C. There are 1,48 Tg of MSW arriving to the landfill and 1% is removed so 1,47 Tg. Therefore, Duquesa landfill receives 535 Gg of carbon per year from MSW.

Regarding the other types of waste representing 14,3% of the total, it can be assumed that the content of carbon is at least equivalent to the one from domestic waste. In fact, commercial waste comes partly from restaurants and markets, institutions waste partly from schools and canteens and 50% of industrial waste from food-processing industry (Castillo Tió, 2001). Consequently, the content of organic carbon is important. With this assumption, the total amount of carbon arriving at the landfill is 625 Gg.

After losses in landfill gas and leachate, the amount of carbon that remains in the landfill is approximately 54% in the first decades (Fellner, 2013) or 337 Gg.

4.2.4.2. Nitrogen

Regarding nitrogen, the same calculations and assumptions than for carbon are made. In the end, with a nitrogen content of 4,8 g/kg, the amount of nitrogen arriving to the landfill is estimated to 8,23 Gg. Releases of nitrogen in landfill on the short-term is estimated to 37,5%. Thus, the remaining amount of N in the landfill is 5,14 Gg.

4.2.4.3. Mercury

Calculation for mercury into landfills has been made in the soil section. As it can be seen in table 4.14, emissions of mercury into are 7227 kg per year.

A negligible part ends up in the leachate and pollutes soil and groundwater.

4.2.5. Sent Outside

Information regarding the export of waste is limited. In fact, as previously explained, a big proportion of the waste is sent directly to the landfill Duquesa. Waste that is not sent there is usually hazardous waste. In fact, the Dominican Republic is part of MEAs such as the Montreal Protocol or the Basel Convention on Hazardous Waste. As a consequence, some specific types of waste are treated or sent abroad. There is one incinerator for hazardous and medical waste in the country and it is located in Santo Domingo.

In 2007, there were 350 tonnes of PCBs waste. As only 200 tonnes could be treated in the country, the leftover 150 tonnes were sent abroad to be treated. The same year, 19 tonnes of HMs were sent abroad as well as inflammable or corrosive substances (Ministerio de Medio Ambiente y Recursos Naturales, 2010: 47–48). Figures adapted to the population of Santo Domingo are 40 tonnes of PCBs and 5,2 tonnes of heavy metals.

Another type of exportation described in the same report concerns sea bed sediments. In fact, as Santo Domingo's coast is polluted, sediments are regularly dredged and removed to clean partially the site. There are three different sites where this operation is performed. For two of them, the dredging sludge is dumped further into the sea. Even if it is not an export as such, it is a solution used to partly send the chemical elements far from the borders of the system analysed.

4.3. Bamako

The capital of Mali represents an interesting city to study for several reasons. Firstly, in West Africa, this is one of the only major cities that is not located on the coast. It is situated in the upper region of the Niger River. Therefore, the discharge of pollutants to the hydrosphere is a more sensible topic. Regarding the thesis, Bamako is also particularly interesting for mercury emissions. Indeed, in spite of the Bamako Convention[19], WEEE is still largely exported from developed countries to Western Africa especially Ghana and Nigeria. These imports contribute to the mercury pollution of the city and constitute more an anomaly than a normal situation. As Mali is not a coastal country, it is less affected by the phenomenon. Secondly, as mentioned in section 2.4.3, the city growth is very important. This already represents an important challenge for the local political authorities that try to at least maintain the same environmental quality and if possible to improve it. Third, the waste management system is quite unusual. In fact, no official landfill exists and even if a project is in development outside of the city, a big share of the waste is today used as fertiliser for agriculture.

Mercury emissions for Bamako have been mostly based on a report about mercury assessment in Burkina Faso. In spite of the smaller area, this neighbouring country has slightly more inhabitants than Mali. Also, the climatic conditions, the culture and the level of development are quite similar. The report written in 2008 is the first one produced in the region and even if some data are missing, it is a good source of information for a substance than does not represent for the countries of the region an urgent problem to solve (Ministère de l'environnement et du cadre de vie, 2008).

4.3.1. Atmosphere

Emissions of carbon, nitrogen and mercury in Bamako or more generally in Mali have not been evaluated for at least a decade. As the capital population doubled between 1995 and 2010, the release of substances in the atmosphere has surely changed consequently. In the recent years, research performed in the city was more focused on aerosols, POPs and fine particles. Indeed, even without regular dust events due to the Sahara desert, the risks associated to fine particles are evaluated

[19] Its full name is "Bamako Convention on the ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa"

to be higher than in a developed city such as Paris (Val et al., 2013: 4). This type of pollution is preoccupying for human health and is, therefore, seen as a priority subject in this low developed country. Another direct consequence of the population increase is the higher amount of carbon in ambient air. The cost of air pollution should also be considered. In Cotonou in Benin, Adoléhoumé evaluated that this cost represented between 1 and 3% of the GDP (2004).

Some important sources of pollution can be clearly identified in Bamako. First, 90% of the energy consumed comes from the use of biomass. In 2000, 876 936 m^3 of wood were used in Bamako (Africa Regional Office, 2003, 6; Ministère de l'environnement et de l'assainissement, 2010, 30). In fact, it is still the cheapest option for households. Emissions in the atmosphere from electricity production are in comparison small because of the low consumption and the use of hydro-power stations (Diarra, 2013). Second, Bamako has a high rate of two-wheel vehicles: the ratio with four-wheel vehicles is 7,8. The pollution generated by scooters or motorbikes is a problem that was recently discovered in Europe. In fact, with a smaller engine, the combustion process is not as efficient and more HC and CO are released into the atmosphere. Third, there are some sites in Bamako that are used for illegal waste dumping. Gases emitted and sporadic fires contribute greatly to atmosphere pollution. A measurement site located close to one of these places is considered to be the most contaminated site in Mali (Klánová et al., 2009: 1961). Lastly, some types of waste such as medical waste are incinerated but the pollution control measures are basic and emissions of pollutants in the atmosphere are important.

4.3.1.1. Carbon

In spite of the low development level, carbon emissions are quite high mainly due to low environmental standards. The table that reports emissions of gases in 1995 in Mali and that is provided by the ministry for the environment and sanitation (Ministère de l'environnement et de l'assainissement, 2010: 59) has been used as a base. Figures are adapted to cover only the capital with today's population. Bamako population was only half in 1995 and represents today 12,4% of the national one. The total amount of carbon emitted is estimated to 391 Gg. For the calculations, it has been assumed that the carbon storage capacity had remained constant since 1995. With the deforestation happening in the country, this is a rather optimistic assumption. However, the local green areas, especially the forest of Yacouba at the

outskirts of the city, have been preserved (Ministère de l'environnement et de l'assainissement, 2009). The second assumption made here concerns agricultural emissions. Bamako does not have an important agricultural activity. However, it has 50% of the country industries and the traffic emissions, especially CO with two-wheeler vehicles are much higher than for the rest of the country. Therefore, it seems reasonable to assume that agriculture emissions are compensated by the emissions from the energy and industrial sectors.

Table 4.15 Carbon Emissions in Mali & Bamako

Gas	Source	Mali in 1995 (in Gg)	Bamako in 2010 (in Gg)
CO_2 (M: 44,01)	Energy	10 002	2 478
	Industrial Activity	9,6	2,4
	Land-use change	-14 853	-1 851
Total CO_2		-4 842	629
CH_4 (M: 16,05)	Energy	29	7
	Waste	35	9
	Agriculture	334	83
	Land-use change	47	12
Total CH_4		445	110
CO (M: 28,01)	Energy	519	129
	Agriculture	271	67
	Land-use change	409	101
Total CO		1 199	297
NMVOCs (C content: 64,2%)		62	15,4
Total Carbon emitted		-434	**391**

In the last decade, a few scientists focused their research on black carbon (BC) and organic carbon (OC) emissions in Africa. In fact, with biomass combustion and low controlled traffic emissions, the total amount of BC and OC were estimated to 1,65 Tg in 2005 for the West Africa (Assamoi et al., 2012). Liousse et al. determined that 2514 tonnes of OC were released in Mali in 2005 (2012) which represents 313 tonnes for Bamako by using the population ratio. For BC, the ratio BC/OC was 0,17 in Bamako (Assamoi, 2011: 176) so the amount of BC was 53 tonnes. The actualisation of figures to 2010 gives 414 tonnes of OC and 70 tonnes of BC. It is rather difficult to determine the carbon content of black carbon and organic carbon. Black carbon contains between 85 and 95% and organic carbon contains less. By assuming a carbon content of 85% for OC and 95% for BC, the total amount of carbon due to BC and OC emitted is 419 tonnes. Even if this represents only 0,1%

of the total amount of C, which is in total 392 Gg, and even if it does not influence much the final result, BC and OC concentrations are a legitimate subject of concern for the city.

Regarding other carbon compounds, NMVOCs in Bamako were estimated and are found to be in a quite high concentration. For example, benzene concentrations can reach 20,5 µg/m^3 which is above the European average (Ministère de l'environnement et de l'assainissement, 2010: 110). Additionally, POPs have been estimated by Bogdal et al. in the whole world. Even if the estimations are not very accurate, here are some of the values given for Mali: 2,07 ng/m^3 for PCBs, 2,18 ng/m^3 for DDTs (2013). These concentrations are quite negligible in regards to carbon emissions. In fact, a simple calculation can be performed to check this assumption. By considering the volume of the atmosphere above Bamako equal to its area multiplied by 11 km of height, and a concentration of benzene (C_6H_6) in the air of 20,5 µg/m^3, the amount of carbon emitted by benzene is 9,3 tonnes. This represents not even 0,003% of the total carbon emitted by the other gases. Therefore, all these gases that are potentially harmful for the environment are in the context of this thesis not relevant to assess the carbon released in the atmosphere.

4.3.1.2. Nitrogen

As for carbon, emissions of nitrous oxide and nitrogen dioxide were given by the ministry in 1995. After an actualisation, the total amount of nitrogen emitted for these two gases is 3,19 Gg.

Table 4.16 Nitrogen Emissions in Mali & Bamako

Gas	Source	Mali in 1995 (in Gg)	Bamako in 2010 (in Gg)
N_2O (M: 44,02)	Energy	1,24	0,31
	Agriculture	1,8	0,44
	Land-use change	0,32	0,08
Total N_2O		3,34	0,83
NOx as NO_2 (M: 46,01)	Energy	17	4,1
	Agriculture	5,2	1,3
	Land-use change	16,8	4,2
Total NOx		39	9,6
Total Nitrogen emitted		13	**3,2**

In addition to NOx and N_2O, ammonia emissions should also be assessed. They mostly depend on the agriculture fields where fertilisers are used. In 2003, the surface cultivated in Bamako was estimated to 300 ha (Zalle et al., 2003). About 200 tonnes of fertiliser were rejected due to agriculture on the Niger's banks (Ministère de l'Energie des Mines et de l'Eau, 2007). Out of these 200 tonnes, we can assume that a quarter is nitrogen compounds. Ammonia naturally volatilises in the atmosphere but this rate can vary between 0 and 50%. An average for arable lands was calculated from the study of Cameron et al. (2013) and gave 17% of evaporation. Therefore, the ammonia emitted in the atmosphere in Bamako is approximately 11 tonnes or 9 tonnes of nitrogen. This represents only 0,3% of the nitrogen emitted by the NO_2 and N_2O. Therefore, the nitrogen emitted is in total 3197 tonnes.

In terms of concentration, NO_2 concentration has important disparities in the city due to traffic. While a peak area would have a concentration of 44.5 µg/m3, the background concentration is 21.9 µg/m3 (Ministère de l'environnement et de l'assainissement, 2010, 109).

4.3.1.3. Mercury

A rough estimation of the mercury emitted in the world has been performed by UNEP. The area of Bamako is supposed to emit between 10 and 100 kg of mercury per year with an uncertainty of 50% (AMAP/UNEP, 2008).

In order to get a better approximation, the figures for Burkina Faso are used. There, mercury emissions in 2008 were estimated at 578 kg per year (Ministère de l'environnement et du cadre de vie, 2008: 21). With a population of 15 730 977 inhabitants (Institut national de la statistique et de la démographie, 2013), the ratio with Bamako's population is 8,7. Then, the amount of mercury emitted for the city in the atmosphere is 66 kg/yr. There are two biases for this result. On the one hand, gold scale mining is not happening in the city. So this type of emission should not be considered. On the other hand, electronic and medical wastes are more abundant in the city and Bamako has 54% of the country's industries (Ministère de l'Energie des Mines et de l'Eau, 2007: 65). Therefore, it is considered that the two opposing factors neutralised each other. With 66 kg of Hg emitted, the range given by the UNEP estimation is verified.

4.3.2. Hydrosphere

Due to its dry season, its warm temperatures all over the year and its closeness of the Sahara desert, Bamako could be expected to face huge problems to supply clean water for its population. Thanks to the Niger River, this is only partly true. The Niger is the main source of water and the main sink for the Bamako's hydrosphere. Indeed, drinking water is pumped and treated before being distributed in the city and waste water is usually rejected directly into the river without any treatment. With the strong increase of population, the pressure on the water body also increased and this dependence may become more and more problematic. For example, a second pumping station is under construction because, currently, 200 000 m^3 per day are missing to cover the city needs (L'Essor, 2013). Mali has also good amount of water stored in aquifers, which cover 51% of the territory. However, these remain at least in Bamako's region mostly unused due to exploitation costs.

In 2006, the total production of drinkable water for Bamako was estimated to 120000 m^3 (Ministère de l'Energie des Mines et de l'Eau, 2007: 58) and actualised this value is approximately 150 000 m^3 per day which is equivalent to 54,8 hm^3.

The upstream water of the Niger River is considered as clean. The only consequent anthropogenic activity is mining. In fact, due to diamond and gold mining, there are local risks of pollution (Aboubacar, 2007: 27). However with an average flow of 1280 m^3/s, the dilution potential of the Niger is quite high. This dilution factor fluctuates highly depending on the season and is at its maximum from August to November. In general, the high volume of water dilutes well the release of carbon and nitrogen. The main problem according to the ministry of energy and water is the bacteriological level (2007). In the last decade, a general degradation has been noticed. The level of oxygen has decreased and aquatic plants are developing due to the presence of fertilisers.

4.3.2.1. Carbon

As organic carbon in water does not represent a priority substance for human health, very little information is found about the carbon content. The only exploitable measurement is the dissolved organic carbon (DOC) in the Niger before reaching Bamako in 1992 that was 2,25 mg/l (Tardy et al., 2004).

The main source of emitted carbon is waste water. In order to have a rough estimation of the emissions of carbon, the value of carbon emitted per capita in

Vienna is used. In the section 4.1.2.1, it has been calculated that 36 364 tonnes of carbon arrives at the WWTP of Vienna. With a population of 1 731 236 inhabitants, the amount of carbon emitted per capita per year is 21 kg. With 1,809 million of inhabitants, the amount of carbon contained in the Bamako waste water is approximately 37 989 tonnes. As for Santo Domingo, it is plausible to estimate a 5% loss of this waste water in the ground before reaching the Niger. No treatment is performed; therefore, 36 090 tonnes of C are released in the Niger. In the 5% seeping into the lithosphere, 20% or 380 tonnes are expected to reach groundwater.

The calculations of the waste discharged in the lithosphere performed in the following section concluded that a part of the carbon emitted was finally reaching the hydrosphere. Firstly, as shown in figure 4.14, 0,2% of MSW is discharged in the gutter and ends up in water bodies. It represents 38 tonnes of C. In addition to that, a part of the leachates generated by waste illegal deposition ends up in groundwater. This represents an additional 7,3 tonnes of C. So the carbon released in the hydrosphere from MSW is estimated to be 45,3 tonnes.

In total, even if the approximation is high, the total amount of carbon released in the hydrosphere is estimated to be: 36090 + 380 + 38 + 7,3 = 36 515 tonnes.

4.3.2.2. Nitrogen

In a city with limited infrastructures for waste water, numerous sources reach groundwater or the river. Regarding nitrogen, some pieces of information were found in the literature and some calculations allow performing additional estimations.

Firstly, the nitrogen contained in waste water is like for carbon derived from the nitrogen content of Vienna in order to get a rough estimation. In Vienna, 10 821 tonnes of nitrogen arrived at the WWTP. This corresponds to 6,25 kg of nitrogen per capita per year. Therefore, in Bamako, the amount of nitrogen in waste water is 11307 tonnes. With a 5% loss to the lithosphere, there are 10 741 tonnes of nitrogen released in the Niger River and 50%, or 283 tonnes, of the losses reach the groundwater.

Secondly, in the section 4.3.1.2, it has been assumed that the 66,7 tonnes of N were rejected from agriculture on the river banks (Ministère de l'Energie des Mines et de l'Eau, 2007). Out of the 83,1% not lost in the atmosphere, 90% is expected to end up in the hydrosphere. So, 50 tonnes of N from agricultural activity on the Niger banks are released to the river.

Thirdly, as explained in the section 4.3.3.5, nitrogen deposition is 7,25 kgN/ha and the nitrogen compounds reach the lithosphere or the hydrosphere depending on the amount of sealed surface. It is estimated that 39 tonnes of N are washed away with the waste water and 77 tonnes end up in groundwater.

Lastly, nitrogen discharges take also place during waste management. As shown in figure 4.14 found in the next section, 0,2% of MSW is discharged in the gutter and ends up in water bodies. It represents one tonne of nitrogen. In addition, a part of the leachates generated by waste illegal deposition ends up in groundwater. This represents an additional 29 tonnes of N.

In the end, the total amount of nitrogen released in the hydrosphere is estimated to be 10741 + 283 + 50 + 39 + 77 + 1 + 29 = 11 171 tonnes.

Regarding nitrogen compounds concentrations, there were measured in 1995 in wells used for drinkable water in Bamako (Ministère de l'Energie des Mines et de l'Eau, 2007: 64). Concentrations of NO_2^-, NO_3^- and NH_4^+ were already quite high, on average 1,1 mg/l for NO_2^-, 76,6 mg/l for NO_3^- and 8,7 mg/l for NH_4^+. This pollution is explained by the infiltration of waste water from septic tanks into the ground that eventually ends up in wells and groundwater. In the report, it is also expected to see the situation worsens. Thus, part of the drinkable water is already quite loaded with nitrogen even before the anthropogenic use.

Furthermore, in 1982, Meybeck measured the concentration of nitrogen compounds in the Niger. The nitrogen sum of NO_2^-, NO_3^- and NH_4^+ was 0,115 mg/l (1982: 408). Fourteen years later, the concentration of nitrogen was 1 mg/l in the Niger River (Cissé, 1997). Even if this important increase can partly be explained by divergence of measurements methods, the rising use of fertilisers most probably increased the concentration of nitrogen in the Niger and it probably continued like that until today. The growing problem of the water hyacinth pollution on the river sides is a visible proof of this phenomenon (Ministère de l'environnement et de l'assainissement, 2010: 113).

4.3.2.3. Mercury

Emissions of mercury into the hydrosphere in Burkina Faso were 130 kg Hg/yr. (Ministère de l'environnement et du cadre de vie, 2008: 23). Nonetheless, 61% of these emissions are coming from gold-mining activities. There is no reason to keep this source of emission for Bamako. Therefore, without gold mining, emissions are

50 kg in Burkina Faso which corresponds to 5,8 kg of Hg for Bamako and 95% ends up in the Niger so 5,5 kg.

In addition to direct emissions, a part of the mercury from the waste infiltrates the ground and ends in the groundwater. From the 140 kg of Hg contained into the waste disposed in Bamako, it is assumed that 5% reaches the hydrosphere. This 7 kg of Hg added to the 5,5 kg calculated above makes a total of 12,5 kg that ends up into the water. With mercury deposition, covered section 4.3.3.6 for details, 1,15 kg need to be added. Therefore, in total, approximately 14 kg of Hg is released in the hydrosphere.

Cissé also established the concentration of mercury in the Niger in 1996 (1997). It was 0,1 µg/l in the water and 0,04 mg/kg in the sediments.

4.3.3. Lithosphere and Landfill

The ministry for the environment and sanitation described in its report the situation of waste management in Bamako as quite alarming. In fact, an important degradation in the last years has been noticed in the capital mainly due to the recent and rapid growth of the population. The increase of MSW[20] quantity worsened a situation where illegal landfills were already a problem. Furthermore, industrial waste, evaluated to 6432 tonnes in 2009 for Bamako (Ministère de l'environnement et de l'assainissement, 2010: 84), is not really controlled and is either burnt, composted or landfilled. In general, very few reliable sources of information covering waste management are available.

The current situation for MSW management is the following: there is no official existing landfill. As a consequence, the non-recovered and incinerated waste that would, in another city, usually end up in the landfill go to illegal dumping sites. Annually, 426 Gg of waste is produced (Guerrero et al., 2013: 49). This represents 236 kg per person or 1712 kg per household.

4.3.3.1. General Description

First of all, 43,8% of the MSW produced is collected by the Groupements d'Intérêt Economique (GIE) that brings it to temporary storage, official and unofficial sites located in the city. An additional amount of MSW is brought there by private

[20] MSW includes in that case also commercial and institutional waste.

collectors or directly by the population. In 2000, according to Barry et al., that represented a share of 65%[21], or 2,77 Gg (2009). However, with the strong increase of population and the degradation of the waste management, it is likely that this figure decreased. Nevertheless, it will be used as such for this thesis. MSW from the temporary storages should then be sent to Noumoubougou, a town located 30 km from Bamako, the only official landfill for the city. However, after more than 10 years, the site still does not operate and 40% of what is collected remains in Bamako. The main barriers for finishing Noumoubougou landfill are the extensive costs of the project and also the high cost prediction for the transportation of waste to the site. The 35% of waste not collected is burnt, dumped illegally or used in people's yard.

Additionally, the UN-HABITAT estimated that 21% is reused or recycled and 31% of the waste generated in Bamako is used on agricultural fields (2010). As it is shown in a documentary about recycling in Dakar (Possemeyer, 2004), the capital of Senegal, wastes such as plastic bags, iron, aluminium, wood, glass and other goods like shoes are either reused or recycled. This is done by the informal sector. Moreover, using waste on fields is a good source of nutrients for crops and this even helped to regenerate soils (Eaton and Hilhorst, 2003). Farmers buy approximately 18 t/ha and they perform a sorting procedure before using them. This process has been used for years without generating any big pollution and it partly explains why Bamako still does not have a proper landfill. In fact, there was no urgent need for disposing waste in a dedicated place. However with the increase of electronic and plastic waste, agricultural fields become polluted with POPs or heavy metals and a sorting should now be done before spreading waste on lands.

Regarding the waste remaining in the city, it has mostly been cleaned off recyclables and fertile waste and it ends up either in one of the numerous rubbish dumps, often located close to the river (Samake and Tang, 2009) or in temporary storages that are closed definitely. For instance, Doumanzana is one of these illegal landfills. The initial goal, in 2001, was to fill the hole caused by excavation of construction material with waste. But the situation deteriorated and the dumping was more and more done beside the hole. The site still constitutes a problem for the

[21] In the report, the real total is 43,8+26,7+5,9=76,4. However, as the total is 111,4%, there is a mistake in the table. According to the UN-HABITAT, the collection rate is 57%. Therefore, it is assumed that the error in the calculation of Barry et al. is coming from the collection rate, which is then reduced to reach a total of 100%.

neighbours. Sporadic fires and emissions of landfill gases pollute the surrounding environment (Coulibaly, 2013).

4.3.3.2. Waste Flow

In order to calculate the amount of carbon and nitrogen released, the distribution of MSW has to be known. There are two types of MSW. Once the share of recyclable and reusable waste removed, the first type of MSW represents 35% of the total amount produced and never reaches transfer sites. As mentioned already, Barry et al. (2009: 52–53) gave this repartition for the year 2000. It is distributed as followed: 10,2% are stored locally, 4,6% are used for kitchen gardens, 8,9% are burnt, 9,6% are illegally dumped, 0,2% are discharged in the gutter and 1,5% are unknown. These 1,5% unidentified can be added to the 9,6% illegally dumped and to the 10,2% stored locally. This 21,2% are considered to directly end up on bare soil. Regarding the burnt waste, the transfer coefficients used for Vienna incinerators are used, thus, 1% of the carbon and nitrogen contained in the 8,9% of the waste are disposed on the ground.

The second source of MSW that stays in Bamako represents 40% of the 65% sent to transfer sites. For the rest of the calculation, it is assumed that 31% of waste used on agricultural fields is sent outside of the city. Furthermore, to simplify the calculation, it is assumed that the recyclable and reusable waste is removed at the beginning of the waste management. In reality, this sorting happens at any level but it does not change anything for the final result. Therefore, 89,5 Gg of recyclables and reusables are removed from the total amount of generated waste. The figure 4.14 summarised the waste flow just described.

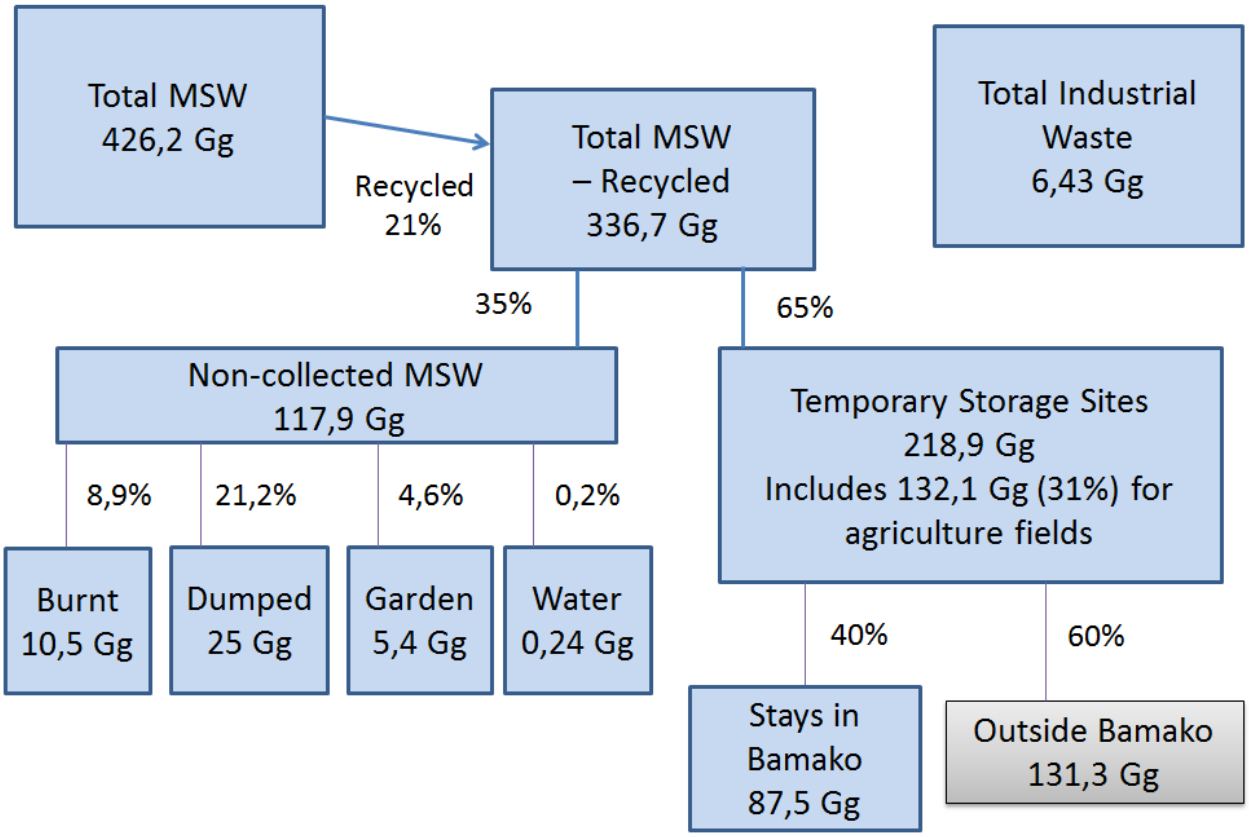

Figure 4.14 Waste Flow in Bamako

4.3.3.3. Waste Composition

The MSW composition of Bamako has been determined by the UN-HABITAT (2010: 12) and is the following: 7% for paper, 4% metal, 1% glass, 0% residue, 2% plastic, around 52% of other, 21% for organic and 17% are not determined. No explanation in the report is given for this last figure. In order to have a total of 100%, Lusaka's waste composition is used as a completion source. Therefore, it is assumed that there are 7% of plastic instead of 2% and 33% for organic instead of 21%. The low organic share is due to the large amount of sand and grit in the waste. By using the same elements' content table as for Vienna and Santo Domingo, the carbon and nitrogen content can be determined. As the recoverable and reused share is theoretically not part of what is disposed, a share of 21% in the composition is removed. It is considered that not all this waste is removed. As a consequence, the element content calculation for MSW is only based on the 79% non-recovered waste. The results are found in table 4.17. A content of 50 g/kg of C and 1 g/kg of N has been assumed for the category "others" which is mostly composed of inert material.

Table 4.17 MSW composition, carbon and nitrogen content in Bamako

Component	MSW in %	MSW without Recoverables In %	Carbon content In g/kg	Carbon Generated In kg/t	Nitrogen content In g/kg	Nitrogen Generated In kg/t
Organics	33	31	375	116	11,7	3,64
Paper	7	2	425	8,51	3, 07	0,061
Glass	1	0,5	200	0,001	0,3	0,0015
Metals	4	1	0	0	0	0
Plastics	7	2	771	15,4	5,5	0,11
Others	52	42,5	50	21,2	1	0,425
Total	100	79		**161,4**		**4,24**

4.3.3.4. Carbon and Nitrogen Content

With the waste composition and flows, the amount of nitrogen and carbon that end up in soils can be easily calculated. In order to be more accurate regarding these quantities, an assumption about the MSW content of elements has been made. Indeed, in the two MSW flows, a substantial part is spread as a fertiliser on agricultural lands and kitchen gardens. This share has been sorted out by the population and contains more nutrients and organic matter than the MSW dumped. Therefore, it is considered that 80% of N and C are contained in this valuable waste and that only 20% of these N and C are disposed and remain in the ground.

After calculations[22] including all the parameters listed above, the releases for the flow “Non-collected MSW” is 5591 tonnes of C and 6,5 tonnes of N. The other flow, “Stays in Bamako”, contains 24 984 tonnes of C and 106 tonnes of N. With 6432 tonnes, industrial waste represents only 1,51% of the MSW generated. As no details have been found regarding the composition of industrial waste, it is assumed that it has the same carbon and nitrogen content as the MSW’s one including the recoverable share. This means that an additional 1038 tonnes of C and 32 tonnes of N are dumped. In the end, the total amount of carbon released by waste in Bamako’s lithosphere is 12 154 tonnes of C and 324 tonnes of N.

[22] The table can be found in the annex V.

Nevertheless, a part of those quantities then either vaporises in the atmosphere or reaches the groundwater due to water infiltration. In fact, these illegal landfills have quite similar characteristics than a normal landfill. Therefore, 45,7% of the carbon is transformed to landfill gas, 0,3% is in the leachates and 54% remains in the ground. As for nitrogen, 37,5% goes with leachates, 0,5% is in landfill gases and 62% remains in the ground. Then, regarding leachates, 80% of the carbon stays in the ground and 20% reaches the groundwater and it is an equal share for nitrogen (Fellner, 2013). However, as there are only precipitations half of the year, the amount of leachate generated can be divided by two. In the end, 6592 tonnes of C and 290 tonnes of N are stored in Bamako's ground from MSW.

4.3.3.5. Other Sources of Carbon and Nitrogen

Apart from dumped waste, nitrogen and carbon can end up in the soil from waste water, from the use of chemicals for agriculture and from deposition.

According to the section 4.3.2.1 and 4.3.2.2, the amount of carbon from waste water that stays in the lithosphere is 1520 tonnes and the amount of nitrogen is 283 tonnes.

Regarding chemicals use, the scientific literature covers the subject due to their relevance in a sub-Sahelian climate. For example, the national use of herbicides, fertilisers and insecticides are known for the year 2007. Respectively, there were in kilolitres 640, 4 576, 717 (Barry et al., 2009: 47). In Mali, 4,7 million of ha are used in agriculture (Aquastat, 2005: 1). Nonetheless, there is no information available about the repartition of these products over the land. As mentioned before the use of fertilisers for Bamako was estimated to be around 200 tonnes, which corresponds roughly to 4,3% of the total use on 0,006% of the cultivated area. It can be expected that this high ratio of fertilisers used on the capital lands also applies to the other chemicals. This would then mean that 28 tonnes of herbicides and 31 tonnes of insecticides are used in the capital. Unfortunately, the composition of these products is not known and the amount of nitrogen and carbon released cannot be assessed.

The last possible source is deposition, though, it applies only for nitrogen. Deposition and emissions of nitrogen have been measured in an agricultural area named Katibougou 60 km after Bamako along the Niger. The deposition is estimated to 7,25 kgN/ha per year with the repartition that can be seen in the figure below (Delon et al., 2010: 2703).

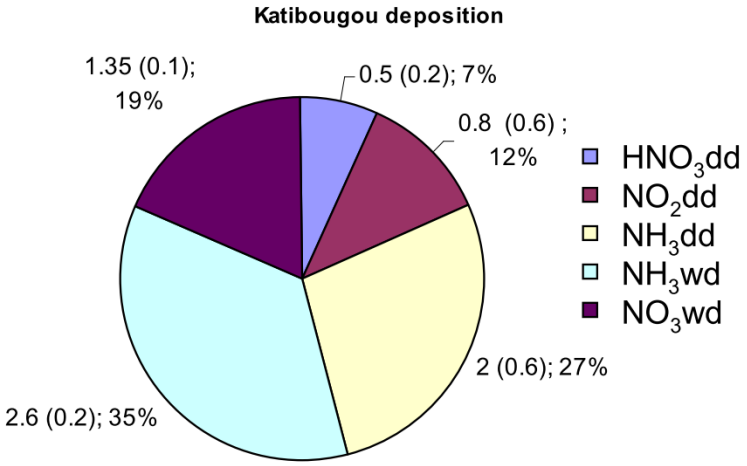

Figure 4.15 Deposition Rate of N in kgN/ha/yr. (dd: dry deposition, wd: wet deposition)

This deposition rate can be used for Bamako and represents in total 193,6 tonnes of N for the whole city. The sealing rate of Bamako is low. Only the main axes are made up of asphalt and not all of the water run-offs end up in the gutters. Therefore, it is assumed that 20%, or 53,4 km², of the city is sealed. On this sealed surface, 38,7 tonnes of N is washed away with the waste water. The deposition of nitrogen on unsealed surface is 155 tonnes. As seen before half of it, namely 77,4 tonnes, stays in the ground and the rest reaches the groundwater. (Fellner, 2013).

In the end, waste water infiltration and deposition could be used. The total amount of nitrogen, which remains in the lithosphere, is therefore 650 tonnes and it is still 8112 tonnes for C. Even if these figures are approximated, they represent most of the emissions taking place in the city.

As for concentrations, Shahandeh analysed soils in Western Mali and found a concentration of 9,16 g/kg of organic carbon and 0,6 g/kg of nitrogen (2004).

4.3.3.6. Mercury

In order to determine mercury emissions, the information from the Burkinabe report is used. Nonetheless, it is adapted to the specific situation of Bamako that sends a part of its waste outside of the city. In Burkina Faso, mercury releases in soil has been estimated to be 1 826 kg/yr. There are also some emissions from products, general waste and specific treatment disposal, which represent 15 kg, and that most probably end up in soils. So for Bamako, these emissions correspond to 229 kg Hg/yr.

As seen before 60% of 65%, or 39% of the MSW is sent outside the city. In addition, some of the mercury disposed infiltrates the soil and reaches groundwater. It is estimated to be 5%. Therefore, only 133 kg of mercury from MSW is stored in the soil.

Moreover, an analysis of lake sediments in Ghana allowed determining the annual deposition rate of mercury. For the last couple of decades, the value was between 16 and 20 µg/m² per year (Poste et al., 2012: 343). By using the same calculation method used for nitrogen, there are 4,8 kg of mercury that are deposited in Bamako. Around 960 g is washed away by waste water, 192 g reach the groundwater and 3,7 kg stay in the ground. So in total, the mercury released into the Bamako's soil is 137 kg.

The normal concentration in soil was also assessed in the work of Poste et al. and is 110 µg/kg of the dry weight.

4.3.4. Sent Outside

If the exportation of MSW is excluded, data found regarding exportation were quite reduced. In the national report about the environment (Ministère de l'environnement et de l'assainissement, 2010), it is written that metals such as iron from waste is exported due to an increasing price on the world market. It is also pointed out that 1100 tonnes of obsolete pesticides have to be handled. These pesticides cannot be used anymore because of their dangerous properties. About the same topic, Diarra explained in 2008 that there had been in two containers in Noumoubougou and will be exported in Europe to be treated (Diarra, 2008).

Regarding the exportation of MSW, 39% of the MSW is sent outside Bamako. By using the method of calculation used earlier, the exportation in terms of weight are 28 263 tonnes of C and 742 tonnes of N.

5. Results of Dilution Factors and Comparison

This chapter covers the results for the necessary dilution factors calculated and their comparison between the three cities. In fact, now that emissions have been estimated for each city and for each element in each available sink, the comparisons can start. In order to obtain relevant results, emissions or concentrations cannot simply be compared with each other. Therefore, it has been chosen to calculate a necessary dilution factor that is more appropriate for comparisons. As explained in the third chapter, in order to determine this factor, concentrations or emissions can be used.

On the one hand, with concentrations, it is easier to find the factor and thus it is more accurate. The main drawback is the complexity associated with the extraction of information for only one year. In fact, every year, elements are emitted and the concentration found is usually an accumulation of successive emissions over, at least, a few decades.

On the other hand, emissions do not have this accumulation problem. However, in order to determine the necessary dilution factor, the amount of emissions has to be transformed first into concentrations by utilising a defined volume. The determination of this volume can be very arbitrary. For example, the atmosphere above a city does not have defined limits and gases such as CO_2 dilute quickly in the whole atmosphere.

In order to stay consistent and because more emissions than concentrations have been found, it has been decided to use only the second method.

5.1. Definition of Target Concentrations and Calculation Description

As explained throughout an example with mercury in the third chapter, the way to determine the necessary dilution factor is to calculate a volume. This volume is based on a target concentration and on the emissions estimated in the fourth chapter. Once this volume has been found, it is compared with the available volume of the sink in the city. Then, it allows estimating whether or not the current volume

available is sufficient to dilute the emissions and a comparison between the three cities is possible.

The formula used is the following:

$$Volume\ required\ for\ the\ dilution = \frac{Emissions}{Target\ Concentration - Initial\ Concentration}$$

Once the volume has been determined, the ratio with the volume available is calculated:

$$Necessary\ Dilution\ Factor\ [in\ \%] = \frac{Volume\ required\ for\ the\ dilution}{Volume\ available} \times 100$$

The factor is given in %, which means than if it is lower than 100, the volume available can dilute the emissions to reach the target concentration set. If it is more than 100%, the target concentration cannot be reached.

In order to calculate the necessary factor of dilution, emissions have already been determined. In addition, the concentrations found in the fourth chapter are used to determine the target and the initial concentrations. If no information could be found, others sources were used. The ideal option for target concentration would be to use legal thresholds. However, due to a lack of time, these values could not be applied here. Most of the target concentrations set below correspond to 110% of the initial concentration. This is because in many cases, the determining information is the difference between the two concentrations.

In order to calculate the volume available, different techniques have been utilised depending on the type of sink. For the atmosphere, a height of 11 km above the ground has been considered. For the hydrosphere, which is split in aquifers and surface waters, the volume was most of the time found in the literature. Regarding the lithosphere, the area of the city is multiplied with a depth of ten metres. The details of the calculations can be found in Annex IV.

5.2. Results for the Sink Atmosphere

As explained above the calculation for the necessary dilution factor in the atmosphere is based on an imaginary cylinder that has the surface of the city as a base and a height of 11 km. In fact, this volume represents most of the troposphere and this is where a majority of interactions with the Earth's surface takes place.

Choosing 11 km is also useful to determine the initial concentration of carbon and nitrogen in the air. In fact, according to table 2.1 available in section 2.1, there are 760 Eg of C and $3{,}95x10^6$ Eg of N in the atmosphere. In addition, 75% of the atmosphere weight is contained in its first 11 km (Withgott and Brennan, 2009) and the Earth surface is 510 072 000 km². Therefore, the concentrations of nitrogen and carbon are respectively 528 g/m^3 and 0,102 g/m^3. The concentration of mercury in the atmosphere is 1,7 ng/m^3 (AMAP/UNEP, 2008: 70). The target concentrations used were 110% of the initial values.

The results for the three cities can be found in table 5.1 below.

Table 5.1 Necessary dilution factors for the atmosphere

in %	Vienna	Santo Domingo	Bamako
Carbon	4 937	2 427	1 281
Nitrogen	0,003	0,004	0,002
Mercury	11 120	23 071	13 318

In order to understand how to interpret these values, here are some explanations with the element carbon. The value in Vienna is 4937. It means that the volume needed to dilute the carbon emitted in Vienna is 49,37 times the one available. The cell is coloured in red because it is the highest necessary dilution factor of the three cities. On the contrary, Bamako, in green, has the lowest ratio. In fact, the amount needed for Bamako to dilute its emissions of carbon is almost 4 times smaller; therefore, the influence of Bamako in terms of carbon release in the atmosphere is not as strong as Santo Domingo and as Vienna. This can be explained by the reduced amount of GHG emissions. Vienna emits more CO_2 and CH_4 and these gases are not filtered. In fact, they do not constitute a priority concern even in the city with environmental policies.

On the same way it can be seen that regarding nitrogen, Santo Domingo is the worst of the three cities but the ratio with Bamako, still the lowest, is only 1,8. Here, Santo Domingo emits nitrogen due to traffic pollution and Vienna is better probably because of its enforcement laws to reduce NOx emissions. It can be seen that the emissions of nitrogen in the atmosphere are almost insignificant for the sink. In fact, most of the nitrogen is stored in the atmosphere, so only a small portion of it is necessary to dilute the emissions from the cities.

With regard to mercury, the environmental actions in Vienna help to reduce the amount of substances released in the air. As explained earlier, in cities, mercury is

emitted by industries and goods. Bamako has a limited use of goods so its impact is almost the same as for Vienna, whereas Santo Domingo needs two times the volume of Vienna. Indeed, Santo Domingo, which is still a developing country, consumes more but still does not have efficient cleaning process like in Vienna.

5.3. Results for the Sink Hydrosphere

As aquifers and surface waters are very different in terms of volume, flow and concentration, it is more logical to calculate a necessary dilution factor for each of these water sinks.

5.3.1. Surface Waters

Water surfaces are in the case of Vienna and Bamako, the Danube and the Niger rivers, whereas for Santo Domingo it is the first few kilometres of the Caribbean Sea along its coast. To determine the volume of water available of the rivers, the average flow is used. The volume is for the Danube 48,27 km^3 and 35,86 km^3 for the Niger. Regarding Santo Domingo, the city coast is 26 km long. By considering, the first 5 km of the sea with an average depth of 400 m, the volume of water available is 52 km^3, which is slightly larger than the one from the two other cities.

The set target values depend on the original concentration found in the fourth chapter. For Vienna, the concentrations used were the ones found in Nußdorf, where the river enters the city. For Bamako, concentrations for nitrogen, carbon and mercury could be found. The initial concentrations for the three elements in the sea were found in the literature (Matsunaga, 1976; Monterey Bay Aquarium Research Institute, 2012a, 2012b). The set target values are equal to 110% of the initial value. The results for the necessary dilution factors are found in table 5.2.

Table 5.2 Necessary dilution factors for the water surfaces

in %	Vienna	Santo Domingo	Bamako
Carbon	79,7	1 898	364
Nitrogen	39,6	12,4	302
Mercury	6,35	1 445	1,53

First, it can be noticed that only for Vienna, the volume of water available is sufficient to dilute the quantities emitted. Regarding carbon, Vienna is doing well compared to the two other cities. This can be explained by the efficient waste

treatment. Bamako has the lowest factor for mercury due to its low emissions in water surfaces. Indeed, most of its mercury goes to the lithosphere. Santo Domingo emits a lot of these two elements and the large volume available is not sufficient to dilute them.

Regarding nitrogen, the sea has a higher capacity of dilution because of the original concentration which is much higher. In addition, Bamako is the worst of the three cities and needs almost 60% of the volume available to dilute its emissions. In fact, it is the lower emitter of nitrogen, but it has the smaller available volume. Another reason could be the low initial concentration used that has been found in the literature. With 1 mg/l, it is less than half of the concentration found in the Danube. There might be a mistake here in the value. Regarding Vienna, its intermediate position is normal. In fact, it releases fewer elements than Santo Domingo thanks to the efficient WWTP, nevertheless, the flow of waste water is quite important.

5.3.2. Aquifers

With aquifer, the results depend greatly on the volume of groundwater available for the dilution. In fact, the capacity of the three cities is different. Vienna with 100 hm^3 has the smallest potential. With 645 hm^3, Bamako has already more than 6 times the volume of Vienna, and Santo Domingo with 1,46 km3 more than 10 times. Regarding the initial concentrations used for the calculation, the values found in Vienna were applied to all the cities. The target concentrations are 110% of the initial ones for carbon and mercury and 200% for nitrogen. Nitrogen target concentration corresponds to the average found in Vienna, 40 mg/l. The results are available in table 5.3 below.

Table 5.3 Necessary dilution factors for the aquifers

in %	Vienna	Santo Domingo	Bamako
Carbon	537	1 784	536
Nitrogen	8,6	6,2	2,6
Mercury	3,7	277	181

As for the water surfaces' results, even if Santo Domingo has the largest volume available, the quantities of carbon and mercury emitted are so important that the necessary dilution factors are much higher. While regarding nitrogen, the emissions are not problematic because of the large volume.

Regarding mercury, a necessary dilution factor of less than 4% for Vienna, it can be seen that the emissions into the hydrosphere are well controlled.

For nitrogen, the three factors are rather small due to the high concentration. The combination of reduced amount of waste water and a sufficient volume available makes Bamako the better diluter. Vienna has the largest necessary dilution factor probably due to the smaller volume available.

The dilution factor for carbon in Vienna and Bamako is almost equivalent. It is important to notice that releases in groundwater are for the three cities five times larger than what the volume could dilute.

5.4. Results for the Sink Lithosphere

The emissions in the lithosphere are very much related to waste and the quality of its management. The depth used to determine the volume available is assumed to be 10 m. In order to know the volume, it was also necessary to use an average density of soil. A good average density is 1802 kg with an optimal level of 11% for moisture (Garden Guides, 2012). Regarding the initial concentrations used, they were all found in the literature and described in the previous chapter. The target concentrations are also 110% of the initial concentrations. The results for the necessary dilution factor can be found in the table below.

Table 5.4 Necessary dilution factors for the lithosphere

in %	Vienna	Santo Domingo	Bamako
Carbon	0,003	0,127	0,184
Nitrogen	0,029	0,035	0,225
Mercury	0,002	0,615	0,258

Regarding carbon and nitrogen, the same conclusions can be made. First, the volume of dilution required is small compared to the one available. Second, Vienna, which has a better waste management system, has a reduced amount of substances that reach the lithosphere and therefore, the necessary dilution factor is the lowest. Regarding Bamako, it is the opposite situation. As it does not have any landfill, waste dumping on the ground has an important effect. However, thanks to the available volume, it does not represent a serious problem. Santo Domingo, which has a landfill but not a very good waste management system, is logically between Bamako and Vienna in terms of dilution factor.

In what concerns mercury, Vienna has a relatively low value due to its good waste management. In Santo Domingo, as explained in the fourth chapter, the uncertainty is quite high regarding the value of mercury released by the waste treatment activity. As seen for the other sinks, Santo Domingo is in an intermediate situation. It is developing so it increases its consumption of elements, but at the same time, it has not yet reached the Western countries' level of waste management. Even if the volume available can easily dilute the emissions of the three cities, the difference between Vienna and the two others cities is very important.

5.5. Interpretations for Landfill & Exported Flow

On the one hand, the landfilling activities are very different in each city and it is difficult to compare them. However, it can be said that in Vienna, the goal is to minimise the amount of carbon, nitrogen and mercury stored in the landfill. Waste is treated, incinerated, reused or sent outside to be recycled or stored in a special landfill. In the case of Santo Domingo, the goal is for the moment to ensure that the city is not polluted by the waste and therefore no real treatment is made. So the flows of elements, which are sent outside or in the air in Vienna, are mostly reaching the landfill in Santo Domingo. The situation in Bamako is also particular. The informal recycling and the use of waste as fertiliser represent 52% of the waste generated. The rest remains in the city and is not properly treated. So there is a motivation like in Vienna to make use of the waste's value before dumping it but due to a lack of money, it is ending up in the lithosphere and hydrosphere and a risk of pollution is present.

On the other hand, the quantities of substances that cannot be handled in the city are sent outside of the system. For Vienna, it represents mainly recyclable goods, which will probably come back to the city as new goods, and waste that cannot be landfilled in the city due to a lack of space or of security for hazardous waste. The amount of nitrogen and carbon exports that could be evaluated are respectively 537 Gg and 63,6 Gg. Santo Domingo sends outside dangerous waste to be treated. Regarding other type of waste, as the Duquesa landfill mostly receives MSW, it is expected that waste, such as construction waste, are also sent outside the city to be landfilled. In Bamako, an important proportion of nitrogen and carbon is sent on the agricultural fields outside of the city, respectively 7,4 Gg and 28,3 Gg. Concerning other types of substances, except valuable waste such as metal, there is no

incentive to send waste outside. The main reason is probably monetary, so this activity does not a priority for the city.

6. Assumptions, Approximations and Missing data

The emissions assessment of three elements in three cities in four different sinks requires having access to a huge amount of information. As it has been seen in the fourth chapter, not all data could be found, so assumptions and approximations had to be made. In addition, the values found in this document have most of the time been rounded up to avoid too long figures. Nonetheless, the calculations performed have been made with the original values.

First of all, with a lack of information, it is possible that some flows have been forgotten or wrongly estimated. In fact, in order to know what to analyse, a rough overview of the elements' flows in the city, before they are emitted, was needed. This visualisation of the paths taken has often been built on several sources of information. This is, however, possible that some of the paths were forgotten in the analysis. Moreover, some of the known flows have been considered as marginal or irrelevant for the emissions' estimation. As these decisions were often based on the information found in reports, they depend directly on the quality of the report.

Furthermore, a certain number of assumptions had to be made in order to obtain a figure for some major sources of emission.

The main assumption made concerns the waste water content in Santo Domingo and Bamako. In fact, the values found in Vienna were used and even if the three cities have some similarities, they all have very different climates and level of developments. The method used was to consider the same carbon and nitrogen releases in the waste water per capita.

Another important assumption made is about waste. The industrial waste and other bulky waste have been assimilated a few times to the MSW, which was in a much higher proportion. Fortunately, if municipal and excavation wastes are excluded, the generation of solid waste for cities of this size is often mostly municipal.

Also, the carbon storage capacity has been assumed to remain constant. Data about deforestation could be found on the national scale but adapting them to the capital of the country was complicated mainly because of the reduced percentage of green areas.

The same type of problems appeared with the ratio of sealed surfaces of the city. In order to determine the deposition, this factor was needed and has been found only for Vienna. Therefore, the ratio assumed regarding Bamako and Santo Domingo is based on the description found in the reports of the two cities and on personal experiences in the two regions. It has also been assumed that some chemical compounds such as POPs or fertilisers were negligible. Indeed, the comparison of units often helped but it is possible that their influences in the total emission of elements are higher than expected.

In addition to assumptions, several approximations have been performed to simplify greatly the study. The most important are presented below.

Firstly, instead of having an average value provided, a range of measurements were often given in reports. The average value was then calculated and utilised. Using an average instead of a range makes things simpler and saves time; however, a highly fluctuating parameter can increase greatly the risk of errors. For instance, the mercury released in soil and landfill in Santo Domingo is quite important. There is a factor of 10 between the minimum and the maximum value and in comparison to the two other cities; this value seems to be disproportionate. The same issue appeared concerning parameters with high fluctuations within the year like for a river flow.

Secondly, the transfer coefficient of flows of elements were sometimes roughly estimated and used in the exact same way for the three cities. In general, these types of information are not provided because they are hard to precisely determine and they also vary quite importantly.

Thirdly, the utilisation of old figures required an update that was only based on the population growth. Indeed, even if written recently, reports dealing with Bamako and Santo Domingo often contained data older than 10 years. The actualisation only used the population growth to calculate the updated value. In fact, in a big city several sources of emissions are directly related to the population, for example, the amount of flue gas from traffic or of waste water. However, the industrial or agricultural sectors are not all the time related to the population. Therefore, other factors such as the GDP evolution could also have been included. The same type of update has been performed when the figures concerned the whole country. Due to the difference of activity and density, it can sometimes appear as a wrong estimation. Therefore, when it was considered as not adaptable, figures were recalculated. This has been done with the report of mercury emissions for the

Dominican Republic. For example, mining activities were removed before dividing the national emissions to get the emissions for the city.

Fourthly, all the data found are not exactly from the same year. Any relevant figure from the last five years was taken as such. In fact, during the research phase, it was always attempted to use the most up-to-date information but sometimes this was not possible. The actualisation of all the figures to the year 2012 with the population growth would have greatly complicated the calculations and has not been done due to time constraints.

Fifthly, the margins of errors have not been kept. In fact, the majority of values found did not have any margin of error. Only scientific papers and a few reports clearly assessed the uncertainty of measurements. Estimations for each value should have been performed. However, the purpose of the thesis was to have a rough idea, so margin of error did not constitute a priority task. With more time available this would have done.

Sixthly, the values for carbon and nitrogen contents, which were found in the table from the Research Centre of Waste and Resource Management, were given in mg/kg of dry matter. However, the mass fractions of the waste used were in mg/kg of wet matter. Hence, the water content was not considered. In fact, this would also have required a lot of additional calculations.

Lastly, some data from other countries have been used. As defined from the very beginning, a type of city for a region was analysed. Nonetheless, the specificities of each city occasionally distort the use of other sources of information. For example, Bamako has no landfill as such. This is an exception in West Africa and therefore, using directly information from other cities on the topic does not seem to be applicable.

To conclude, several approximations and assumptions had to be made in order to get final results. There is also the probability that some flows had been wrongly assessed. In any case, the goal of the study was to obtain rough estimations that could verify or not the assumptions used for the research questions. The maximum has been made to avoid estimations, to consider the most probable assumptions and to keep a global consistency but due to the large scope to cover, there was no other choice to approximate.

7. Discussion of the Results

The analysis performed and the results obtained allowed reaching the goal of the thesis. Necessary dilution factors could be determined for each element, city and sink. Even if approximations were numerous, it is possible to compare the impact of Vienna, Bamako and Santo Domingo in regards to their emissions of carbon, nitrogen and mercury. Indeed, the necessary dilution factor mainly depends on the element emitted and its quantity in regards to the volume available.

In fact, for mercury, Vienna controls its emissions, therefore the releases that would normally end up in one of the city sink are sent in the outside flow. So in that case, the amount of resources consumed is compensated by the end-of-pipe technology to avoid direct harmful emissions. On the contrary, Bamako uses and, thus, releases relatively low amounts of mercury. The lack of pollution control is compensated by the reduced amount of emissions. As for Santo Domingo, it has an intermediary situation. It means that it consumes and, therefore, emits more than Bamako, but does not control the releases as much as Vienna, which emits relatively low amount in its sink because of its environment. Therefore, regarding the four sinks, Santo Domingo always has the worst necessary dilution factor.

For carbon and nitrogen, the situation is not as clear but the same type of conclusions can be drawn. In fact, when Vienna stops the emissions of an element into a sink, the big amount of resources used and then emitted is controlled and the necessary dilution factor is usually lower than for Santo Domingo and sometimes Bamako. This is the case for the lithosphere emissions and releases in the Danube. Whereas, when Vienna is unable to control its carbon emissions into a sink like atmosphere, the quantity parameter has then much more influence. On the contrary, Bamako often has the best necessary dilution factor due to the relatively low amount emitted in the atmosphere and the hydrosphere. However, most of the resources end up in the lithosphere after illegal dumping. The conclusion for Santo Domingo done for mercury is almost similar for the two others elements. With high emissions in sinks combined to low control, Santo Domingo has only 1 time out of 12 the lowest dilution factor and has 7 times the worst one. Bamako has 5 times the lowest necessary dilution factor and 3 times the highest, and Vienna respectively 6 times and 2 times.

In the end, the worst situation for the dilution of emissions is to be intermediary, in this case Santo Domingo, because emissions are already consequent and they are not enough controlled. In addition, the dilution factors are often ten times more important than the volume available. The dilutions in Bamako are not as important and easier to dilute. Nevertheless, by considering the environmental aspects and health problems that could derive from the releases, it is not the best situation. The only big problem for Vienna is the emissions of carbon in the air. The nitrogen in the aquifer is due to a small volume and the dilution factor is relatively low. In fact, for Vienna only 3 times out of 12 the dilution factor is higher than 100%.

In addition to these results, a graphical representation of the emissions per city and per element has been made and is available in Annex VI. It is interesting to see that for carbon, the main sink is the same for the three cities, the atmosphere, whereas for nitrogen and carbon, the repartition between the sinks depends on the waste treatment. Regarding nitrogen, the hydrosphere is the main sink for Santo Domingo and Bamako, but for Vienna, it is the output flow. In fact, with the treatment performed, the waste containing nitrogen is recycled but outside Vienna. Regarding mercury, Vienna, which treats its waste by incineration, releases mainly the element in the atmosphere, whereas in Santo Domingo and Bamako, the mercury follows the main flow of waste and ends up in the official landfill for Santo Domingo and in the lithosphere due to the illegal dumping for Bamako.

To conclude, the last research question was: In which city are the sinks demands the least impacting for the environment? Vienna seems to be the most appropriate city to dilute its emissions of carbon, nitrogen and mercury. After Vienna comes Bamako and then Santo Domingo.

8. Conclusion

The main idea behind the thesis was to verify if a correlation exists between the level of development of a city and the pressure exerted on the environment due to urban emissions. The precise goals were, first, to determine the emissions of carbon, nitrogen and mercury of three cities in the available sinks, then, to evaluate the necessary factor of dilution for each element and sink in each city, and finally, to compare the factors between cities.

All the goals have been successfully achieved and the main conclusion is that the emissions in a developed and environmentally advanced city like Vienna generally requires a smaller dilution than, first, a weakly developed city in Africa like Bamako, and than a developing city in the Caribbean like Santo Domingo.

Even if this estimation required a wide range of information and several calculations, the necessary dilution factor finally obtained allows determining simply for each element the pressure exerted by the city on the sink. Moreover, these factors can easily be compared between cities and represent a valuable source of information for policy makers who would try to have an estimation of the repartition of cities emissions on the atmosphere, hydrosphere and lithosphere.

Although necessary dilution factors, in the end, could be determined, the work performed in this thesis has strong limitations that need to be kept in mind. To start with, it is complex and time consuming to understand exactly how a city manages its water and waste flows and what its interaction is with its available sinks. This first step is however essential for the rest of the analysis. Then, it is challenging to find accurate information for the elements. In fact, with four sinks, at least 12 values per city need to be determined. When information cannot be found, realistic assumptions have to be taken and reasonable approximations to be made. The calculations are time consuming but do not represent the most challenging part of the work. Among these difficulties, the most challenging one is probably to get the exact data wanted. In fact, literature sources are rarely giving directly the values desired and in the case of cities in the developing world, there are often no direct incentives from local authorities to research on topics that are not directly impacting their local ecosystems or population.

In addition, it has to be reminded that the estimation performed in this thesis is highly approximated and that the main goal was to get a global overview on the situation. In fact, a precise and accurate research would require a much longer period and more reliable sources. The ideal research would be to visit the city analysed, to meet the local experts on water bodies, air pollution, waste management and soil pollution; and if still needed to perform measurements directly on site.

Therefore, this research can be performed on different levels of depth and accuracy. This depends mainly on the amount of information and the time available for the work. From this thesis, the necessary dilution factors obtained could not represent a reliable source for other scientific works. However, the methodology, the approximations or assumptions made, and some of the emissions calculated could be reused.

A possible continuation to this work would be to study another type of city for example in Asia, or to include another element in the analysis such as copper, or to analyse in a more accurate way the emissions of one element or one sink. Thus, there are several possibilities to complete the research performed in this thesis.

To conclude, the results of such study can be used to understand in more details how a city handles its solid and liquid waste. They could also help to determine where in the system and which type of actions could be taken in order to improve a situation. As, in 2008, the urban population reached 50% of the world population and is expected to reach 70% by 2030 (United Nations Population Fund (UNFPA), 2007), this type of work could be useful to assess in a new way the relative impact of cities on the world ecosystems.

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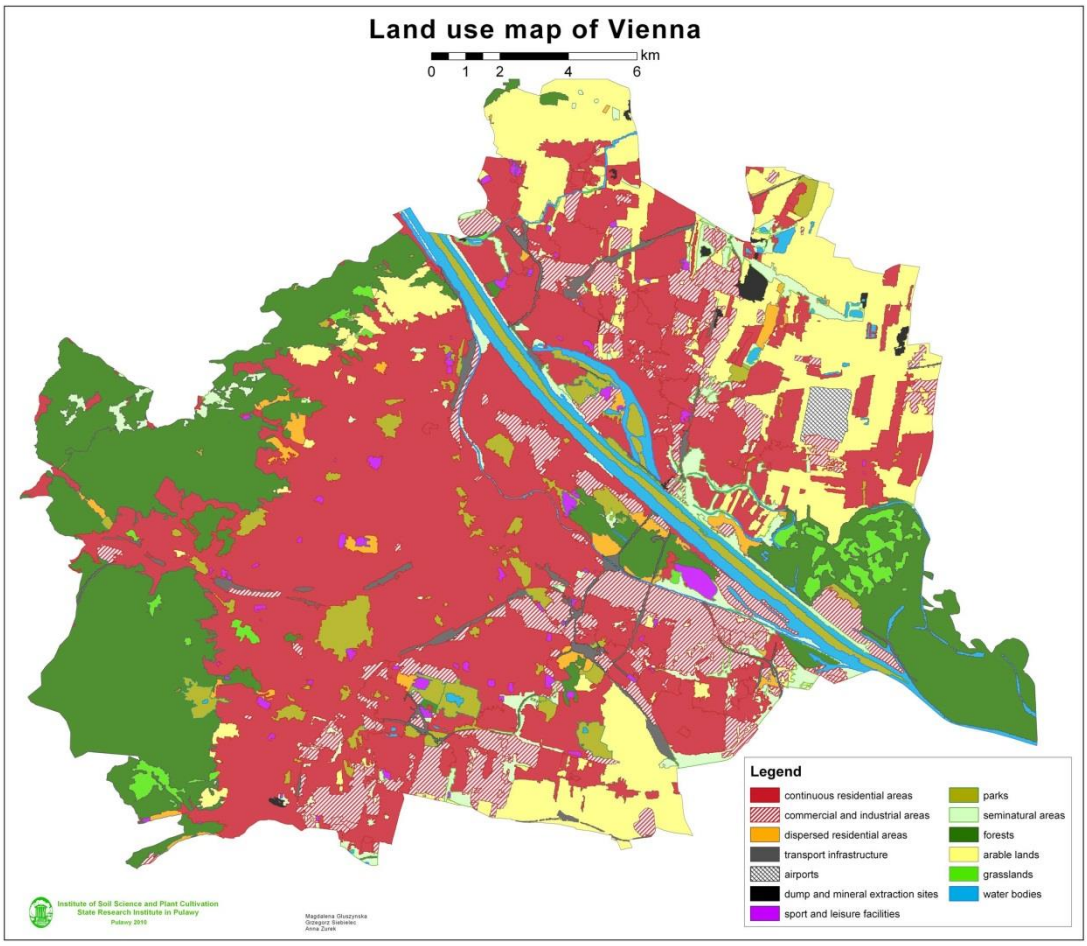
List of Figures and Tables

Annex

Annex I: Land use map of Vienna



(URBAN SMS, 2011)

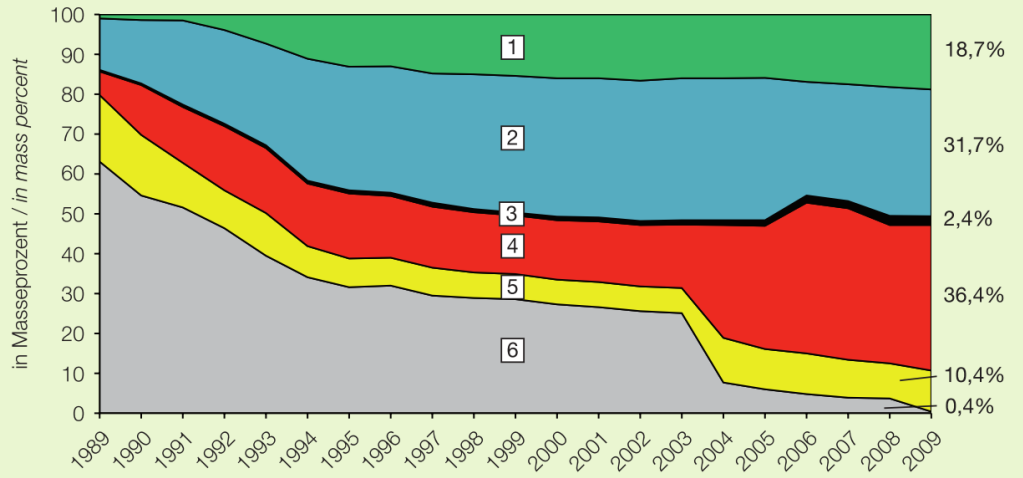
Annex II: Exported hazardous waste in 2009 in Austria

Exported hazardous waste in 2009 – Largest quantities		
Codes	**Waste designations in acc. with ÖNORM S 2100 in due consideration of the amendments to the List of Waste Ordinance (1 January 2007)**	**Exported hazardous waste in tonnes**
31223	dust, ash and dross from other smelting processes	58,577
31211	salt slag, containing aluminium	34,208
17207	railway sleepers	25,948
31309	fly ash and dust from waste incineration plants	16,209
57805	hazardous contaminated fractions and filter dust from shredder plants	11,003
31217	filter dust containing non-ferrous-metal	10,025
54102	waste oils	9,715
52725	other watery concentrates	6,510
94801	sludge from sewage treatment with hazardous constituents	3,954
31312	solid residues containing salt from flue gas cleaning of waste incineration plants and waste pyrolysis facilities	2,917
55224	solvent-and-water mixtures without halogenated solvents	2,477
55370	solvent-containing sludge without halogenated organic components, paint and varnish thinners (e.g. "diluents for cellulose lacquers"), also antifreeze	2,301
31466	glass, ceramic with production-specific additives	2,078
54701	sand filter contents containing oil or cold cleaning solvent	1,780
52103	acids, acid mixtures with application-specific additives (e.g., pickling, ion exchanging eluates)	1,723
54930	solid fuel contaminated with grease and oil (waste from workshops, industry and filling stations)	1,618
35322	lead accumulators	1,569
51112	other galvanic sludge	1,567
55374	solvent-and-water mixtures without halogenated solvents	1,342
31203	slag from non-ferrous metal smelting	1,298
94801 91	sludge from sewage treatment with hazardous contents	1,256
31633	glass grinding sludge with production-specific harmful additives	1,232
31217 91	filter dust containing non-ferrous-metal	1,103
35210	picture tubes (based on the cathode-ray tube principle)	1,031
	others exports of 58 hazardous waste types	13,058
	Exported hazardous waste	**214,499**

(Lebensministerium, 2011a: 86)

Annex III: Evolution of MSW management in Austria

Verwertung und Beseitigung von Abfällen aus Haushalten und ähnlichen Einrichungen, 1989 - 2009 / *Recovery and disposal of waste from households and similar establishments, 1989 - 2009*



Erste Behandlungswege / *first steps of treatment:*

Erste Behandlungswege / *first steps of treatment:*

1 Verwertung von biogenen Abfällen insbesondere aus der getrennten Sammlung und Grünabfällen
recovery of biogenic waste in particular from the separate collection and from green wastes

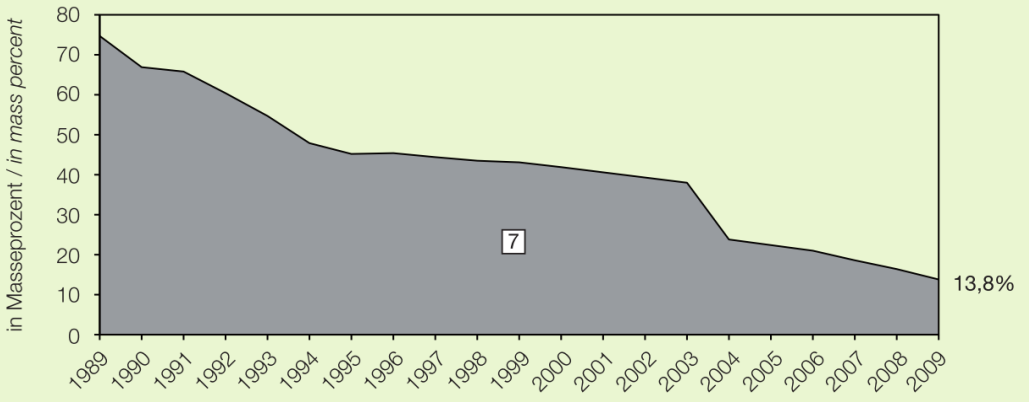
2 Verwertung von Altstoffen insbesondere aus der getrennten Sammlung
recovery of waste materials in particular from separate collection

3 Behandlung von Problemstoffen und von Elektro- und Elektronik-Altgeräten aus der getrennten Sammlung
treatment of hazardous household waste and of waste electrical and electronic equipment from separate collection

4 Thermische Behandlung (MVA und Mitverbrennung)
thermal treatment (waste incineration plant and co-incineration plant)

5 Biotechnische Behandlung in (M)BA / *biotechnical treatment in (mechanical)-biological treatment plant*

6 Ablagerung / *landfilling*



Letzter Behandlungsweg / *last step of treatment:*

7 Ablagerung sämtlicher Abfälle aus der Behandlung / deposition of all wastes from treatment

lebensministerium.at

Quelle: Umweltbundesamt, April 2011 / *Source: Environment Agency Austria, April 2011*

(Lebensministerium, 2012: 19)

Annex IV: Calculations of Necessary Dilution Factors

- **Calculation for the Atmosphere**

Height of the atmosphere in km	11

Vienna

Air	Area km²	Height km	Volume Air in km3			
	414,9	11,0	4 563,6			
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio
C	2 345,6	0,112	g/m3	0,102	230887,1423	50,59353582
N	6,5	580,80	g/m3	528,000	0,12222341	2,67824E-05
Hg in kg	86,3	1,87	in ng/m3	1,7	507470,5882	111,2003515

Santo Domingo

Air	Area km²	Height km	Volume Air in km3			
	421,0	11,0	4 631,0			
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio
C	1 170,0	0,112	g/m3	0,102	115168,8884	24,86911864
N	9,5	580,80	g/m3	528,000	0,179924132	3,88521E-05
Hg in kg	181,6	1,87	in ng/m3	1,7	1068411,765	230,7086514

Bamako

Air	Area km²	Height km	Volume Air in km3		Dilution Factor		
	267,0	11,0	2 937,0				
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio	
C	391,8	0,112	g/m3	0,102	38566,81238	13,13136274	
N	3,2	580,80	g/m3	528,000	0,060549205	2,0616E-05	
Hg in kg	66,5	1,87	in ng/m3	1,7	391176,4706	133,1891286	

in %	Vienna	Santo Domingo	Bamako	Ratio Max/Min	Ration Max/Mi
Carbon	5 059,354	2 486,912	1 313,136	3,853	2,034
Nitrogen	0,003	0,004	0,002	1,885	1,451
Mercury	11 120,035	23 070,865	13 318,913	2,075	1,732

Ratio target concentration/initial concentration in %	10

Vienna

River/Sea	Flow in m3/s	Second in Year	Volume Water in m3			
Danube	1 723	28 014 552	48 269 073 096			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	9 888,0	2,83	g/m3 or mg/l	2,57	38474,70817	0,797088191
N	3 958,2	2,28	g/m3 or mg/l	2,07	19121,73913	0,396148878
Hg in kg	21,5	0,08	mg/m3 or µg/l	0,07	3064,285714	0,063483417

Santo Domingo

River/Sea	Sea shore in km	Depth x length in km²	Volume Water in m3			
Danube	26	2	52 000 000 000			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	50 241,5	0,56	g/m3 or mg/l	0,509	987061,8861	18,98195935
N	10 936,0	18,70	g/m3 or mg/l	17	6432,941176	0,123710407
Hg in kg	375,6	0,01	mg/m3 or µg/l	0,005	751222	14,44657692

Bamako

River/Sea	Flow in m3/s	Second in Year	Volume Water in m3			
Danube	1 280	28 014 552	35 858 626 560			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	36 089,6	3,04	g/m3 or mg/l	2,76	130563,972	3,64107565
N	10 830,3	1,10	g/m3 or mg/l	1	108303	3,020277417
Hg in kg	5,5	0,11	mg/m3 or µg/l	0,1	550	0,015338011

in %	Vienna	Santo Domingo	Bamako	Ratio Max/Min	Ration Max/Mid
Carbon	79,71	1 898,20	364,11	23,814	5,213
Nitrogen	39,61	12,37	302,03	24,414	7,624
Mercury	6,35	1 444,66	1,53	941,881	227,565

Ratio target concentration/initial concentration in %	10

Vienna

Aquifer			Aquifer in m3			
Danube			100 000 000			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	66,0	1,35	g/m3 or mg/l	1,23	536,5853659	5,365853659
N	171,1	40,00	g/m3 or mg/l	20	8,555	0,08555
Hg in kg	0,0	0,08	mg/m3 or µg/l	0,07	3,714285714	0,037142857

Santo Domingo

Aquifer			Aquifer in m3			
Danube			1 464 000 000			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	3 213,9	1,35	g/m3 or mg/l	1,23	26128,86179	17,84758319
N	1 825,0	40,00	g/m3 or mg/l	20	91,25	0,062329235
Hg in kg	28,4	0,08	mg/m3 or µg/l	0,07	4057,142857	2,771272443

Bamako

Aquifer			Aquifer in m3			
Danube			645 500 000			
	Emissions in tonnes	Target Value	Units	Initial Concentration	Volume in hm3	Volume Ratio
C	425,2	1,35	g/m3 or mg/l	1,23	3456,829268	5,355273847
N	340,4	40,00	g/m3 or mg/l	20	17,018825	0,026365337
Hg in kg	8,2	0,08	mg/m3 or µg/l	0,07	1171,428571	1,814761536

in %	Vienna	Santo Domingo	Bamako	Ratio Max/Min	Ration Max/Mid
Carbon	536,59	1 784,76	535,53	3,333	3,326
Nitrogen	8,56	6,23	2,64	3,245	1,373
Mercury	3,71	277,13	181,48	74,611	1,527

Ratio target concentration/initial concentration in %	10

Depth of the ground in m	10	Average soil density in kg/m3	1802,077088

Vienna

Soil	Area km²	Depth km	Volume Soil in km3			
	414,9	0,010	4,1			
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio
C	0,3	13,09	g/kg	11,9	0,000123107	2,96737E-05
N	0,3	1,76	g/kg	1,6	0,001196536	0,000288412
Hg in kg	4,6	330,00	µg/kg	300	8,5087E-05	2,05093E-05

Santo Domingo

Soil	Area km²	Depth km	Volume Soil in km3			
	421,0	0,010	4,2			
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio
C	13,4	15,32	g/kg	13,925	0,005334124	0,001267013
N	1,9	7,71	g/kg	7,01	0,001493759	0,000354812
Hg in kg	541,0	127,60	µg/kg	116	0,025880098	0,006147292

Bamako

Soil	Area km²	Depth km	Volume Soil in km3			
	267,0	0,010	2,7			
	Emission in Gg	Target Value	Units	Initial Concentration	Volume in km3	Volume Ratio
C	8,1	10,08	g/kg	9,16	0,004914271	0,001840551
N	0,7	0,66	g/kg	0,6	0,006011582	0,002251529
Hg in kg	136,6	121,00	µg/kg	110	0,006891038	0,002580913

in %	Vienna	Santo Domingo	Bamako	Ratio Max/Min	Ration Max/Mi
Carbon	0,003	0,127	0,184	62,026	1,453
Nitrogen	0,029	0,035	0,225	7,807	6,346
Mercury	0,002	0,615	0,258	299,732	2,382

Ratio target concentration/initial concentration in %	10

Annex V: Calculations for the amount of carbon and nitrogen released in the lithosphere from MSW

Total MSW Generated	Total Recycled	Total Used on land
426227	89507,67	132130,37

MSW - Recycled
336719,33

MSW collected
218867,5645

Industrial Waste in tonnes
6432

MSW Non-collected
117851,7655

	Nitrogen	Carbon
MSW staying in Bamako (20% of C & N)	87547,0258	7065,957952
MSW sent outside (80% of C & N)	131320,5387	28263,83181

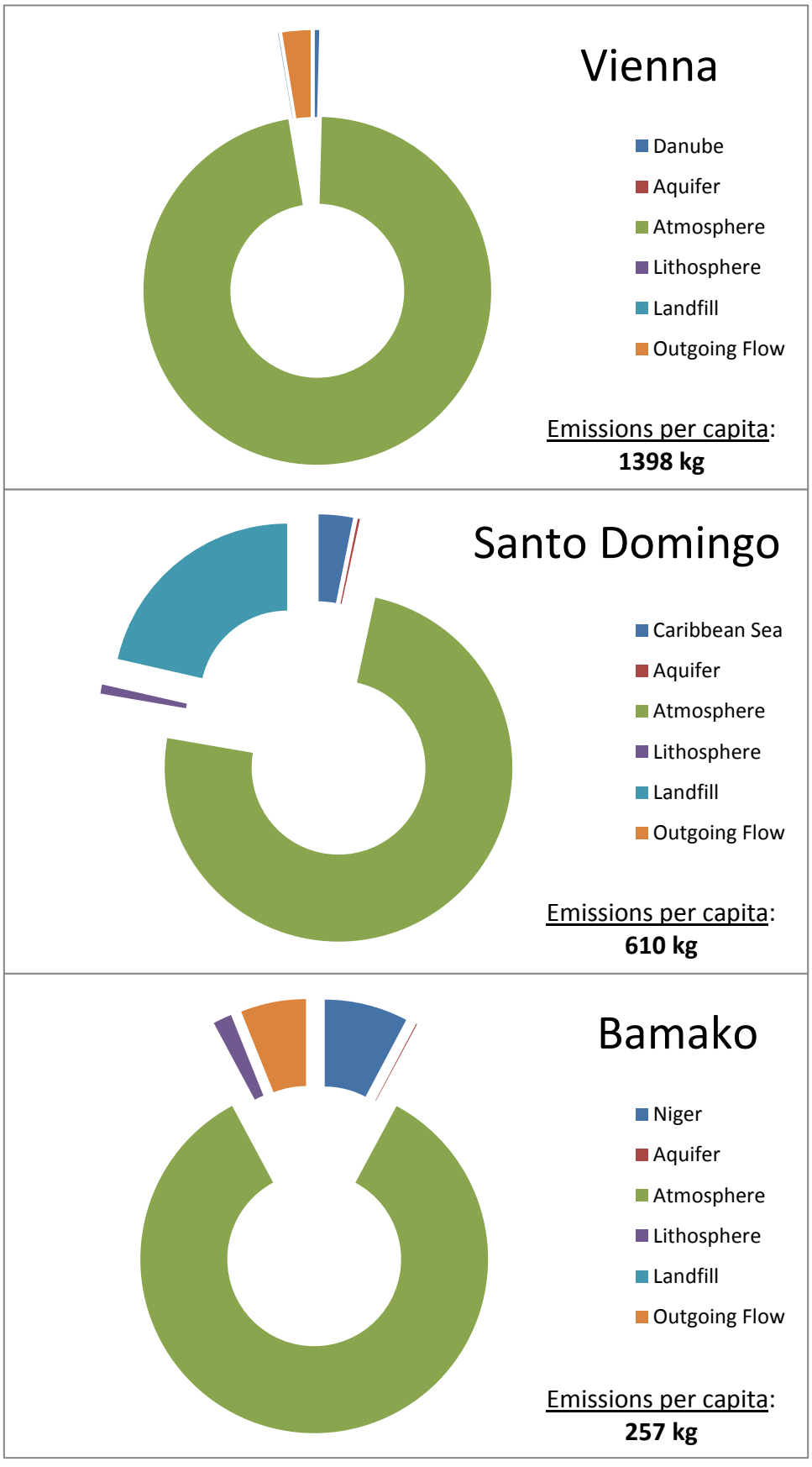
	Nitrogen	Carbon
MSW burnt	10488,8071	16,9311
MSW dumped	24984,5743	4033,0314
MSW garden	5421,1812	875,0917
MSW water	235,7035	38,0475
SUM to the lithosphere		4049,9625
	106,3877	

MSW Content	N Content	C Content
in g/t	4 240,3	161 420,9
in t/t	0,0042	0,1614

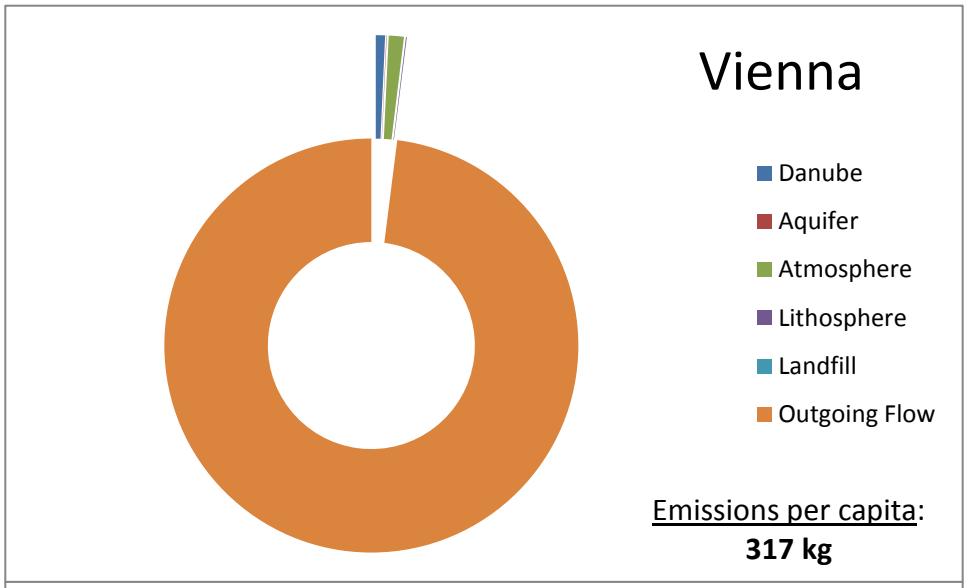
MSW illegally dumped in tonnes	Nitrogen	Carbon
SUM of collected and non-collected	292,00	11115,92
Industrial Waste	32,16	1038,26
SUM of waste	324,16	12154,18
Remain in Landfill %	0,8075	0,54
Remain in Landfill	261,76	6563,26
Leachates %	0,1875	0,003
Leachates	58,35	36,46
Leachate Ground	29,17	29,17
Leachate Groundwater	29,17	7,29
Gas emitted %	0,005	0,457
Gas emitted	1,62	5554,46
Amount remaining in the lithosphere	290,94	6592,43

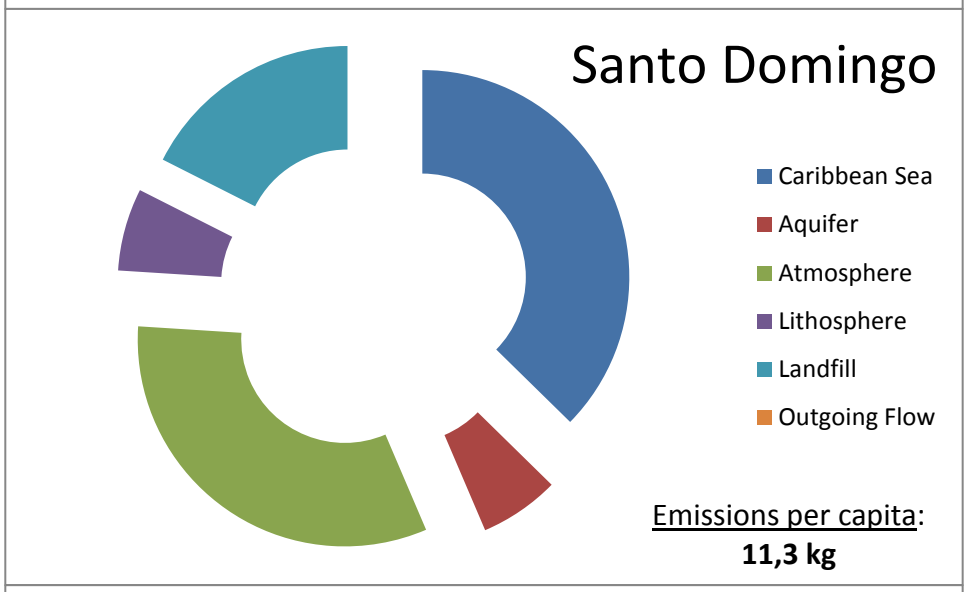
Annex VI: Emissions per element and per city

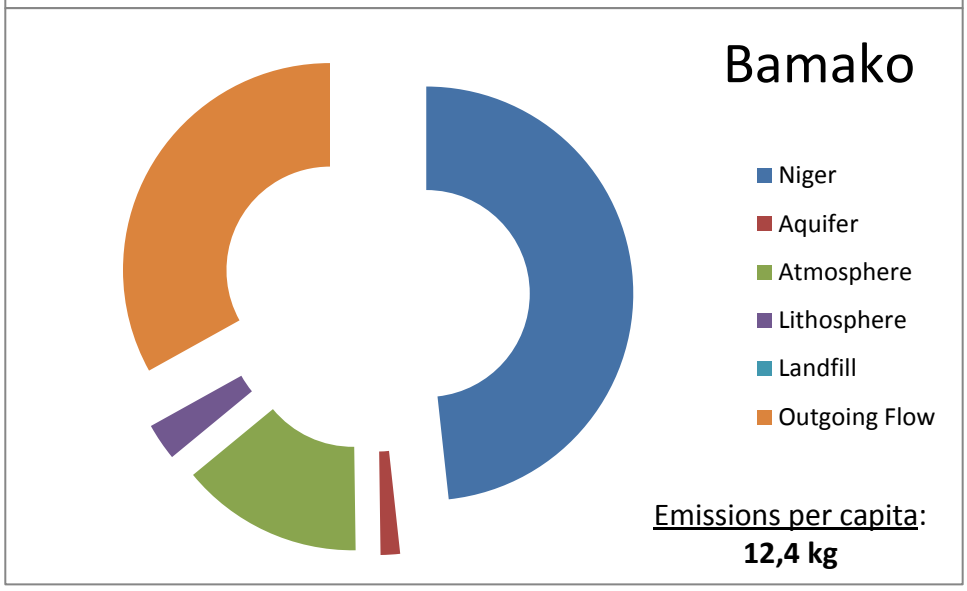
- **Carbon**



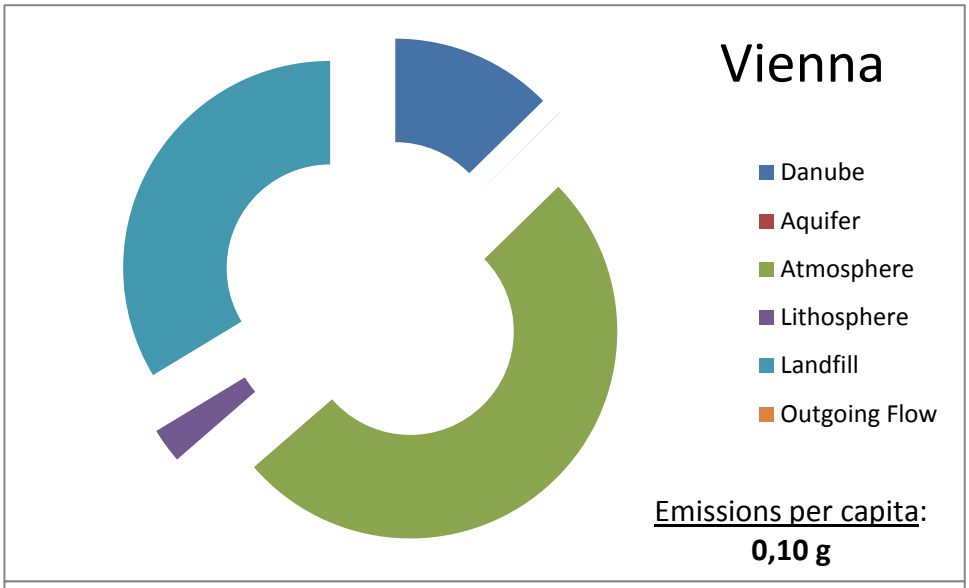
- **Nitrogen**

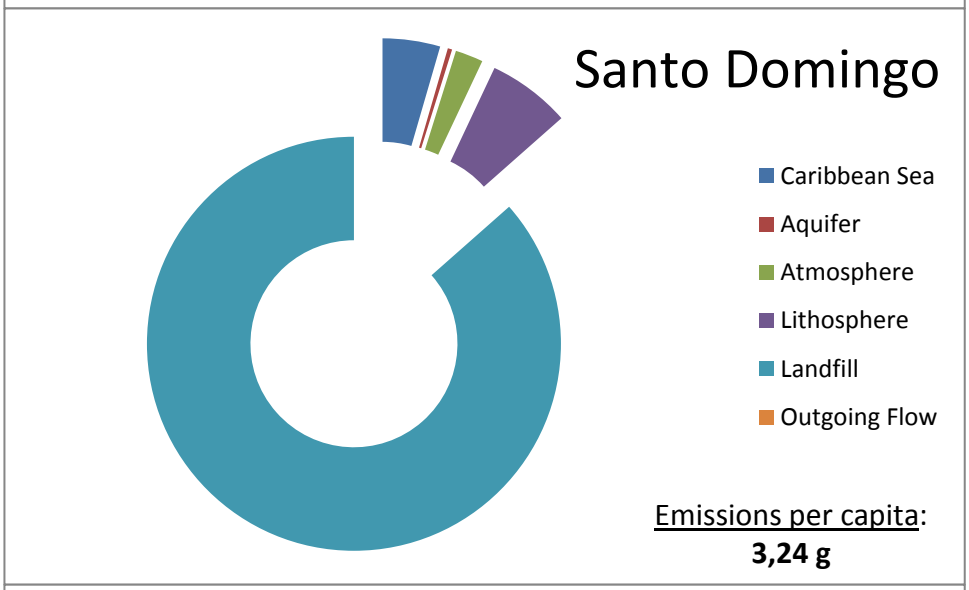

Vienna
Danube
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
317 kg

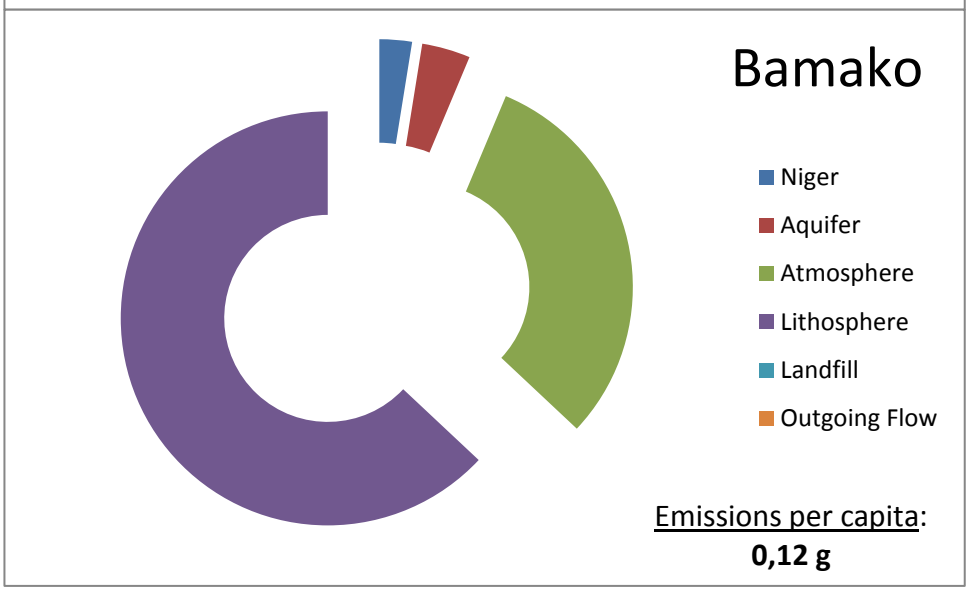

Santo Domingo
Caribbean Sea
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
11,3 kg


Bamako
Niger
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
12,4 kg

- **Mercury**


Vienna
Danube
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
0,10 g


Santo Domingo
Caribbean Sea
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
3,24 g


Bamako
Niger
Aquifer
Atmosphere
Lithosphere
Landfill
Outgoing Flow
Emissions per capita:
0,12 g