MSc Program
Environmental Technology & International Affairs

"Anthropogenic Resource Use: Cycles, Dissipation and Final Sinks"

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

supervised by
O.Univ.Prof. Dr. Paul H. Brunner

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Vienna, 09.06.2011

Affidavit

I, **JOACHIM GAMPER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ANTHROPOGENIC RESOURCE USE: CYCLES, DISSIPATION AND FINAL SINKS", 102 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:

This thesis explores the anthropogenic resource use of an average Viennese citizen on the base of air, water, construction materials, iron, copper and zinc. With the method "Material Flow Analysis" (MFA), which is the base for the Material accounting, the most important flows and processes, which determine the use of the mentioned resources, are explored in detail. The results are summarized in the system "Vienna" were the most important flows and stocks for the city of Vienna are highlighted. The relatively small amounts of dissipative losses are described and discussed separately.

The thesis comes to the conclusion that during one year each Viennese citizen uses nearly 140 tons of the six explored materials. Water together with air contributes to more than 90% of this amount. Among the flows of the other resources, the flows of construction materials are with distance the biggest ones. These and all the other main findings are illustrated in the conclusive table. The assessment of the energy use per Viennese citizen is not part of this thesis.

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1. Introduction

A lot of effort was made to determine the scarcity of resources. Less research has been done to explore the complete cycle resources undergo when used by humans. So far only few studies have been made in regard to the origins of resources, the use and the recycling of them and little is known about the dissipation and the final sinks of resources.

The exploration of the anthropogenic resource use, from the origins of the resources till the final sinks, is not only useful to understand where in the anthroposphere the resource are stocked, which the most important processes and flows are, but it can also be used to plan the anthropogenic resource use better.

The planning of the anthropogenic resource use will become more and more important as resources are scarce and their demand is growing. Especially is this true for the flows and processes in urban regions: Already today more people live in urban regions than in rural and this trend will hold on [Worldbank, 2011].

These high density regions have a big resource demand and huge stocks considering their superficies. This requires coordinating and planning the processes and flows in detail. As it will remain difficult to uncouple the demand completely from population growth, the planning will be even more essential in the future.

As the natural stocks of resources decrease by the anthropogenic resource use and the anthropogenic stocks increase, it will become more important to manage the stocks and flows thoughtfully. Therefore it is likely that the stocks in the cities will be used as sources for resources [Daxbeck et al., 2009], where the recycling and disposal of materials is crucial.

To be able to handle these challenges it is essential to understand well the cycles resources undergo during the anthropogenic use. Therefore, this thesis was made. Not with the aim to entirely solve the issues which arise from the anthropogenic resources use, but to show that it is possible to determine the most important flows and stocks of resources to, from and within a city.

For practical reasons, only a few materials have been considered: Fossil fuels are left out, mineral non-metal resources will not be considered individually but summed up as construction materials and only iron, copper and zinc are considered out of the metal group. The two biggest anthropogenic flows [Brunner et al. 1996], water and air, are explored as well in this thesis.

For each of this materials an own is system defined and explored These systems are finally put together into the system “Vienna”, which illustrates the most important flows and process of the mentioned materials for the city of Vienna. The method *Material Flow* Analysis was used to build these systems, which have a temporal border of one year.

The results and observations are explained and illustrated, as well are some findings discussed more in detail. The desired conclusion of this thesis is to illustrate a complete and comprehensive quantitative table which shows the three goods and the three substances on the vertical axis and the flows and stocks (imports, exports, use, origins, stock, delta stock, recycle and the final sinks) on the horizontal axis.

2. Objectives and research questions

The object of this thesis is to determine the evolvement of the material budget of the city of Vienna during one year. This includes quantifying and determining the origins and the imports of the mentioned substances, showing their flows, stocks and processes in an illustrative city (Vienna). Furthermore this thesis will try to detect the dissipation and the final sinks of these substances.

The following questions should be answered:

- Is it possible to determine the evolvement of the material budget of the six chosen materials for the city of Vienna?
- Which ones are the most important flows and stocks of these materials?
- Can the six materials be presented in one system?
- Is it possible to determine how much materials a Viennese citizen uses in one year and can the results be shown in one comprehensive table?
- Which data is available, which assumptions need to be made?
- How strong influence the assumptions the general results?
- (Can this thesis have practical value?)

3. State of the Art

The methodology and structure of this Thesis is based on the *Project Pilot “Der anthropogene Stoffhaushalt der Stadt Wien”* from the IWA institute of the Technical University of Vienna [Bunner et al., 1996], which, in turn, used the methodology to describe systems of the study *“Die Stoffanalyse”* [Baccini & Brunner, 1991].

The *Project Pilot* was a first step towards the objective of the quantification and control of the material budget of the city of Vienna. On the basis of three substances -Carbon, Nitrogen and Lead- the applicability and the worthiness of this method, the so called “material flow analysis”, for the system “Vienna” was shown [Brunner et. al. 1996]. This study built a complete material budget for Carbon, Nitrogen and Lead [Brunner et. al. 1996]. It identified the most important processes and flows and indicated all sources [Brunner et. al. 1996]. Furthermore gave it practical perspectives of how to take efficient measures to keep the material flow equilibrate and environmental compatible [Brunner et. al. 1996]. The study showed that it is possible to determine the material budget of an urban metabolism via materials accounting and the method of Material Flow Analysis (MFA) [Brunner et. al. 1996]. The MFA is today an important tool of industrial ecology [Erkman et al., 2000].

With the help of this methodology used in the *Project Pilot* and the input of actual data it should be possible to quantify the flows and to identify the most important processes which determine the anthropogenic resource use of a Viennese citizen during one year. The final system and most other systems under investigation have the same system border as the system in the *Project Pilot,* corresponding to the political border of the city of Vienna and to one year. Some systems though, when not enough data for Vienna was found, have the system border of Austria,

Although the spatial frame is the same, the border of Vienna did not change, and the temporal dimension has the same size, the base year of most data sources is not anymore 1991 as in the *Project Pilot,* but 2009. This is the year from which today the latest dataset from *Statistics Austria* is available. *Statistics Austria* is a supplier of statistical data with great experience in gathering and processing statistical information of all areas within Austria. Political, social, economic and environmental data are published at least yearly and are attributed to the Federal States of Austria.

The *yearbook 2011* contains the data of the year 2009. Further literature which was used to compile this thesis has, where and when it was possible, has as well data from 2009. If this was not the case, the closest accessible data was used and compared with other data from the same year. However, are the stocks extrapolated to the year 2011 and the flows where assumed to be valid as well for that year (See assumptions in detail in chapter 4.2.2). Thus leads to the graphs with the base year 2011 although the data sources are from different years.

As not all information are available for the Federal State of Vienna, some data refers to Austria or Austrians as all amounts are divided by the respectively population they are referring to. In these cases it was assumed that an average Austrian is equal to an average Viennese and therefore they are interchangeable. The author is aware that these data may divergence from correct data, but it was necessary determine the anthropogenic resources use of all six materials. It is stated which data is derived and the methods of how these data was derived or assumed is shown in chapter 4.

A second point which differs the systems of this thesis from the systems of the *Project Pilot* is the way to illustrate the flows and stocks of Vienna. The units do not refer to the whole population of Vienna but to each individual citizen of Vienna. Only in the calculations, chapter 3, the amounts for the whole city of Vienna or Austria are sometimes given.

For certain flows, as for example direct exports of fresh water this unit may not be the best suitable, nevertheless it gives an idea of how big this amounts are in relation to other flows. The only problem which stays, is that the units refer to an average Viennese citizen which does not exists – but this is the problem is common all statistical data at individual level.

The aim of breaking down the units of the population of Vienna by its citizen is an expected better understanding of the anthropogenic resource use by individuals. For most individuals it is hard to imagine quantities which are in the range of 10^{*6} or bigger. This leads to two problems when illustrating a MFA of a city like Vienna. The population of Vienna is about 1.714.000 today (first quarter 2011) [Statistics Austria], 1.693.000 in 2009 [Statistics Austria], and flows and stocks for the whole city exceed often numbers with ten-digits. By breaking the amounts for the whole city of Vienna by its citizen (1.693*10*[6]), for example, the iron stock in Vienna goes down from 554.513.280 tons in Vienna to about 323 tons per Viennese citizen, which is equal to the iron content of about 400 midsize cars[1]. The units at individual basis are easier comparable to another city, to another base year or to both.

Table 3.: Comparison Vienna vs. Austria

Vienna versus Austria	**Vienna**	**% of Austria**	**Austria**
Area of Vienna in ha[1]	41.650	0,5	8.387.899
Settlement are in ha[1]	33.352	1	3.243.953
Households[1]	771.706	23	3.342.347
Population 2009[1]	1.693.000	20	8.363.000
Population 1991[1]	1.513.000	19,5	7.755.000
Density (c/ha)[1]	40,8		1
Rainfall (l/m2)[1]	900		863 - 2052
Delivered water (without losses) (t/c*a) [1]	71.54		17,9 - 137.6
Carbon emission (t/c*a)[2]	5,2		10,6

[1][Statistics Austria, 2011]
[2][Bednar, 2010]

[1] Up to 70% of a car is iron or steel [Klaffl et al., 2011]

The reason to choose Vienna as investigation object can be summarized into the following four points:

- **The Available Dataset**: Being aware of the accuracy of different former studies of Vienna, which is an important information base, it was assumed that for the city of Vienna valid and recent data is available.
- **Previous studies**: The institute “IWA” of the Technical University of Vienna accomplished already different studies of the urban metabolism of Vienna using MFA’s.
- **Local proximity**: As it was clear that no data would have been measured by the author, is the local proximity to the sources of the data and the information of advantage.
- **Personal interest:** The gain of information about the own consume of resources and “where they and up” as well as to see whether it would be possible to accomplish a complete MFA for a citizen of Vienna, have driven the author to choose this topic.

Extra emphasis was put on quantifying, where possible, the dissipation of resources. The quantification of the dissipation, which compared to other flows are relatively small, nearly negligible, is one aim of this thesis and without those flows, it would not be correctly possible to define the sinks and subsequently the final sinks of materials, which is another aim of this thesis.

In accordance with o. Prof. Dr. Paul H. Brunner, three goods and three substances were chosen to represent anthropogenic flows of the city of Vienna. These are air, which accounts for about 18% of all flows, water, which accounts for about 75% of all flows, construction materials, which account for about 5% of all flows, iron, zinc and copper which account together to about one percent of all flows (see results). Energy flows and consumption were not an aim of this thesis although the carbon flows per capita was used to calculate the air need.

4. Methods:

To reach the objective of this thesis, the determination of the evolvement of the material budget of the city of Vienna during one year, a material accounting has to be done. *"The Material accounting is a recurring and cost-efficient way of measuring the amount of all important good and substance flows within a (well defined) system, presuming that by measuring only a few key flows & stocks we know all substance flows in the whole system."* [Brunner, 2010b]

"The base for material accounting is a Material Flow Analysis (MFA), which serves in understanding the system of study and in identifying the appropriate parameters" [Brunner, 2010b]. This method is designed to describe and analyse a metabolic system. A system is characterized by the area of the metabolism (system border), in- and outputs (flows) from the metabolism and processes and flows within the metabolism. The Material flow analysis is a systematic assessment of the flows and stocks of materials within an arbitrary system, defined in space and time. It is based on the principle of mass conservation (Input= Output ~ stock changes).

Although it is kept as simple as possible it is a valid and important tool for decision making [Brunner, 2010b]. The STAN (substance flow analysis) software allows performing MFA systems with the support of a graphic model (flow chart). The graphic illustrations are easily comprehensive and present the whole system with its processes and flows in a clear way [STAN manual].

For the systems explored in this thesis the temporal border is one year (2011, the data input was assumed to be valid for that year or it was extrapolated to that year) and the spatial system border is equal to the political border of the city of Vienna or to the state of Austria. Generally, with some exemptions (rain, rivers and the water cycle which refills the aquifer), only the anthropogenic flows where considered. For each of the six materials a separate assessment was made to have correct systems which guarantee the differentiation of these resource cycles. The results for each of these systems are shown in chapter 5. To define the material budget and its evolvement different processes and flows were defined for each system (chapter 4.1.). The amounts were retrieved and calculated were possible. For some flows it was necessary to take assumptions. The author is aware that taking assumptions could bring along misleading data, but it was done conscientious, with a conservative approach and it is always clearly stated what was assumed.

The exact way of how the results were put together is shown for each process and flow in chapter 4.2. All results refer to weight per capita and year. One further system was put into place which summarizes all other systems in one. This system is defined and elaborated on the basis of the information of the other systems which explore the six materials. The results are further discussed and summarized in chapter 6 and illustrated in one table in chapter 7.

The Information retrieval was mainly based on internet research of academic papers, studies and official reports. The research of books and studies in the TU library was as well productive. Further information was gained with telephone interviews with employees of different departments of the MA (Municipal Department) of Vienna and the Viennese water treatment plant EBS.

Main sources

The main sources apart of Statistics Austria (Statistical yearbook 2011), was the report „Klimaschutzbericht 2010“from the Austrian Environment Ministry [Schneider et al. 2010], the report “Bundes- Abfallwirtschaftsplan 2011 Entwurf” [Klaffl et al., 2011] the report „Steel Statistical Yearbook 2009“ [Worldsteel Committee on Economic Studies, 2010], the article *“Urban mining: Die Stadt – das Bergwerk der Zukunf*” ([Daxbecket al., 2009], the study “*Machtbarkeitsstudie Nationale Stoffbuchhaltung; Testbeispiel Zink* ” [Brunner et al., 1998] and the report “*Die volkswirtschaftliche Bedeutung mineralischer Rohstoffe in Österreich”* from Forum Rohstoffe, [responsible, Hennrich, 2007].

4.1. System descriptions:

Each of the six materials is explored in an own system, which is characterized by different processes and flows. Generally, these processes and flows can be grouped into three different types of processes, the supply, use and treatment processes. Each process of a system depends on different input flows, output flows, stocks as well as stock deltas.

The spatial system boarders, depending on the data sources of the explored material, are either Vienna or Austria. The temporal system boarder is for all systems one year, which should represent the year 2011, as:

- the stocks are extrapolated to the year 2011 (01.January).
- most data sources for the flows are coming from the year 2009 and 2008, which are recent years with similar economic activity. This is due to the economic downturn, which hindered the growth of the economy and the levels of 2008 will be reached again only this year, (e.g. construction materials, steel production [Worldsteel Committee on Economic Studies, 2010]).
- the two resources which amount together to more than 90% of the anthropogenic resource flows of the explored resources are not expected to change at individual level as long as the behaviour of individuals does not change (significantly)[2]. The amount of treated sewage though, may be different as it depends on the amount of yearly rain; with direct repercussions on the water release of the wwtp.

The last sub-chapter describes the system Vienna where all other six systems are summarized in one. The structures of the systems are described in the following sub-chapters.

[2] New technology can reduce the use of resource use as well, but none significant were put in place the last years

4.1.1. System “Air”

This system has the system boarder equal to the political border of the city of Vienna with the overlying atmosphere with an altitude of 11km above sea level and the year 2011. Three processes for the system “air” were considered. These are:

- **The Atmosphere:**

The process “Atmosphere” has air imports and offgas exports. It provides the process “Human activities” and the process “Combustion of fuels” with fresh air and takes up the used air. Furthermore it provides the process “Ventilation” with air and takes the discharged air up again. The atmosphere has a huge stock which does not change.

- **The human activities:**

Two sub-processes were considered for the process “Human activities”. The first one is the human respiration where the oxygen of the air is used to oxides the carbon. The air is provided by the atmosphere, the carbon is imported via food. The second sub-process consists of the import of water which is evapotranspirated and therefore transferred to the atmosphere.

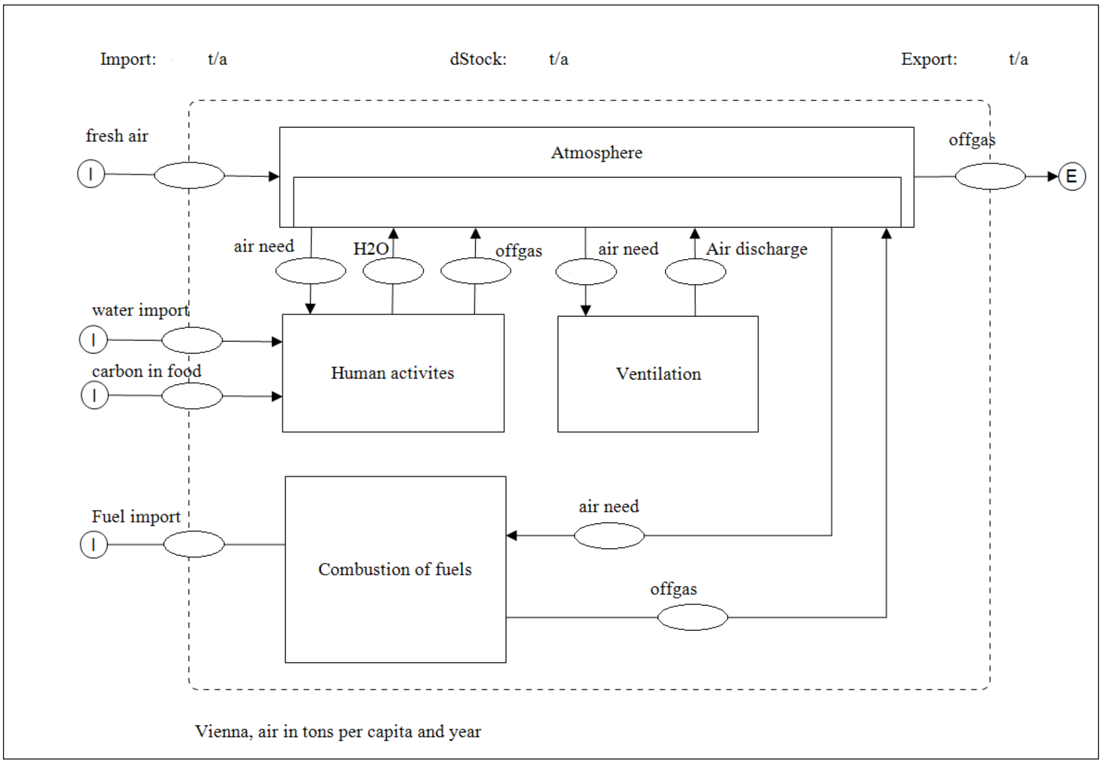
- **Combustion of fuels:**

The process “Combustion of fuels” includes nearly all anthropogenic combustion activities which release gasses into the atmosphere. The input is fuel and air, the output consists of the input air and substances coming from the fuel. The fuel consists mainly of carbon but also small amounts of nitrogen, sulphur and particulate matter.

- **Ventilation:**

The process “Ventilation” consists of the air which is used for the ventilation of working places. The ventilation of working places is done to dilute the carbon dioxide content in the air. The inflow amount of air and the outflow is equal as it was assumed that this air is not used for oxidation processes. Therefore, this process consists only of a circulation of air. The amount of air which is used for oxidation is considered in the other two processes.

Graph 4.1.1.: Layout of the system "Air"



4.1.2. System "Water"

The system "Water" consists of three different types of processes, the water supply, the use and the treatment processes. The first type includes the "Public water supply" process and the "Groundwater" process. The second type includes the processes "Domestic use" and "Industrial use". The water treatment processes consist of the "Sewer system" process, the "Waste water treatment" process. In the following paragraphs each process is described. The System boundary is the political borders of Vienna and one year.

- Water supply processes:

The water supply processes include the import and the extraction of water as well as the supply of fresh, use and process water for private households, for the industry, for the community and for some neighbouring communities. Public as well as private water supply is considered.

The "**Public water supply"** process has water inflows from the two spring pipelines, which bring the water from Styria and Lower Austria to Vienna, and from the aquifers Lobau and Moosbrunn. This water amount covers the domestic and industrial water use, as well as direct exports, own consumption and losses.

The "**Groundwater"** process supplies the "Public water supply" process and the "Industry" process with water. It consists of its aquifer stock and gets recharged by natural water flows (imports) and the losses of the "Public water supply" process.

- Water consumption processes:

The consumption processes include the use of water in nearly all processes which take place in the household and the industry. It consists of the import of water from the public and private water supply services and the discharge of used water into the sewer system or the atmosphere.

In the **"Domestic use"** process water is supplied by the "Public water supply" process and the used one is either running of in the sewer system or evapotranspirated (plants watering, cooking, human being). The own supply with groundwater for private households is not considered in this thesis because no deep wells for households are officially in use [Statistics Austria, 2011]

The “**Industry use”** process is either supplied with water by the public water supply process or it gets the water from its own deep wells. The only output is the sewage.

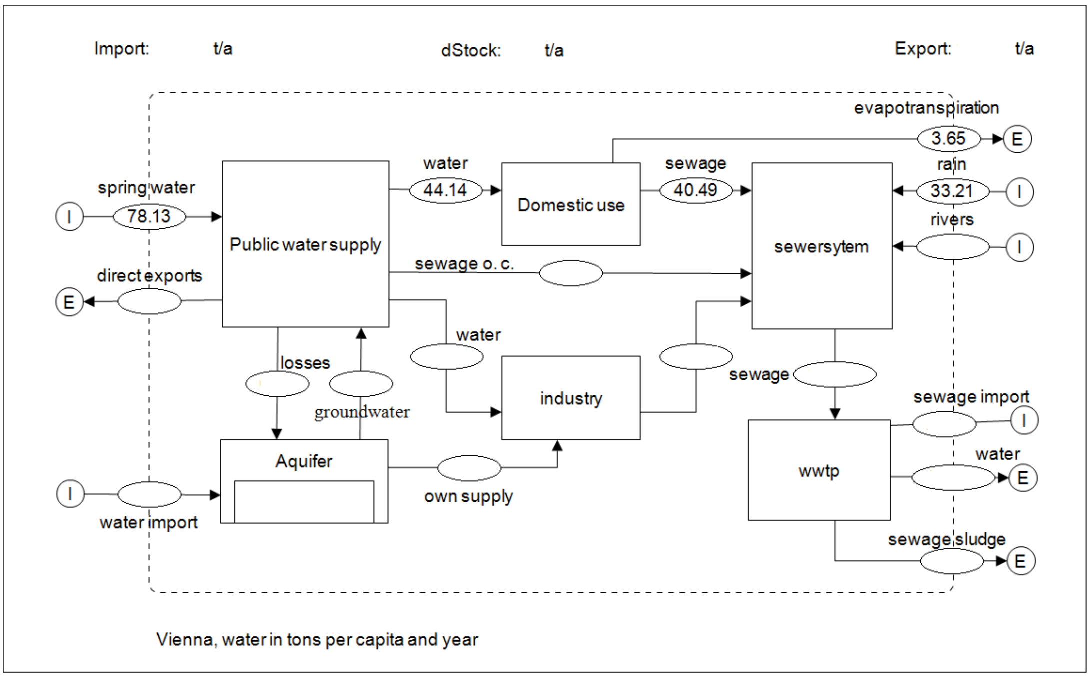
- Water treatment processes:

The water treatment processes include the collection of all sewages from households, the industry and from the public water supply process as well of the water intake from rain, rivers and some neighbouring communities, and the further transfer of the collected miscellaneous waters to the waste water treatment plant where the water is cleaned and released to the river and the sewage sludge is sent to the waste incineration plant.

The **“Sewer system”** process collects the sewage from households and the industry and as well as water from some rivers and rainwater. The only outflow of this process is the sewage which is transported to the only waste water treatment plant of Vienna located in Simmering.

The “**Waste water treatment plant”** process gets the sewage from the sewer system and from imports. The cleaned water is discharged into the canal which merges with the Danube. The sewage sludge is transported to the waste incineration plant which lies outside of this system.

Graph 4.1.2.: Layout of the system ”Water”



4.1.3. System “Construction materials”

The system “Construction materials” consists of five processes. These are the “Hinterland” process, the “Consumption” process, the “Waste management” process, the “Recycling” process and the “Landfill” process. The system boundary is equal to the boarder of Austria and to one year.

The “**Hinterland”** process consists of the stock and the out-flowing construction materials which determine alone the stock delta.

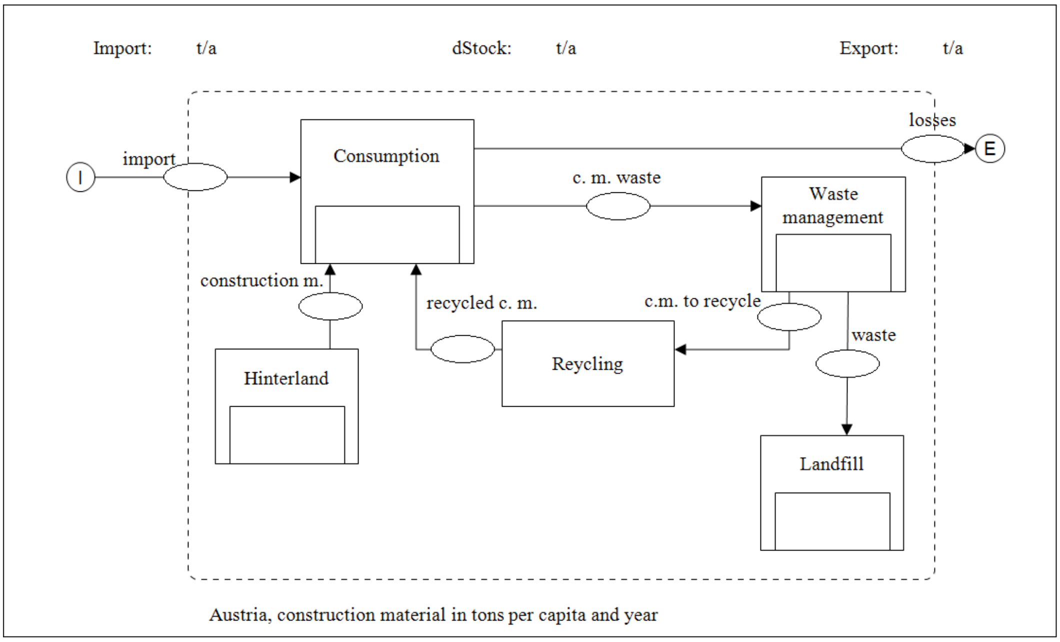
The **“Consumption”** process depends on the construction materials coming from the “Hinterland” process or from imports, the recycled construction materials, the used construction materials which are collected by the “Waste management” process and the losses. All this flows together determine the stock delta. This process is representative for all production and consumption sub-processes.

The **“Waste management”** process has its only inflow from the consumption process in form of used construction materials. Within this process the used construction materials are divided into recyclable construction materials, waste which will be landfilled and construction materials which will be stored before reused.

The **“Recycling”** process has its only inflow coming from the waste management process in form of recyclable construction materials; it recycles them and sends them as recycled construction materials to the consumption process.

The **“Landfill”** process has only one flow, the waste inflow. It alone determines the stock delta of the landfill process.

Graph 4.1.3.: Layout of the system "Construction materials"



4.1.4. System “Iron”

The system “Iron” consists of three different types of processes, the production, the consumption and the waste processes. The first type includes the “Iron mine” process, the “Pig iron” process, the “Production of steel” process and the “Production of goods” process. The second type includes the process “Consumption”. The waste processes consist of the “Waste management” process and the “Landfill” process. The System boundary is the border of Austria. The stocks were extrapolated to the year 2011 (01.January), the data source for the flows are from the year 2008, which was the last year before the economic downturn had its repercussions on the steel sector. The reason why the 1 day of 2011 was chosen for the stocks was the purpose to keep the data as actual as possible. Flows for 2011 are expected to be similar to the flows before the economic downturn. In the following paragraphs each process for the system iron is described.

- The production processes:

The production processes considers all processes which are needed to produce steel products from iron ore. For practical reasons other materials than iron, which are needed in these processes (e.g. coke) are not considered.

The **“Iron mine”** process consists of the only Austrian mining processes, the Erzberg in Styria. Material which is removed by the excavation of iron ore is not considered.

The **“Pig iron”** process consists of the inflow of iron ore from abroad and from the process “Iron mine” and the outflows of pig iron towards the “Production of steel” process, the export of pig iron and slag, which is produced by this process. Other materials, than iron ore which are necessary for the production of pig iron, are not considered.

The **“Production of steel”** process consists of the inflow of pig iron from the “Pig iron” process and from abroad as well as the inflow of scrap iron from abroad and from the “Waste management” process. The outflows are the produced crude steel and the carbon losses of this process. Other materials necessary for the production of crude steel are not considered.

The **“Production of goods”** process consists of the inflow of crude steel from the “Production of steel process” and the import of semi finished and finished steel products. The outflows are the export of semi finished and finished steel products, steel products for the “Consumption” process and steel waste which is transferred to the “Waste management” process.

- The consumption process:

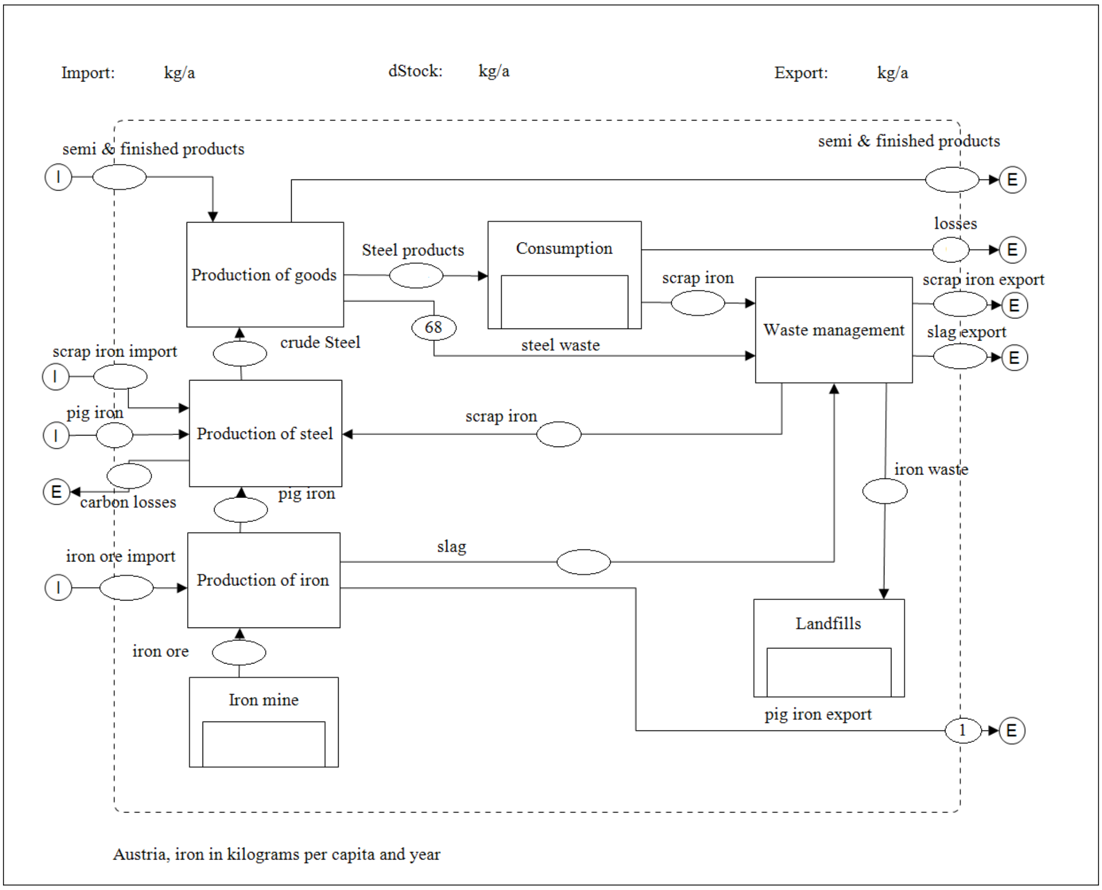
The **“Consumption”** process depends on the inflow of steel products, the outflow of scrap iron, the stock and the stock delta of steel as well as the losses.

- The waste processes:

The **“Waste management”** process consists of the inflow of scrap iron from the “Consumption” process, the inflow of waste steel from the “Production of goods” process and the inflow of slag from the “Pig iron” process. The outflows are recycled scrap iron, scrap iron exports, iron waste and slag exports. Slag is normally not exported outside of Austria, but it is assumed to be free of iron and therefore not relevant for this system. This process includes also the recycling of scrap iron.

The **“Landfill”** process consists of the inflow of iron waste and its stock and stock delta of iron.

Graph 4.1.4.: Layout of the system "Iron"



4.1.5. System “Copper”

The system Copper consists of four processes. These are the “Consumption” process, the “Waste management” process, the “Recycling” process and the “Landfill” process. The system boundary is the boarder of Austria and one year.

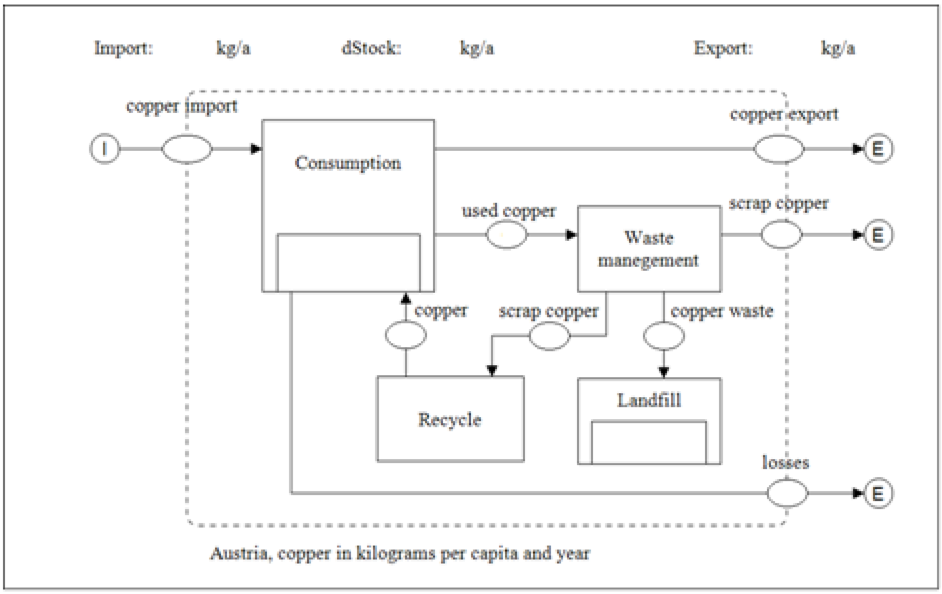
The “**Consumption”** process depends on the import and export of copper (products) the used copper collected by the waste management process, the losses and the stock delta. This process is representative for all production and consumption sub-processes.

The **“Waste management”** process has its only inflow from the consumption process in form of used copper (products). Within this process the used copper is divided into scrap copper exports, scrap copper for recycling and copper waste which will be landfilled

The **“Recycling”** process consists of scrap copper coming from the waste management. It is recycled and sent as copper to the “Consumption” process.

The **“Landfill”** process has only one flow, the copper waste inflow. It alone determines the stock delta of the landfill process.

Graph 4.1.5.: Layout of the system "Copper"



4.1.6. System "Zinc"

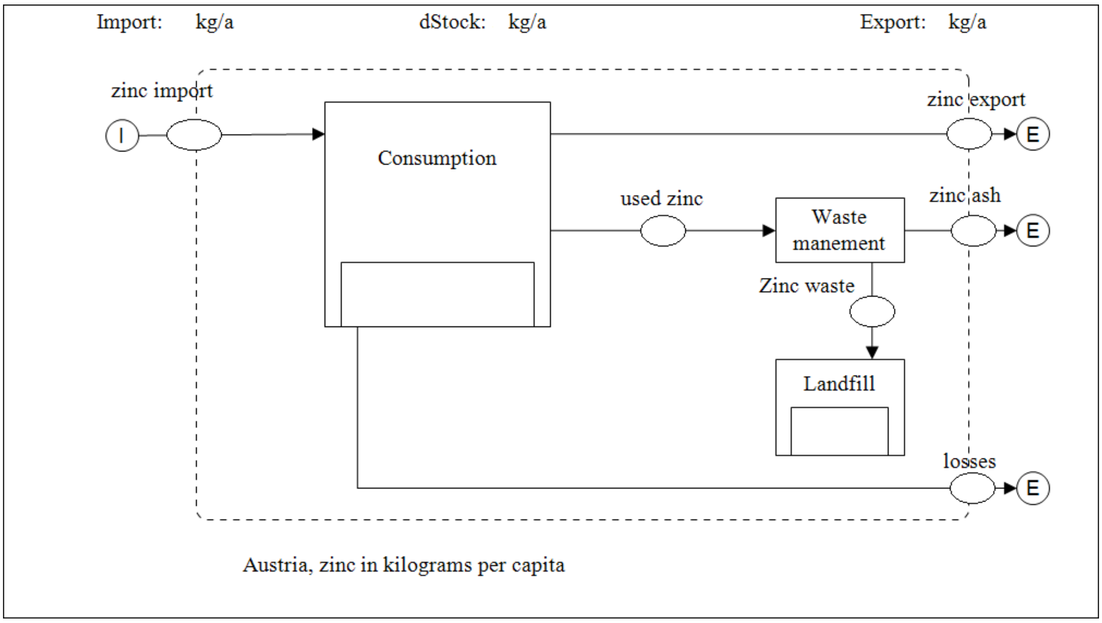
The system Zinc consists of three processes. These are the "Consumption" process, the "Waste management" process and the "Landfill" process. The system boundary is the boarder of Austria and one year.

The **"Consumption"** process depends on the import and export of zinc (products) the used zinc outflow collected by the "Waste management" process, the losses and the stock delta. This process is representative for all production and consumption sub-processes.

The **"Waste management"** process has its only inflow from the consumption processes in form of used zinc (products). Within this process the used zinc is divided into zinc ash which will be exported and zinc waste which will be landfilled.

The **"Landfill"** process has only one flow, the zinc waste inflow. It alone determines the stock delta of the "Landfill" process.

Graph 4.1.6.: Layout of the system ”Zinc”



4.1.7. System "Vienna"

The system "Vienna" summarizes the six systems defined in the last six subchapters. It is ment to give an overlook of how much resources a Viennese citizen consumes and stocks during a year. It gives also an idea of how big the total anthropogenic stocks per capita are. The considered materials of this system are the one explored in the six previous systems. The system is based as well on use per capita and its boarder is equal to the political boarder of Vienna. The temporal border is assumed to be the year 2011. The data for the system is coming from recent years with a similar economic activity and therefore are the flows assumed to be applicable for the year 2011. The stocks are extrapolated to that year.

The system considers only processes which take place within the borders of Vienna and it is solely explores what a Viennese citizen is consuming. Therefore is the export of goods excluded, which is resulting in smaller imports. However exports of waste are still considered as they are by-products of the processes of this system. A certain amount of this waste is caused by the exports, this is although neglected.

The system consists of four processes, the "Atmosphere" process, the "Supply" process, the "Use" process and the "Treatment" process. All processes of the previous systems, which fulfil the above mentioned definitions, are summed up in these four processes. The same is done for the flows of the same materials. These flows are subsequently as well grouped into broader flows. The four processes are described as followed:

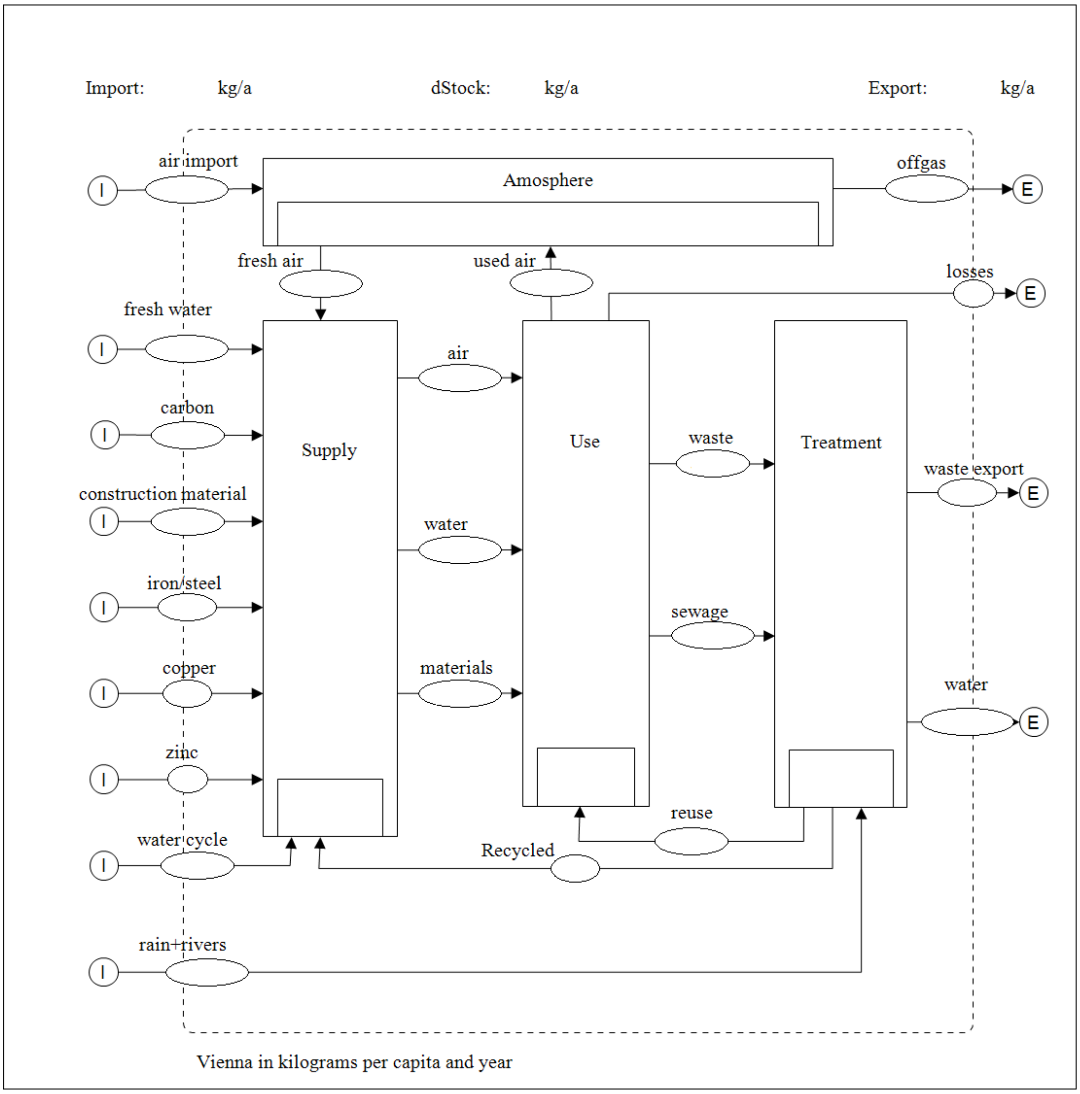
The **"Atmosphere"** process depends on the air import, the offgas export as well as the fresh air delivered to the "Supply" process and the used air inflow comming from the "Use" process.

The **"Supply"** process has imports of fresh water, carbon (in fuels and food), construction materials, iron/steel, copper, zinc and water provided by the natural water cycle. The other inflows are the fresh air from the "Atmosphere" process and the recycled material flow coming from the "Treatment" process. The outflows consist of the air, water and goods provided to the use process.

The **"Use"** process has inflows of air, water and goods coming from the "Supply" process as well as the reuse flow coming from the treatment process. The outflows are the used air sent to the "Atmosphere" process and the waste and sewage sent to the "Treatment" process as well as the losses which leave the system.

The "**Treatment"** process gets waste and sewage from the "Use" process. It sends recycled materials to the "Supply" process and reuse materials to the "Use" process. The cleaned sewage and different waste materials are exported.

Graph 4.1.7.: Layout of the system "Vienna"



4.2. Data Procurement: Methods, assumptions and calculations

Acknowledgements:

- All losses flows, a part of the losses flow of the system “water”, are assumed to leave entirely the systems. Due to the relatively small amounts of this flows, has this assumption a non significant effect (see Balance of the systems) on the total balance of the systems. The further pathways and the final sinks of these uncontrolled flows are discussed separately in the subchapters of chapter 5.
- In the following subchapters amounts are often expressed in kilograms per capita. These amounts are shown with two comma digits. This is not due to the fact that these numbers are correct to the second comma digit, they are not, but the rounding of this numbers during the calculations would diminish the exactness of the results. The results are shown as well with the two comma digits in these sub-chapters. In chapter 5 the results, which are expressed in kilograms per capita, are rounded and shown without comma digits.

4.2.1. System “Air”

Atmosphere:

For the process “Atmosphere” the following flows and stock was considered:

-Fresh air: The import of fresh air by the atmosphere of Vienna is depending on the needs of the process “Human activities” and the process “Combustion of fuels”. It amounts in total to 32.85 tons per capita. 10.64t are delivered to each person and the corresponding of 22.12t per capita is delivered to the process “Combustion of fuels”.

-Offgas: The export of offgas from the atmosphere of Vienna is depending on the outflows of the process “Human activities” and the process “combustion of fuels”. It amounts in total to 38.19 tons per capita. It consists of the by human activities evapotranspirated water (3,65t), the amount of air provided in the first place(22.12) and the carbon emitted by a human (0,21t) and the per capita amount of the combustion of fuels process (1,46t). 0,02 tons is the amount of other substances emitted by the combustion of fuels.

-Stock: The stock of the atmosphere is the weight of the atmosphere defined by the sea level altitude of 11km and the borders of Vienna. Up to an altitude of 11km lies 75% of the weight of the worldwide atmosphere [Withgott, Brennan, 2009], which is equal to 3,75*10’15 tons. The surface of the earth is 510,072,000 km^2 [Withgott, Brennan, 2009], the one of Vienna is 414,65km2 [Statistics Austria, 2011] Therefore is the weight of the atmosphere of the system of Vienna: (414,65/510.072.00)*3,75*10’15= 3,05t*10’9

Divided by the population of Vienna (2009: 1.693.000) gives an air stock of 1800t per capita.

Human activities:

For the process “Human activities” the following flows were considered and calculated:

-Water import: The flow “water import” is calculated is equal to the evapotranspirated water flow “H2O” and amounts to 3,65 tons per capita.

-H2O: The flow “H2O” is the evapotranspirated water which is shown and calculated in chapter 4.3.3.2. It amounts to 3,65 tons per capita.

-Air need: The flow “air need” is the air which a person consumes via respiration. It amounts to 1 cubic meter per hour. 5,5 (5 to 6) breaths per minute,3 litre average inflow volume, 60 times per hour =990 l/ => 1m³) which corresponds to 8760m³ per capita and year. The average air density 2009 was calculated (see next paragraph) and amounts to 1.215 kilogram per cubic meter. Multiplying the numbers with each other gives the weight of the air consumed in one year which is equal to 10,64 tons per capita.

The density of humid air is found by the following formula:

$$\rho = \frac{pd}{Rd \times T} + \frac{pv}{Rv \ \times T}$$

where:

ρ …is the density of the humid air (kg/m³)

pd …is the partial pressure of dry air (Pa)

Rd …is the specific gas constant for dry air = 287.058 J/(kg·K)

T … is the Temperature (K)

Pv …is the pressure of the water vapor (P)

Rv … is the specific gas constant for water vaport, 461.495J/(kg×K)

Parameters:

-Average temperature in Vienna in 2009: 11 degree centigrade = 284,15 Kelvin [City of Vienna, 2011]

-Average humidity in Vienna in 2009: 74% [City of Vienna, 2011]

-Air pressure: 1 bar (arbitrary chosen) = 10000 Pa (Pascal)

By putting the parameters into the formula it gives the average air density of Vienna in 2009 which is 1,215 kilogram per cubic meter.

-Offgas: The “offgas” flow equals the “air need” flow (10,64 tons) plus the “carbon in food” flow (0,21 tons) and amounts to 10,85 tons per capita and year.

-Carbon in food: The “carbon in food” flow calculation is based on the “offgas” flow. A human consumes about 10,64 tons of air each year. The air consists of 21% of oxygen and while breathing a human consumes about 5% (Crombie, 2001) of the oxygen of the air. That results in a consumption of oxygen of 0,56 tons a year. The respiration reaction in the lungs of a human is C+O2, where the carbon has a molecular mass of 12 and the oxygen has a molecular mass of 16×2. The relation of 12 to 32 is equal to 210 to 560. That means that a human consumes 0.21 tons of carbon each year which he releases as CO_2 to the atmosphere.

The “carbon in the food” which a human consumes each year will be bigger than the one he expels via respiration as not all carbon is used by the human body. For practical reasons the amount of carbon in the food is assumed to be equal to the carbon released via the lungs.

Combustion of fuels:

The “Combustion of fuels” process includes all green house gases as well as non greenhouse gases. The sources of the green house gases for the city of Vienna are the are traffic (38%), energy production (31%), small user (19%), industry (9.2%), other (2,6%) and agriculture (0,2%) [Bednar, 2010].

For this process the following flows where considered and calculated:

-Offgas: The “offgas” flow is composed of the “carbon” sub-flow, the “nonGHG emissions” sub-flow and the” air need” flow. This flows amount to respectively to 1,46 tons per capita 0,02 tons per capita and to 22,21 tons per capita (see air need). This gives the total sum of the offgas which amounts to 23.69 tons per capita. The sub-flows are calculated the following way:

1) The “carbon” sub-flow is calculated on the basis of the carbon footprint. The carbon footprint for Vienna is 8.900.000 tons of CO_2 equivalent greenhouse gases for the year 2007 [Bednar, 2010]. As in 2007 Vienna had a population of 1.668.000 [Statistics Austria] the carbon footprint of a Viennese citizen 5,33 tons of CO_2 equivalent a year. As 93% of the greenhouse gases is carbon dioxide [Anderl et al, 2010] all 5,33 tons of CO_2 equivalent GHG are considered to be carbon **dioxide**. The combustion reaction which undergoes the fuel is $C+O_2$, where the carbon has a molecular mass of 12 and the oxygen has a molecular mass of 16×2. 5,33 tons divided by the relation of 12C to $32O_2$ gives 1,46 tons of carbon and 3,87 tons of oxygen.

2) The emissions of “non greenhouse gas” flow for Vienna for the year 2008 is the sum of the following substances [Anderl et al, 2010]:

-NOx is for practical reasons considered as NO_2 (Nitrogen dioxide): 23.100t

-NMVOC (non methane volatile organic compounds): 22.2000t

-SO_2 (Sulphur dioxide): 760t

-NH_3 (Ammonia): 740t

-PM 2.5 (Particulate matter smaller than 2.5 micrometer): 1.400t

-PM 10 (Particulate matter smaller than 10 micrometer): 2.200t

As ammonia and the particulate matter do not consume oxygen during their reactions, their amounts were taken as they are and dived by the population of 2008 which amounts to 1.690.000 [Statistics Austria]. The same is done for non methane volatile organic compounds. Nitrogen and sulphur react with oxygen and have a molecular mass relation compared to oxygen respectively of 14:32 and 32:32. That means that out of the 23.100 tons of nitrogen dioxide 7.030 tons consists of nitrogen and 16.070 tons consists of oxygen and that out of the 760t tons of sulphur dioxide 380 tons are sulphur and the other halve is oxygen.

Summing up all amounts of non greenhouse gases without the oxygen part of nitrogen dioxide and sulphur dioxide it gives an amount of 33.950 tons emitted substances a year. This amount corresponds to 0,2 tons per capita and year.

-Fuel import: The “fuel import” flow considers only the carbon part of the fuel and is equal to the emitted carbon and the emitted non greenhouse gases without the oxygen as listed above. This requires the assumption that no fuel is lost.

-Air need: The “air need” flow is calculated on the carbon and on a part of the non greenhouse gases. For the calculation of how much air is needed to burn 1,46 tons of carbon two assumption were made. First it is assumed that all reactions are the same and that the need 120% of the stoichiometric amount oxygen (air excess of 20%), which is true for coal combustion but varies for other combustion reactions (see table below). Second assumption is that the complete amount of oxygen is consumed. The 3,87 tons of oxygen of the stoichiometric amount needed to burn 1,46 tons of carbon needs to be increased by 1.2 times. The resulting 4,65 tons need to be dived by the percentage of oxygen in the air to arrive to the amount of air which is needed. It is 22.15 tons of air per person and year for the combustion of fuels in regard to carbon.

For the combustion of nitrogen and sulphur the following amounts of air is required. The same assumptions as for the combustion of carbon were made:

For the nitrogen combustion 16.070 tons are required by the Stoichiometric equilibrium. Adding the stoichiometric amount of oxygen for the sulphur combustion gives 16450 tons. This amount times 1.2 and dived by the percentage of oxygen in the air gives 94.000 tons of oxygen need in Vienna, which corresponds to about 0,06 tons per Viennese citizen.

The total air needed is given by the amount of air for the combustion of carbon, sulphur and nitrogen and is equal to **22,21 tons per capita** and year.

Table 4.2.1.A.: Values of excess air for some common fuels

Fuel	Excess of Air (%)
Anthracite	40
Coke oven gas	5 - 10
Natural Gas	5 - 10
Coal, pulverized	15 - 20
Coal, stoker	20 - 30
Oil (No. 2 and No. 6)	10 to 20
Semi anthracite, hand firing	70 to 100
Semi anthracite, with stoker	40 to 70
Semi anthracite, with traveling grate	30 to 60

Source: http://www.engineeringtoolbox.com/fuels-combustion-efficiency-d _167.html accessed the 01.05.2011

Ventilation:

The process "Ventilation" consists of the "air need" and "air discharge" flow. The flows are equal as it is assumed that the properties of the air used in this process do not change. The air which is needed to ventilate working places is calculated the following way:

The Austrian law, § 24 AStV and § 22 ASchG, requires 12 m³ of free air space for works with low physical activity (e.g. office), 15 m³ of free air space for works with normal physical activity (hairdresser), 18 m³ of free air space for works with great physical exertion or aggravating conditions (e.g. smith). In addition, 10 cubic meters for every other person present at the same time (e.g. customer / internal, patient / s) is required. This does not apply to commercial spaces and guest rooms in commercial enterprises.

The assumption was made that most workers in Vienna have a work with low physical activity (70%), and fewer have a work with normal physical activity (20%) or great physical activity. Furthermore it was assumed that 10% of the workers have always another person present (as defined by law). This gives an average air volume of 14,8m³ per person. Another 0,2m³ meter was added to this average for assumed bigger free air space as required by the law.

In 2009 798.200 people were working in Vienna [Statistics Austria, 2011]. As no data was found of how many work spaces are ventilated three scenarios were considered: These are that 20%, % 50 or 80% of all working places are ventilated. There was no reason to consider 100% of all working places would be ventilate as even the works which take place outside were considered.

The calculation is free air space per person times the workers times the air density times the ventilation percentage and all dived by the population of Vienna.

Table: 4.2.1.B.: Air use for Ventilation by person

Percentage ventilated work places	Free air space per capita	Workers in Vienna	Air density of Vienna 2009[3]	Population of Vienna	**Results** (Viennese citizen)
20%	15m³	798.200	1,215kg/m³	1.963.000	**2,58** tons
50%	15m³	798.200	1,215kg/m³	1.963.000	**6,44** tons
80%	15m³	798.200	1,215kg/m³	1.963.000	**10,31** tons

For practical reasons it was assumed that 50% of all working places are ventilated. From here on only that amount (6,44t/c) is taken into consideration.

[3] See chapter 3.2.1.1 „Human activities“

4.2.2. System “Water”

It was assumed that **water** has always the density of 1 kilogram per litre, independent of its temperature and of the transported substances. This was done for the practical reasons as no data of the average temperature of water is available and to fulfil the objective to show all flows in weight per capita. This leads to the possibility to derive the volume of water by exchanging tons with cubic meter.

- Water supply processes:

For the **“Public water supply”** process the following flows were considered and calculated:

-Spring water: The quantitative data comes from the statistical yearbook Austria 2011 [Statistics Austria, 2011], and amounts to a total of 132.276.000t. Divided by the population of Vienna, it gives 78.13 tons per capita for the year 2009.

-Groundwater: The quantitative data comes from the statistical yearbook Austria 2011 [Statistics Austria, 2011], and amounts to a total 7.625.000t. Divided by the population of Vienna, it gives 4.5 tons per capita for the year 2009.

-Domestic use: No complete data of the total domestic water use was found. The amount of 44.14 tons per capita is a result of the other flows which were identified:

Spring water (78.13) + groundwater 4.5 – direct exports (5.17) – losses (6.05) –industry supply (24.14) – own consumption (3.13) = 44.14 tons per capita for the domestic use.

-Industrial use: The quantitative data available in the statistical yearbook Austria 2011 [Statistics Austria, 2011] gives the amount of sewage discharged by the industry in Vienna into the sewage system which is 153.055.000t or 33 tons per capita. The industrial own supply (15.000.000t [Brunner et al., 1996] divided by the population of Vienna gives 8.86 tons per capita. Therefore, the only remaining inflow must be equal the rest of the out flowing sewage. The “rest” is provided by the public water supply system and amounts to 24.14 tons per capita.

-Own consumption: The own consumption (services for the community) is given by the Project Pilot (Brunner et al., 1996) and amounts to 5.300.000, which corresponds to 3.13 tons per capita. The assumption that the amount did not change since then is due to the fact that the general amount of water consumption by the industry did not change as water saving production processes and new technology as well as a decrease in losses was able to uncouple the industrial water need from economic growth [Austrian Ministry for Life, 2010].

-Direct exports: The quantitative data is derived from the statistical yearbook Austria 2011 [Statistics Austria, 2011]: Total water supply without losses is 129.657, the one delivered within the borders of Vienna is 120.896.000, therefore is the amount of the directly exported water 8.788.000t which corresponds of a direct export of 5.17 tons per capita.

-Losses: The quantitative data is derived from the statistical yearbook Austria 2011 (Statistics Austria, 2011): The total supply for Vienna amounts to 139.902.000t, the total water supplied without losses amounts to 129.657.000, therefore amounts the water loss to 10.245.000t, which is equal to a water loss of 6.05 tons per capita.

For the process **"Aquifer"** the following flows were considered and calculated:

-Aquifer stock: The total amount of Vienna's Groundwater is estimated to be 100.000.000t [City of Vienna, MA 31, 2003] which corresponds to 59,07t per capita. It was assumed that the stock of the aquifer does not change. For practical reasons were the two Groundwater systems of Mosbrunn and Lobau considered to lie completely within the borders of Vienna.

-Losses: For practical reasons losses of the public water supply process are considered to seep completely trough the groundwater and refill it. The quantitative data is derived from the statistical yearbook Austria

2011 [Statistics Austria, 2011]: The total supply for Vienna is139.902.000t, the total water supplied without losses is 129.657.000, therefore is the water loss 10.245.000t, which is equal to a water loss of 6.05 tons per capita.

-Imports: The import flow is due to the natural water cycles (groundwater flows and water seeking trough (rain)). As it was assumed that the stock of the aquifer does not change, the supply of groundwater to the public water supply (4.5t/c) and to the industry plus the gain from the losses (6.05t/c) a natural import of 7.31 tons per capita is required.

-Groundwater for water supply: The quantitative data comes from the statistical yearbook Austria 2011 [Statistics Austria, 2011], and amounts to a total of 7.625.000 tons. Divided by the population of Vienna, it gives 4.5 tons per capita for the year 2009.

-Groundwater for own supply industry: The quantitative data comes from the Project Pilot (Brunner et al. 1996) and amounts to 15.000.000t which corresponds to 8.86 tons per capita. It was assumed that this amount did not change since then (due to the fact that the general amount of water consumption by the industry did not change as water saving production processes and new technology as well as a decrease in losses was able to uncouple the industrial water need from economic growth [Austrian Ministry for Life, 2010]).

- Water consumption processes:

For the **“Domestic use”** process the following flows were considered and calculated

-Public water supply: No complete data of the total domestic water use was found. The amount of 44.14 tons per capita is a result of the other flows which were identified:

Spring water (78.13) + groundwater 4.5 – direct exports (5.17) – losses (6.05) –industry supply (24.14) – own consumption (3.13) = 44.14 tons per capita for the domestic use

-Sewage: The sewage of the domestic water use is the difference between the supplied water (44.14t/c) and the evapotranspirated water (3.65t/c.) It amounts to 40.49 tons per capita.

-Evapotranspiration: The amount is calculated on the average consume of water which is evaporated by the plants in the garden, cooking, the Human body and other processes. It amounts to 10l per person and day (Baccini et al., 1993) and corresponds to 3.65 tons per year and capita.

For the **“Industry”** process the following flows were considered and calculated:

-Public water supply: No complete data for the public water supply for the industry was found the amount is a result of the following considerations. The industrial own supply (15.000.000t [Brunner et al. 1996] divided by the population of Vienna is 8.86 tons per capita. The sewage is 33 tons per capita. The “rest” is provided by the public water supply system and must amount to 24.14 tons per capita.

-Own groundwater supply: The industrial own supply (15.000.000t [Brunner et al., 1996] divided by the population of Vienna gives 8.86 tons per capita. It was assumed that this value did not change for the year 2009. (see “groundwater for own supply industry”)

-Sewage: The quantitative data available in the statistical yearbook Austria 2011 [Statistics Austria, 2011] gives the amount of sewage discharged by the industry in Vienna into the sewage system which is 153.055.000t or 33 tons per capita.

- Water treatment processes:

For the **“Sewer system”** process the following flows were considered and calculated:

-Domestic sewage: The domestic sewage is given by the difference between the supplied water (44.14t/c) and the evapotranspiration (3.65t/c) and amounts to 40.49 tons per capita.

-Industrial sewage: The quantitative data available in the statistical yearbook Austria 2011 (Statistics Austria, 2011) gives the amount of sewage discharged by the industry in Vienna into the sewage system which is 153.055.000t or 33 tons per capita.

-Sewage from own consumption of the public water supply: It refers to services done for the community (fountains), for practical reason it is assumed to reach completely the sewer system. The amount is given by the Project Pilot (Brunner et al., 1996) and amounts to 5.300.000, which corresponds to 3.13 tons per capita.

-Rain: No direct data was found for the amounts of rain water joining the sewer system. The total amount of sewage transferred to the sewer system is known (129,23 t/c) as well as the sewage import from households (40.49t/c), the industry (33t/c), the public water supply (3,13t/c) and the rivers(19,4t/c). Therefore are the remaining 33,21 tons coming from rain water which joins the sewer system.

-Rivers: The dry weather flows of the rivers which join the sewer system amount to 19,4 tons per person and are derived the following way:

Total mmaximum sewage dry weather for 3,25 EGW (Einwohnergleichwerte = fictive amounts per resident): 552.000 tons/d = a (EBS, 2011)

Total maximum water consumption: 506.980t/d = b (MA 31, 2011)

Total losses (see water supply process): 28.062t/d =c

Total evapotranspiration: 16.930t/d =d

(a – (b-c-d))/1.693.000 *365 = 19,4 t/(c*a)

-Sewage transferred to waste water treatment plant: The amount of 129.23tons per capita is derived from the amount of water treated by the wwtp (612.222 tons per day (= 131,99t/c*a) sewage import statistical yearbook Austria 2011 [Statistics Austria, 2011]) minus the import of sewage from outside Vienna (2,67 tons per capita).

For the **“Waste water treatment plant”** process the following flows were considered and calculated:

-Sewage from sewer system: The amount of 129.23tons per capita is derived from the amount of water treated by the wwtp (612.222 tons per day (=

131,99t/capita and year) sewage import statistical yearbook Austria 2011 [Statistics Austria, 2011]) minus the import of sewage from outside Vienna (2,67 tons per capita).

-Sewage import: The sewage import is calculated with the help of the data form EBS (2011). According to it the sewage of 3.250.000 EGW (Einwohnergleichwert = fictive amounts per resident) is cleaned in the only wwtp of Vienna. The sewage of 62.000 of these fictive individuals is imported from outside Vienna. As 3.250.000 responds to an amount of 131.99 tons, 62.000 equals an amount of 2.76t. That means that per Viennese citizen 2.76t of sewage are imported.

-Water: As the whole amount of transferred sewage in the wwtp is known and cleaned (131.99t/c) the out flowing cleaned water must equal the treated water minus the water in the sewage sludge (0.11t/c), which is 131.88tons per capita. The Viennese water treatment plant takes more than 98,2% of BOD_5, 94,1% COD, 93,7% TOC and 84,7 Ntot out of the sewage [EBS, 2011]. Therefore, it is assumed that the purified sewage is water.

-Sewage sludge: According to EBS [EBS, 2011] 180.000 tons are transferred to the waste incineration plants. The sewage sludge contains about 60 to 65% of water. As the non water part before reaching the wwtp was transported by the sewage and for practical reasons the whole amount is considered water, which is 0.11 tons per capita in 2009.

4.2.3. System "Construction materials"

The main source of the data for the system copper is the research paper *"Die volkswirtschaftliche Bedeutung mineralischer Rohstoffe inÖsterreich"* [Hennrich et al., 2007]. The base year of the dataset is the year 2002. The population of Austria in the year 2002 was 8.082.000 (Statistical yearbook Austria 2011, Statistics Austria).

A second data source, for the amounts of waste, was the *"Bundesabfallwirtschaftsplan 2011"* [Klaffl et al., 2011]. The base year of it is 2009, when Austria had a population of 8.363.000(Statistical yearbook Austria 2011, Statistics Austria). For this system the year 2011 was chosen as base year, as it was assumed that all data is still valid for that year in relation to amounts per capita. The stocks were actualized by the yearly stock deltas. It was further assumed that no construction materials are exported.

The **"Hinterland"** process consists of the following flow and stock:

-construction materials: The amount of construction materials used per year is 100.000.000 tons [Hennrich et al., 2007] in Austria, which amounts to about 12 tons per capita. 2,4 tons of this amount are provided by recycled materials. For the remaining 9,6 tons the following assumption was made: As the construction materials is coming generally from less than 30 kilometres distance [Hennrich et al., 2007] it was assumed that the amount provided by the hinterland amounts to about 99% which corresponds to 9,5 tons per capita.

-stock: the stock is chosen arbitrary and amounts to 100.000 tons per capita.

-stock delta: the stock delta is equal to the provided construction materials.

The **"Consumption"** process consists of the following flows and stock:

-construction materials: The amount of construction materials provided by the hinterland amounts to 9,5 tons per person. (see hinterland process).

-construction materials import: The import of construction materials is estimated to be about 1% of the total used construction materials and amounts therefore to 0,1 tons per Austrian.

-used construction materials: The total amount of used and discharged construction materials amounts to 6.870.000 tons [Klaffl et al., 2011], but only 5.370.000 tons [Klaffl et al., 2011]are considered as the rest are metals, wood or oil derivates (tar). Furthermore was the excavation material considered which amounts to 23.465.000 tons1 [Klaffl et al., 2011]. The sum of both discharged material groups amounts to 28.835.000 tons which corresponds to about 3,5 tons per capita.

-losses: No specific data was available for the weathering losses of construction materials in Vienna or in Austria. The assumption was made that Vienna has fifteen times as much construction materials surfaces than copper surfaces. The corrosion of marble in urban processess is on average about 15 times as high as the corrosion of copper (0,5-50 micrometers against -2 micrometers a year [Leygraf, Graedel, 2000]), the corrosion of normal limestone is on average about 45 times as high (10 to 150 micrometers a year [Leygraf, Graedel, 2000]). For other construction materials an even higher corrosion rate was assumed, this leads to the assumption of an overall corrosion rate of 45 times as the corrosion rate of copper.

As the dissipation of copper in Vienna is explored and amounts to 26 grams per person and year , but only 8,9 grams are due to the corrosion of buildings, [Obernosterer et al., 2003] it is assumed that the overall corrosion of iron is about 40 times as high as the one of copper per square meter. The density of copper is about 3,7 times as high as the density of copper. 15 times 45 times 8,6, all divided by 3,7 amounts to about 1,6 kilograms per person. Another 3,4 for kilograms where added for the elutriation of loose construction materials. Finally it was assumed that the losses of construction materials amount to 5 kilogram per Viennese citizen and year.

-stock: The total anthropogenic stock is estimated for the year for the year 2002 to 350 tons per capita [Daxbeck et al. 2002]. It was assumed that the stock since then increased steadily each year by 10 tons. Therefore, the total anthropogenic stock for the 1. January of 2011 amounts to about 440 tons per capita. As the stock delta of the consumption processes has a relation of about nine to one towards the stock delta of the landfill stock, it was assumed that 90 percent of it lies within the consumption process and that about ten percent is in the landfill stock. For the consumption process the stock is 400 tons per person.

-stock delta: The stock increase is the difference between the construction materials from the hinterland or imported plus the recycled construction materials and the sum of the used construction materials export and the construction materials losses. It amounts to 8,5 tons per capita.

The **waste management** process consists following flows and stock:

-used construction materials: 3,5 tons per capita of construction materials are used and discharged each year. (see consumption process).

- Construction materials to recycle: The amount of recycled construction materials is given and amounts to 5.500.000 tons a year [Klaffl et al., 2011], the amount of recycled excavation material amounts to about 15,5 million tons [Klaffl et al., 2011]. This to amounts correspond to 2,4 tons per capita. It is assumed that the recycling process has an efficiency of 100%.

-construction materials waste: The amount of landfilled construction materials is given and amounts to 510.000 tons a year [Klaffl et al., 2011], the amount of landfilled excavation material amounts to about .8,1 million tons. This amount corresponds to 1 tons per capita.

-stock and stock delta: 890.000 tons of used construction materials is stored [Klaffl et al., 2011] (about 100 kilogram per person). It was assumed that each year the same amount is stored since 5 years and not yet reused. This gives a stock of 500 kilogram per person and a stock delta of 100 kilograms.

The **recycling** process consists of the following flows:

- Construction materials to recycle: The amount of recycled construction materials is given and amounts to 5.500.000 tons a year [Klaffl et al., 2011], the amount of recycled excavation material amounts to about 15,5 million tons [Klaffl et al., 2011]. This to amounts correspond to 2,4 tons per capita. It is assumed that the recycling process has an efficiency of 100%.

-Recycled construction materials: The amount of recycled construction materials is by definition equal to the amount of construction materials to recycle and amounts to 2,4 tons per person.

The **landfill** process consists of the following flow and stock:

-construction materials waste: The amount of landfilled construction materials is given and amounts to 510.000 tons a year [Klaffl et al., 2011], the amount of landfilled excavation material amounts to about .8,1 million tons. This amount corresponds to 1 tons per capita.

-stock: The total anthropogenic stock is estimated for the year for the year 2002 to 350 tons per capita (Daxbeck et al. 1996, updated 2002). It was assumed that the stock since then increased steadily each year by 10 tons. Therefore, the total anthropogenic stock for the 1. January of 2011 amounts to about 440 tons per capita. As the stock delta of the consumption processes has a relation of nine to one towards the stock delta of the landfill stock, it was assumed that about 90 percent of it lies within the consumption process and that about ten percent is in the landfill stock. For the landfill process the stock is 40 tons per person.

-stock delta: As the process landfill has only one inflow and no outflow it is equal to the construction materials waste flow.

4.2.4. System “Iron”

It was assumed that for the process of steel production no other materials than iron ore are needed. Nevertheless, some waste products of this process were considered. The amounts of the flows have the base year 2008 and are divided by the population of 2008 which amounts to 8.333.000 persons [Statistics Austria, 2011]. The stocks which are calculated for the year 2011 are divided by the population of 2011 which amounts to 8.403.000[Statistics Austria, 2011].

- The production processes:

The **“Iron mine”** process consists of the following flows and stocks:

-Iron ore: The extraction of iron ore amounts to 2.033.000 tons for the year 2008 [U .S. Geological Survey Minerals, 2011] and corresponds to 243.88 kilograms per Austrian.

-Iron stock: In 2008/2009 the stock of Iron in the Erzberg was 5,5 tons per capita [Daxbecket al., 2009a]. As per year nearly 250 kilograms per capita are extracted it is assumed that the stock amounts in 2011 to 5 tons per capita.

The **“Production of iron”** process consists of the following flows:

-Iron ore: The amount the excavation of iron ore in the iron mine of Erzberg amounts to 2.033.000 tons a year which corresponds to 243.88 kilograms per capita.

-Iron ore import: The iron ore which is imported amounts to 5.017.000 tons which corresponds to 601,85 kilogram per capita

-Pig iron export: The amount of exported pig iron is given and amounts to 0,72kilogram per person [Worldsteel Committee on Economic Studies, 2010].

-Pig iron: As the amount of total production of pig iron is given (5.795.000t/a [Worldsteel Committee on Economic Studies, 2010]), the flow of is equal to it minus the exports and results in 694,46 kilograms per capita.

-Slag: As no other materials than iron ore were considered in this process, the amount of slag is smaller than in reality and amounts in these calculations to 150,55 kilograms per capita, which is the difference between the other in- and outflows.

The **“Production of steel”** process consists of two different techniques. 90,5% of the steel is produced via oxygen blown converters, the rest is produced via electric furnaces [Worldsteel Committee on Economic Studies, 2010]. The following flows were considered for this process:

-Crude steel: The total amount of crude steel produced in 2008is known and amounts to 7.594.000 tons, which corresponds to 910,99 kilograms per capita [Worldsteel Committee on Economic Studies, 2010].

-Pig iron: As the amount of total production of pig iron is given (5.795.000t/a [Worldsteel Committee on Economic Studies, 2010]), the flow of is equal to it minus the exports and results in 694,46 kilograms per capita.

-Pig iron import: The amount of imported pig iron is known and amounts to 5,28 kilograms per capita [Worldsteel Committee on Economic Studies, 2010].

-Scrap iron import: The amount of imported scrap iron is given and amounts to 215,57 kilograms per capita. [Worldsteel Committee on Economic Studies, 2010] It is assumed that all the imported scrap iron is used for the production of steel and not directly re-exported.

-Carbon losses: As pig iron contains between 3,5% and 4,5% of carbon [Camp, Blaine Francis,, 1920] and most steel contains about 0,35% [Capudean, 2003], it was assumed that in this process 3,5% of the weight is lost as carbon emissions. 3,5% of 910,99 kilograms amounts to 31,88 kilograms.

-Scrap iron: As it is assumed that all imported scrap iron is used in this process another 27,56 kilograms of scrap iron from the waste management process needs to be added to produce the given amount of crude steel.

The **“Production of goods”** process

Three different types of steel are used to produce goods. For 95,5% percent continuously-cast steel is used, for 4,3% of the products steel ingots are used and for 0,2% liquid steel is used. [Worldsteel Committee on Economic Studies, 2010]

The following flows were considered for this process:

-Crude steel: The total amount of crude steel produced in 2008is known and amounts to 7.594.000 tons, which corresponds to 910,99 kilograms per capita [Worldsteel Committee on Economic Studies, 2010]

-Semi & finished products import: The import of semi finished and finished products is known and amounts to 4140.000 tons iron, which corresponds to 496,64 kilograms per person [Worldsteel Committee on Economic Studies, 2010].

-Semi & finished products export: The export of semi finished and finished products is known and amounts to 7153.000 tons iron, which corresponds to 855,93 kilograms per person [Worldsteel Committee on Economic Studies, 2010].

-Steel products: The amount of used steel products is known and amounts to 4.033.000 tons of steel, which corresponds to 483,81 kilograms per person [Worldsteel Committee on Economic Studies, 2010].

-Steel waste: As the steel use in terms of crude steel (4.599.000 tons [Worldsteel Committee on Economic Studies, 2010]) is not equal to the steel use of finished products (Steel products), the difference is assumed to be steel waste. It amounts to a total of 566 tons a year, which corresponds to 67,89 kilograms per capita.

- The consumption process:

In the consumption processes no differentiation of processes was made and therefore only one process, which includes all sub-processes, is considered.

The **“Consumption”** process consists of the following flows and stock:

-Steel products: The amount of used steel products is known and amounts to 4.033.000 tons of steel, which corresponds to 483,81 kilograms per person [Worldsteel Committee on Economic Studies, 2010].

-Stock: In 2008/2009 the anthropogenic stock of Iron was 4,5 tons per capita [Daxbecket al., 2009a]. As the stock increase by more than 300kilograms per capita and year it is assumed that the stock amounts in 2011 to 5,2 tons per capita, where 90% lie in the consumption process and 10% in the landfills [Fellner, 2010][4]. Therefore the stock is equal to 4,68 tons per capita.

-Scrap Iron: The scrap iron consists of iron and steel wastes. Only the iron content of these wastes are considered. The amounts are given by the following dataset of 2009 (population 8.363.000[Statistics Austria, 2011]):

-Iron and steel waste without electric equipments, old cars and (iron) packing materials: 1.167.000t [Klaffl et al., 2011]

-electric equipments: 159.994 tons, 62,5% iron content- assumption 100% is recycled- => 100.000 tons [Klaffl et al., 2011]

-Car tire wires: 5820 tons [Klaffl et al., 2011] recycled

-Old cars [Klaffl et al., 2011]: 85.000 tons 55% to 70% iron,- assumption 62,5%- overall recycling rate of old cars 84% => 44625 tons iron recycled

- packing material: 28.500 tons [Klaffl et al., 2011]

Total = 1.345.945 tons = 160,09 kilograms per capita

-Losses: No specific data was available for the weathering losses of iron or steel in Vienna or in Austria. The assumption was made that Vienna has halve as much iron or steel emitters than copper emitters. The corrosion of weathering steel in urban processess is about 5 times as high as the corrosion of copper (4-10 micrometers against -2 micrometers a year [Leygraf, Graedel, 2000]), the corrosion of normal carbon steel is

[4] in this system: delta stock consumption: delta stock landfills = 9,1:1

about 25 times as high (23 to 71 micrometers a year [Leygraf, Graedel, 2000]).

As the corrosion of copper in Vienna is explored and amounts to 26 grams per person and year [Obernosterer et al., 2003] it is assumed that the overall corrosion of iron is about 15 times as high as the one of copper per square meter. For practical reason was the small density difference (copper slightly heavier than steel) neglected. 50% times 15 times 26 is about 200 grams, which was finally assumed to be the steel or iron losses per Viennese citizen a year.

-Delta stock: The stock delta is given by all the flows of this process and increases by 323,52 kilograms per person.

- The treatment processes:

The treatment processes include the “Waste management” process where the waste is collected, recycled, exported or sent to the landfill, and the landfill process.

The **“Waste management”** process consists of the following flows:

-Scrap iron: As it is assumed that all imported scrap iron is used in the pig iron process another 27,56 kilograms of scrap iron from the waste management process needs to be added to produce the given amount of crude steel.

-Scrap iron export: The scrap iron export is given and amounts to 165,43 kilogram per person [Worldsteel Committee on Economic Studies, 2010]. For practical reasons it is assumed that the scrap iron comes from within the system and that no imported scrap iron is directly re-exported.

-Steel waste: As the steel use in terms of crude steel (4.599.000 tons [Worldsteel Committee on Economic Studies, 2010]) is not equal to the steel use of finished products (Steel products), the difference is assumed to be steel waste. It amounts to a total of 566 tons a year, which corresponds to 67,89 kilograms per capita.

-Iron waste: The Iron waste consist of the difference of all other flows and amounts to 35,54 kilograms per person.

-Slag: As no other materials than iron ore were considered in the production of iron process, the amount of slag is smaller than in reality and amounts to 150,55 kilograms per capita, which is the difference between the other in- and outflows. The yearly recycled slug amounts to 165.000 tons and 5.580 tons of iron can be recovered, which corresponds to 0,22 kilogram per person.

-Slag export: It is assumed that the slug without any Iron leaves the system "Iron". The efficiency of the iron recovery is not known but it is assumed to be 40%. Which equals to 0,22 kilogram, therefore another 0,33kilogram Iron per person will stay in the system and be landfilled. The slug export amounts therefore to exact 150 kilograms per person.

The **"Landfill"** process consists of the following flow and stock:

-Iron waste: The Iron waste consist of the difference of all other flows of the waste management process and amounts to 35,54 kilograms per person.

-Stock: In 2008/2009 the anthropogenic stock of Iron was 4,5 tons per capita [Daxbecket al., 2009a]. As the stock increase by more than 300kilograms per capita and year it is assumed that the stock amounts in 2011 to 5,2 tons per capita, where 90% lie in the consumption process and 10% in the landfills [Fellner, 2010][5]. Therefore the stock is equal to 0.52tons per capita.

-Delta stock: As this process has only one inflow and not outflow the delta stock is equal to the iron waster flow and amounts to 35,54 kilograms per person.

[5] in this system: delta stock consumption: delta stock landfills = 9,1:1

4.2.5. System "Copper"

The main source of the data for the system copper is coming from the article *"Urban mining: Die Stadt – das Bergwerk der Zukunf*" (Daxbecket al., Ressourcen Management Angentur) published in 2009. As the base year of the dataset is not specified it was assumed that the base year is 2008, which is partially confirmed by a stock-value comparison of the 1. January 2009.

The population of Austria of the year 2008 was 8.336.000 [Statistics Austria, 2011]. The year 2011 was chosen as base year, as it was assumed that the amounts per capita are still the same for that year. The stocks were actualized by the yearly stock deltas.

The **"Consumption"** process consists of the following flows and stock:

-copper import: The import of yearly copper amounts to 305.000 tons [Daxbecket al., 2009a] and corresponds to 36,5 kilogram per Austrian.

-copper export: The copper export amounts to 223.000 tons a year and is equal to 26,8 kilograms per person

-copper: The amount of recycled copper is given and amounts to 28.000 tons a year [Daxbecket al., 2009a], which is equal to 3,4 kilograms per capita.

-used copper: The amount of used copper is deducted by the amounts of recycled, exported and landfilled copper and amounts to 6,2 kilogram per person.

-losses: The losses are estimated and amount to 26 grams per Viennese citizen [Obernosterer et al., 2003].

Where 8,9 grams are emitted by buildings, 2 grams are emitted by the activities to nourish and clean, 14 grams are lost by the traffic (vehicles), 0,02 grams are emitted by the waste incineration plant and 1,4 grams is emitted by the wwtp.

-stock: The stock is given for the year 2008 and amounted than to 270 kilograms per person [Daxbecket al., 2009a]. It was assumed that the stock since then increased each year by the same amount as in 2008 (6,87kg/c).

Therefore, the stock for the 1. January of 2011 amounts to about 290 kilograms per person.

-stock delta: The stock increase is the difference between the copper import plus the recycled copper and the sum of the copper export, the used copper and the copper losses. It amounts to 6,874 kilogram per person.

The **“Waste management”** process consists following flows:

-used copper: The amount of used copper is deducted by the amounts of recycled, exported and landfilled copper and amounts to 6,2 kilogram per person.

-scrap copper: the amount of recycled copper is given and amounts to 28.000 tons a year [Daxbecket al., 2009a], which is about 3,4 kilograms per capita. It is assumed that the recycling process has an efficiency of 100%.

-scrap copper export: The export of scrap copper has a relation of four to six [Daxbecket al., 2009a] to the amount of recycled copper and amounts therefore to about 18.500 tons a year, which corresponds to 3,2 kilograms per capita.

-copper waste: The copper waste which is landfilled is about 10% [Daxbecket al., 2009a] of the used copper. If the sum of the recycled copper and the scrap copper export amount to 90%which is equal to about 5,4 kilograms per person, the copper waste which is landfilled amounts to 0,6 kilograms per person.

The **“Recycling”** process consists of the following flows:

-scrap copper: The amount of recycled copper is given and amounts to 28.000 tons a year [Daxbecket al., 2009a], which is about 3,4 kilograms per capita. It is assumed that the recycling process has an efficiency of 100%. Therefore, the copper inflow to the recycling process is equal to the outflow.

-copper: The amount of recycled copper is given and amounts to 28.000 tons a year [Daxbecket al., 2009a], which is about 3,4 kilograms per capita

The **“Landfill”** process consists of the following flow and stock:

-copper waste: The copper waste is which is landfilled is about 10% of the used copper. If the sum of the recycled copper and the scrap copper export amount to 90%which is equal to about 5,4 kilograms per person, the copper waste which is landfilled amounts to 0,6 kilograms per person

-stock: The stock amounts to about 300.000 tons for the year 2008 [Daxbecket al., 2009a], which corresponds to 36 kilogram per person. With a steady increase of 0,6 kilograms per person and year, the stock for the 1. January 2011 will amount to about 38 kilograms per person.

-stock delta: As the process landfill has only one inflow and no outflow it is equal to the copper waste flow.

4.2.6. System "Zinc"

The main source of the data for the system zinc is coming from the article "*Machtbarkeitsstudie Nationale Stoffbuchhaltung; Testbeispiel Zink*" [Brunner et al.,1998] published 1998. As the base year of most data is 1995 it was assumed that all data refer to that year. Although the data is relatively old it was assumed that the per capita consumption of zinc did not change since then.

The population of Austria of the year 1995 was 7.948.000 [Statistics Austria, 2011]. The year 2011 was chosen as base year, as it was assumed that the amounts per capita are still the same for that year. The stocks were actualized by the yearly stock deltas.

The **"Consumption"** process consists of the following flows and stock:

-zinc import: The import of yearly zinc amounts to 80.000 tons [Brunner et al., 1998] and corresponds to 10 kilogram per Austrian.

-zinc export: The zinc export amounts to 21.000 tons a year [Brunner et al., 1998] and is equal to 3,9 kilograms per person

-used zinc: The amount of used zinc amounts to 30.000 tons which corresponds to 3,8 kilogram per person.

-losses: The losses are estimated and amount to 82 grams per Viennese citizen [Obernosterer et al., 2003].

Where 44 grams are emitted by buildings, 10 grams are emitted by the activities to nourish and clean, 18 grams are lost by the traffic (vehicles), 0,08 grams are emitted by the waste incineration plant and 10 grams is emitted by the wwtp.

-stock: The stock amounted in 1995 to 320 kilograms per person [Brunner et al., 1998]. It was assumed that the stock since then increased steadily each year by the same amount as in 1995 (2,22kg/c). Therefore, the stock for the 1. January of 2011 amounts to about 360 kilograms per person.

-stock delta: The stock increase is the difference between the zinc import and the sum of the zinc export, the used zinc and the zinc losses. It amounts to 2,22 kilogram per person.

The **“Waste management”** process consists following flows:

-used zinc: The amount of used zinc amounts to 30.000 tons [Brunner et al., 1998] which corresponds to 3,8 kilogram per person.

-scrap ash export: The export of zinc ash has is given and amounts to 5.000 tons a year [Brunner et al., 1998], which corresponds to 0,63 kilograms per capita.

-zinc waste: The zinc waste which is landfilled is given and amounts to 25.000 tons a year [Brunner et al., 1998], which is equal to 3,17 kilograms per person

The **“Landfill”** process consists of the following flow and stock:

-zinc waste: The zinc waste which is landfilled is given and amounts to 25.000 tons a year [Brunner et al., 1998], which is equal to 3,17 kilograms per person

-stock: The stock amounts to about 450.000 tons [Brunner et al., 1998], which corresponds to 57 kilograms per person. With a steady increase of 3,17 kilograms per person and year, the stock for the 1. January 2011 will amount to about 90 kilograms per person.

-stock delta: As the process landfill has only one inflow and no outflow it is equal to the zinc waste flow.

4.2.7. System "Vienna"

The system "Vienna" consists of four processes, the "Atmosphere" process, the "Supply" process, the "Use" process and the treatment process.

The **"Atmosphere"** process consists of the following flows and stocks; calculations which are not shown here are explored in the system "air":

-Air import: 32.850 kilogram per capita.

-Fresh air: The provided fresh air consists of the air need of the Human activities process, of the Ventilation process and the combustion of fuels process. In total it amounts to 39.290 kilogram per capita and year

-Used air: The used air consists of the fresh air provided by the atmosphere plus the imported burned carbon and the evapotranspirated amount of water. In total it amounts to 44.630 kilograms per person.

-Offgas: The offgas which leaves the system is equal to the used air minus the not consumed air which corresponds to the air used by the Ventilation process. In total it amounts to 38.190 kilograms per person.

The **"Supply"** process consists of the following flows and stocks, calculations which are not shown are explored in the other systems:

-Fresh air: The amount of air provide by the supply is by definition (only fictive the passage in the supply process) equal to the amount of the air import. It consists of the air need of the Human activities process, of the Ventilation process and the combustion of fuels process. In total it amounts to 39.290 kilogram per capita and year

-Carbon: The import of carbon is equal to the amount of carbon in food and in fuels minus the amount of carbon which is released by the production of steel process. It total it amounts to 1.658,12 kilograms per person.

-Fresh water: The import of fresh water is equal to the total import of fresh water minus the direct exports. It amounts to 72,96 tons per capita.

-Construction materials: The amount of construction materials imported to the city of Vienna consists of the import and the hinterland flow and amounts to 9.600 kilograms per person.

-Iron/Steel: The amount of imported iron/steel is equal to the imported iron and steel minus all exports of iron and steel apart of scrap iron, slag and losses, plus the amount of iron ore coming from the iron ore process. In total it amounts to 706,57 kilograms per person.

-Copper: The amount of copper import is derived from the system “copper”. It is equal to the copper import flow minus the copper export flow of the stated system. It total it amounts to 9,7 kilograms per capita.

-Zinc: The amount of zinc import is derived from the system “zinc”. It is equal to the zinc import flow minus the zinc export flow of the stated system. It total it amounts to 6,1 kilograms per capita.

-Water cycle: As assumed in the system “water” is the aquifer refurnished by the natural water cycle by the same amount as is taken out and not refilled by the water losses.

-Stock: The stock of the city of Vienna consists of the solely aquifer stock. By definition lies the groundwater completely within the political boarder of Vienna.

-Recycled: This flow amounts to the amount of waste which is recycled and reused by the supply process. It consists if the recycled iron and amounts to 27,56 kilograms per person.

-Water: The amount of water consists of the imported water plus the groundwater use. In total it amounts to 80.270 kilograms per person.

-Goods: The amount of goods transferred to the use process consists of the amounts of construction materials, carbon, iron/steel, copper, zinc and the recycled goods (equal to recycled iron). In total it amounts to 12.008.05 kilograms per person.

-Delta stock: The stock delta is the result of all above mentioned flows and amounts to 0.

The **“Use”** process:

-Air: The amount of air provide by the supply is by definition (only fictive the passage in the supply process) equal to the amount of the inflowing fresh air and amounts therefore to 39.290 kilograms per person.

-Water: The amount of water consists of the imported water plus the groundwater use. In total it amounts to 80.270 kilograms per person.

-Goods: The amount of goods transferred to the use process consists of the amounts of construction materials (import plus hinterland), carbon, iron/steel (import plus hinterland), copper, zinc and the recycled goods (equal to recycled iron). In total it amounts to 12.008.05 kilograms per person.

-Reuse: The reuse flow consist of the recycled materials which are reused in the use process. It consists of recycled construction materials and copper. In total it amounts to 2.403.4 kilograms per person.

-Used air: The amount of used air is equal to the amount of air, carbon and water (the part which will be evapotranspirated) provided by the supply process. In total it amounts to 44.630 kilograms per capita.

-Waste: the amount of waste consists of the construction materials waste, the scrap iron, slag from the pig iron production, steel waste from the production of goods, the used copper and the used zinc. In total it amounts to 3.888.53 kilograms per person.

-Sewage: The amount of sewage is equal of the water inflow minus the evapotranspirated water. It is equal to 76.620 kilograms per person.

-losses: The losses consist of the losses of construction materials, iron/steel, copper and zinc. In total amount of these uncontrolled flows is equal to 5,31 kilogram per person.

The **treatment** process:

-Waste: the amount of waste consists of the construction materials waste, the scrap iron, slag from the pig iron production, and steel waste from the production of goods, the used copper and the used zinc. In total it amounts to 3.888.53 kilograms per person.

-Sewage: The amount of sewage is equal of the water inflow minus the evapotranspirated water. It is equal to 76.620 kilograms per person.

-Rain + river: The amount of extraneous water joining the sewer system is explored in the system “water” and amounts to 52.610 kilograms per person.

-Reuse: The reuse flow consist of the recycled materials which are reused in the use process. It consists of recycled construction materials and copper. In total it amounts to 2.403.4 kilograms per person.

-Recycled: This flow amounts to the amount of waste which is recycled and reused by the supply process. It consists if the recycled iron and amounts to 27,56 kilograms per person.

-Waste export: The amount of waste which is exported consist of the sludge from the water treatment process, the scrap and slag export from the system “iron”, the copper scrap export and the zinc ash export. In total it amounts to 428,26 kilograms per person.

- Water export: The amount of treated sewage which leaves the system is equal to the sewage inflow and the rain + river water minus the sludge export. In total it amounts to 129.120 kilograms per person.

5. Observations and Results:

Acknowledgement:

- In respect to chapter 4 are the amounts which are expressed in kilograms per person, in this chapter rounded to the last number before the digit.

5.1. System “Air”:

Air is a global good. The source and “final sink” is the atmosphere which interacts with the soil, the vegetation and the sea to change its chemical properties, where especially the exchange of carbon dioxide is of great human interest. Generally it can be stated that dry air by volume consists of about 78.09% nitrogen, 20.95% oxygen, 0.93% argon, 0.039% carbon dioxide, and small amounts of other gases. In average it contains about 1% of water which can increase up to 4%. The atmosphere reaches an altitude of 100 kilometres where the so called Kármán line divides the earth from the space [Withgott, Brennan, 2009]. Although it reaches this altitude it becomes very sparse, three quarters of its total weight of 5×10^{15} tons lies within the lower 11 kilometres [Withgott, Brennan, 2009],

As mentioned above is the natural carbon dioxide exchange or better said the reduction of carbon dioxide in the air of great human interest as it reaches, in a closed space, relatively fast toxic levels. Carbon dioxide toxicity and its effects increase with its concentration, air with 5% of carbon dioxide is considered as toxic. *1% can cause drowsiness with prolonged exposure. At 2% it is mildly narcotic and causes increased blood pressure and pulse rate, and causes reduced hearing. At about 5% it causes stimulation of the respiratory center, dizziness, confusion and difficulty in breathing accompanied by headache and shortness of breath. Panic attacks may also occur at this concentration. At about 8% it causes headache, sweating, dim vision, tremor and loss of consciousness after exposure for between five and ten minutes.* [The guardian, 2008]

5.1.1. Balance of the good "Air"

The biggest anthropogenic air flow is the offgas which leaves the system "Vienna" via the atmosphere and amounts to 38,19 tons per capita. The biggest part of this flow is caused by the combustion of fuels which needs 22.21 tons of air and releases all together 23.69 tons of gases per capita and year. The second biggest part is caused by the respiration of a Viennese citizen which requires 10,64 tons of fresh air each year and releases 10.85 tons of offgas to the atmosphere. The last part is caused by water which is evapotranspirated by human activities, which include as watering of the garden/plants, cooking, sweating and others.

The second biggest flow is the import of fresh air into the system of Vienna by the atmosphere. It amounts to 32.88 tons and it is to one third consumed by the human respiration and to two third by the combustion of fuels, mostly fossil.

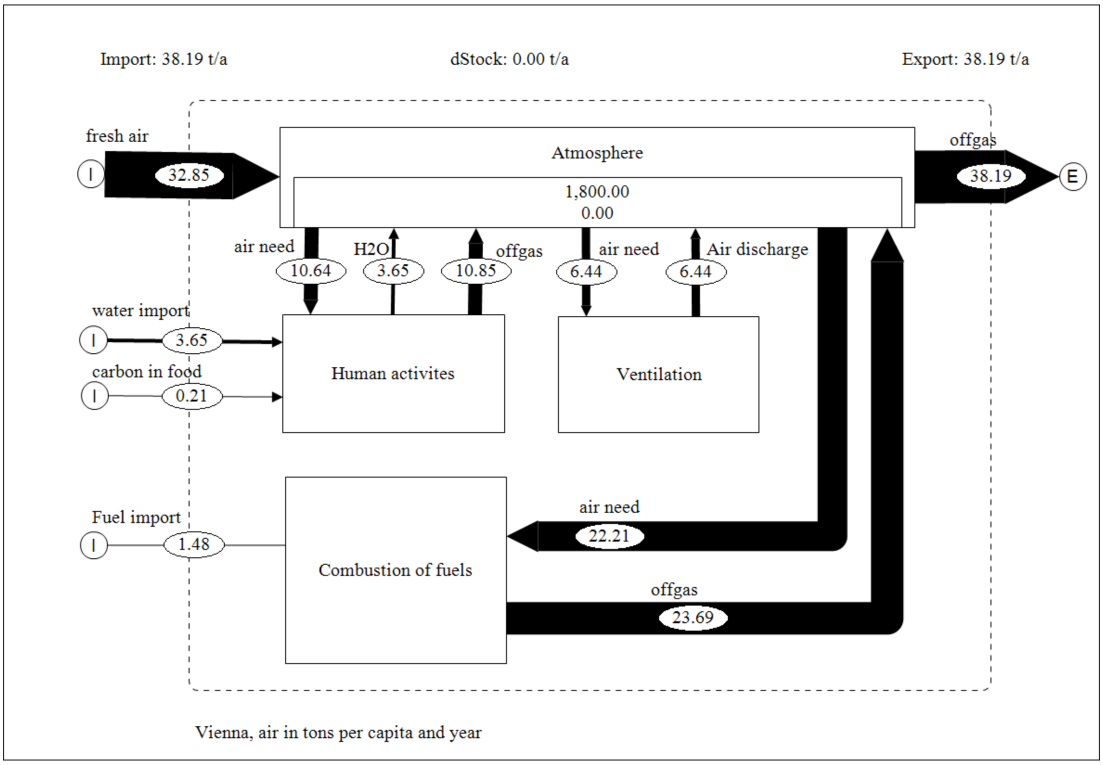
From the other imports the import of water which is evapotranspirated is the biggest one and amounts to 3,65 tons per capita and year. To mention is also that the impact of non greenhouse gases in terms of weight in relation with the green house gases is negligible small. It amounts to less 1,4%.

The circulation of air between the atmosphere and working places is shown by the process "Ventilation" and amounts to 6, 44 tons per Viennese citizen. This is only the third or fifth biggest flow within the system "Vienna", but about 30% or 60% of the two biggest flows of the other two processes.

The stock, volume, of air which is within the system of Vienna does not change over a year. In terms of weight it changes only with the weather, less if it is raining or/and warm, more if the air is dry and cold. This is due to the fact that air expands when it is warmed and because water molecules have a lower weight than nitrogen or carbon molecules. Generally it can be said that in the system Vienna the stock of air in the material flow analysis does not take and important role, as it is exchanged with the atmosphere outside of the system. Nevertheless it is clear that a stock of 1.800 tons per capita would be consumed quite fast by the system of Vienna. 32.85 tons of air is consumed by for each citizen of Vienna each year. This would be enough for more than 50 years if the concentration of CO_2 would not become toxic for humans or the oxygen level would get to low. Considering that when the oxygen reaches a level of

15% of the air volume becomes insufficient the stock of air of the city of Vienna would be enough for only 15 years. Each year about 6,12 tons per capita reach the atmosphere (1,67 of carbon are consumed, divided by its molecular mass of 12, multiplied by the molecular mass of CO2 of 44, gives 6,12 tons). Considering the toxicity of CO2 (see begin of chapter 4.1), which starts at 1%, the stock would be enough for less than three years. 5to 8% of CO2 concentration are deadly. In that case, till the severe risk would treat the human population, the stock would be enough for less than 15 years.

Graph 5.1.1.: System "Air"



5.1.2. Dissipation and final sinks

Air, as water, has no final sink as it is lying on the earth surface composing the atmosphere. Research is being made to find out how to store greenhouse gases and other gases before releasing them to the atmosphere. Technology, like filters and catalysts, is already in place to limit emissions to an acceptable level.

Air has many uncontrolled flows, but in this thesis no dissipation of air is considered as the uncontrolled flows always and up or happens in the atmosphere.

As mentioned, air has no final sink and it is not considered to be a final sink for substances as in the atmosphere no substance has a lifetime of more than 10.000 years. Nearly all substances react within the atmosphere, settle to the surface again or are taken out of the atmosphere via different processes.

In regard to the final sink of the substances which compose the carbon footprint, the ecological footprint gives an exact table of much land and sea processes is needed to clean the used air. [Daxbeck et al., 2009b]

The Ecological Footprint of Vienna is 3.9 ha/c. The calculation included 36 materials as a measure for the direct processes use, 7 energy carrier groups, and 53 groups of materials as an additional energy input from imported and disposed materials. [Daxbeck et al., 2009b]

*"The categories most dominant in Vienna's Footprint are the CO2 Processes, Grazing Land and Cropland. Together these categories are responsible for 91 % of Vienna's Ecological Footprint. The key components of the CO2footprint Processes are liquid fuels (28 %), energy embodied in the materials (26%) and natural gas (26 %). Meat and milk products are largely responsible for the Grazing Land component of the Footprint. Cropland usage is primarily influenced by food consumption (largely cereal*s)." [Daxbecket al., 2009b]

The atmosphere is partially, relatively very small amounts, lost into the space or parts can be taken up by the oceans, as carbon which than reacts, settles and forms limestone. This process though has significant effects only in the in the long term (1000 of years). The atmosphere can get even recharged by eruptions of volcanoes so that it stays in a variable equilibrium. The composition of the atmosphere changes in the long term caused by volcanoes, the biosphere and lately also by human activities.

5.2. System “Water”:

Water is vital for human needs and it is scarce. These two factors combined make water conflicts very likely to occur as soon as the scarcity of water has repercussions on the daily life of people. Kofi Annan in 2002 already warned about these possible conflicts: “*Fierce national competition over water resources has prompted fears that water issues contain the seeds of violent conflict.*” [BBC, 2002]

Water is not only the biggest anthropogenic flow amounting to about 75%, but it is also the biggest natural flow on earth. The ultimate source of all fresh water is rain, which either runs off in rivers till joining the sea or big lakes, or it is stored in aquifers. Worldwide is this stored water, the groundwater, the most important source of fresh water for humans. It amounts to 97% of the available world freshwater. This is due to the fact that only 2.67% of the $1{,}36 \times 10^{15}$l [Wirtschaftsmuseum, 2003] worldwide water is sweet; more than two thirds of it is frozen in both poles and glaciers. Liquid surface drinkable water would anyway represent only 1% of the total sweet water, but it is mostly contaminated. Actually, only 0.6% [Wirtschaftsmuseum, 2003]

Of the water of the blue planet is liquid freshwater but only 0.27 [Wirtschaftsmuseum, 2003] is theoretical available for human needs for human needs. Therefore, humanity is shifting its focus towards the sustainable exploitation of water. The first step in doing so is to understand the anthropogenic water use. In this regard MFA’s are an important tool.

In Austria not Groundwater but spring water is the main source of fresh water with 50% [Wirtschaftsmuseum, 2003]. Still 49% of the fresh water is provided by groundwater reservoirs, the remaining 1% is coming from surface waters [Wirtschaftsmuseum, 2003]. Vienna, a part of special situations, could cover its water need entirely with spring water. This is not the case for other European countries. Germany covers its needs mainly with groundwater, 64%, only 8% is covered with spring water. [Wirtschaftsmuseum, 2003] Great Britain has no spring water at all and relies mainly on surface water 75%. Other attempts to find new sources are made in Singapore where sewage is cleaned till it reaches drinking water quality to covering 30% of the water need (228.000t/d) of its 4.6 million people.

[Siemens, 2010]. This technology was first installed from Orange County, California where today the largest plant, the Groundwater Replenishment System is since 2008 in use and produces 265,000 tons of water per day (Bryan Walsh, 2008).

According to the Austrian Ministry of Life (2010), the most water worldwide is used for agriculture with about 70% of the total turnover. In Europe, however, it is in terms of overall water use 24% and in Austria only 5%. Worldwide 20% of the water use is in industry, which is often not specified whether the cooling water for power generation is included in this number or not. About 11% of the total European water is used in industry

Still according to the Austrian Ministry of Life (2010), an Austrian consumes in average 130l a day at home which increase to 242l if the total water consume is considered. This direct accounting of the water use is not the only way of calculating the average water consumes per person. Another approach is the **water footprint.** It considers the total volume of freshwater used to produce the goods and services consumed by the individual. It does not only consider the purely anthropogenic flows but also the natural ones like rain used to produce corn. Following this method it leads a world average consume of 1385 tons per capita and year. (Water Footprint Network) An Austrian consumes 1598tons of water, where 68% (Water Footprint Network) of it is consumed abroad for his needs. The water footprint is not considered in this thesis.

For Vienna is to mention that since the opening of the “Wiental Kanal”, a new sewer (since 2005 in operation) which can store 110.000 tons of water in case of heavy rain, the sewer system does need to use the overflow mechanism and all sewage is flowing to the Viennese waste water treatment plant (MA 30,2011). This central waste water treatment plant cleans all Viennese sewage and releases it afterwards to the “Wien Kanal” which joins shortly after the Donau.

5.2.1. Balance of the good “Water”

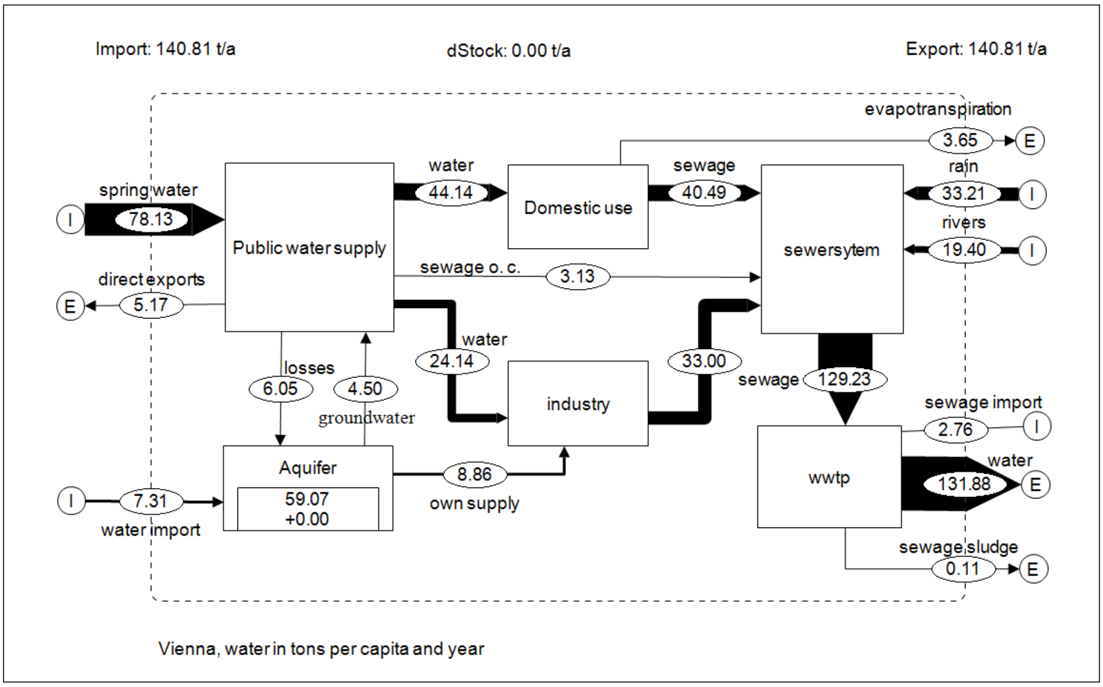
The biggest anthropogenic water flows are the sewage which reaches the water treatment plant and the cleaned water which leaves the plant with respectively 129.23 and 131.88 tons per head. The small difference is due to the relatively small amount of sewage import (2.76t/c*a) into the system “Vienna” and the nearly negligible amount of 0.11 tons per capita of sewage sludge, which corresponds to less than 0.1% and is transferred to the waste incineration plant. 41%, and therefore the biggest flow of the sewage in Vienna is due to rainfall and rivers merging the sewage system. 31% of the sewage is coming from domestic households, 25% is coming from the industry and 3% from the own use of the public water supply. To mention is that the average precipitation in the year 2009 was 900l per square meter which is 143% (Statistics Austria, yearbook 2011, 2011) of the normal precipitation.

After the water export of the waste water treatment plant and the water coming from the sewer system the spring water import is the third biggest flow with 78.13 tons per capita. As only 13.36 tons per capita are extracted by the public and privately, more than 80% of the water used in Vienna is imported. If the groundwater, which is not entirely within the border of Vienna, would be considered the right way, this percentage would be even higher.

The biggest users of fresh water are private households where each person consumes in average about 120l a day. This corresponds to more than 44 tons a year and it is about halve of the water used in Vienna. The industry “consumes” about 40% of the water and discharges it completely into the sewer system whereas the households only transfer 92% of the water to the sewer system, the rest, 3.65 tons per capita, is evapotranspirated. Non negligible are the losses which amount to 6.05 tons per capita, which corresponds to more nearly 7% of the total water consume in Vienna. The remaining 3% are used by the public services and completely discharged to the sewer system. To mention is also that another 5.17 tons per capita reach Vienna, but they are directly exported to neighbouring communes.

The Aquifers may have only a relatively small stake in the water supply of Vienna, but they are of great importance as they can provide the city with water during special periods when, for example, the spring water pipelines need to be maintained or exceptional high water quantities are demanded.

Graph 5.2.1.: System "Water"



5.2.2. Dissipation and final sinks

Water, as air, has no final sink as it is flowing around the earth in the known water cycle. Only huge aquifers like the Guarani aquifer in South America and the Great Artesian Basin could be considered as such, because thee recharge time is estimated to be far above 10.000 years. The Great Artesian Basin has an average groundwater flow of 1 meter per year, with a length of 1000 kilometres, the water travels for a million years from the source till the other end of the aquifer system [Herczeg, 2008]. The Guarani aquifer has an average groundwater flow of 0,5 meters per year, with a maximum length the of over 1000 kilometres from the main source to the opposite end the water travels even longer [OAS, 2009]. Nevertheless is it the case of non contaminated water the discussion of a final sink not of concern.

Rather can water be a final sink for many substances, as the black sea, which is an appropriate final sink for the cadmium emissions of Vienna (Brunner dixit, 2010) and other processes which discharge cadmium into the Danube.

In the best case scenario are substances which are discharged into the water by human activities transported to the waste water treatment plant where they are taken out of the water, incinerated and subsequently landfilled in way that guarantees a final sink quality. This is not yet the case as landfill storage has not yet reached final sink quality [Fellner, 2010] and the waste water treatment plants and the waste incineration plants have not an efficiency of 100%. Furthermore not all by Human activities polluted water reaches a waste water treatment plant. Not to forget that in water dissolved substances cannot be taken out by a waste water treatment plant.

Once polluted water joined a river most substances end up in an ocean which sometimes is an appropriate substance (black sea for cadmium) and sometimes it is not, as in the case of the Baltic Sea where excessively amounts of phosphor, which is used and washed out from arable land, is causing enormous problems of eutrophication. [Fellner, 2010]

Not necessary are oceans the final sinks for substances in river. Some settle in the river belt others end up in the delta of a river, if there is one and the river has a steady flow. This is the case of the Nile delta, which became the (final) sink for many substances when the Assuan dam was opened.

The dissipation of water is considered by two flows in this thesis. The losses of the supply system air assumed to end up in the groundwater and the evapotranspirated water goes to the atmosphere.

5.3. System “Construction materials”:

Nearly all construction materials in Austria are coming from places which distance on average 30 kilometres from the place where they are needed. This is shown also by the fact that every second Austrian village has its own production activity [Hennrich et al., 2007]. Only few exotic construction materials are imported as for example the coveted marble stone (e.g. the Austrian parliament is made out of Laser marble, imported from South Tyrol).

As in cities huge amounts of construction materials are needed, plays the hinterland of the city an important role as source. This leads to the problem of causing big holes in the hinterland, which are not refilled, and increasing the stock in the cities.

Generally about 95% of the construction materials used in Austria, about 95.300.000 tons, consist of gravel, sand, clay and kaolin [Hennrich et al., 2007]. The rest, 4.800.000 tons, consists of natural stones (Die volkswirtschaftliche Bedeutung mineralischer Rohstoffe inÖsterreich” from Forum Rohstoffe, (responsible, Dr. Carl Hennrich). 90% of the total amount of construction materials is used by the industry in first place of which 60 million tons are used directly and 30 million tons are farther processed before they are used. [Hennrich et al., 2007]. The remaining 10 percent are used to produce either glass or detergents or used in the agricultural sector [Hennrich et al., 2007]).

5.3.1. Balance of the good "Construction materials"

The biggest flow in this system is the construction materials flow coming from the hinterland and joining the consumption process with 9,5 tons per capita and year. Another 2,4 tons are provided to this process by the recycling. Further it was assumed that about 100kg of construction materials per person are imported from abroad.

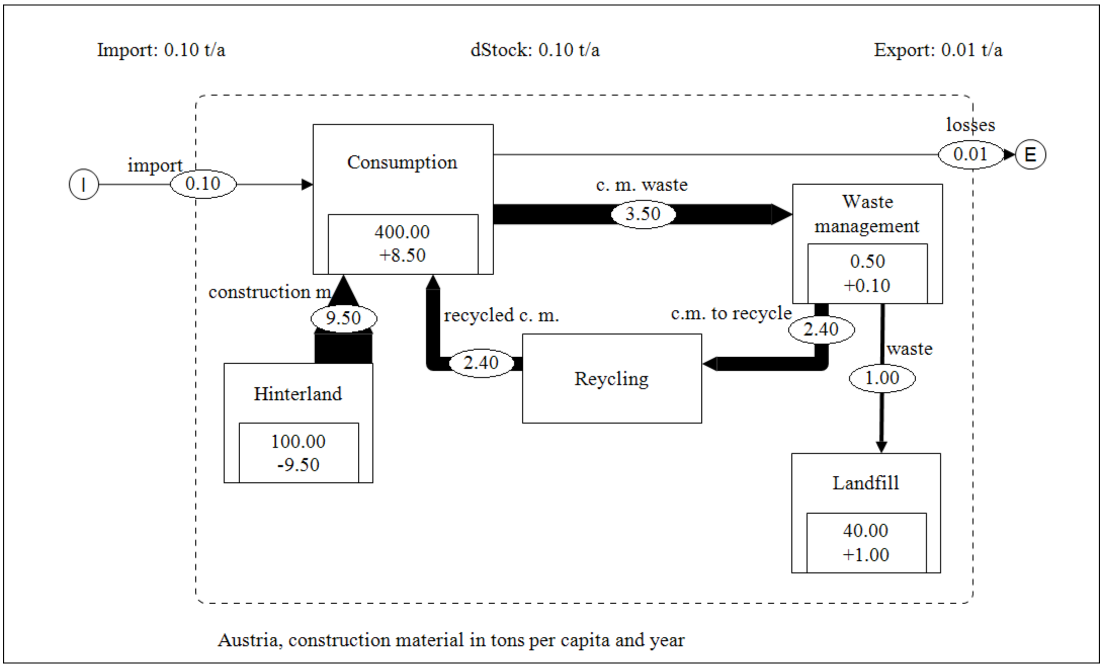
The second biggest flow is the waste from the consumption process with 3,5 tons per capita. More than 65 % of this flow is recycled and flows back into the consumption process. About 30% is landfilled and 3% of the construction waste is stored. This shows clearly that the recycle process is an important source for new construction materials and the regulation 2008/98/EG [Klaffl et al., 2011], which requires a recycling rate of 70% by 2020, is already nearly fulfilled.

Every person "possesses" nearly 450 tons of construction materials, of which 400 tons are in the consumption process and 40 tons is in the landfill stock. The stock increase of the consumption and landfill process is equal to the negative stock delta of the hinterland, which is not refilled. The stock of the hinterland is not estimated but only arbitrarily chosen and amounts to 10.000 tons per person.

The stock of the waste management process is due to the yearly stored construction materials which amount to about 100kilograms per person. Most of this stored material will be reused in the future. This stock is arbitrary chosen to amount to 500 kilograms per person which is equal to the sum of material stored over five years.

The smallest flow is the losses flow which is assumed to be about 5 kilograms per person and year. This amount is partially recovered in the waste water treatment plant, but it is not considered in this thesis.

Graph 5.3.1.: System “Construction materials”



5.3.2. Dissipation and final sinks

The environmental impact is not yet assessed in detail. Graedel and Leygraf explore the corrosion of carbonate stone (Atmospheric Corrosion, 2000) by either CO_2 or dissolved SO_2 (So_4^{2-}). The runoff enriches the river with calcium, which anyway occurs in water naturally and functions as a pH stabilizer, other substances which runoff are as well naturally present in water. Therefore, it was assumed that the runoff of construction materials has no big environmental impact.

Generally it can be said, that the sediments which are not recovered in the waste water treatment plant find their sinks in soils, which can be the bottom of a river, deltas, the ocean belt (where Calcium together with Carbon forms carbonate stones) or flooded land. They seem to be appropriate sinks because of the natural properties of this runoff.

Problematic is the dissipation of construction materials from old constructions, which risk collapsing or losing their glaze as it is the case for old Roman or Greek artefacts.

5.4. System “Iron”:

The worldwide iron production, resources, and consume is shown in the following table:

Table 5.4.: Iron worldwide:

	IRON
Production worldwide	787,09 million tons
Resources	79 billion tons
Consume worldwide	1.059,4 million tons
Application	Car industry, construction industry, machines, plants
Main producers by nations	Brazil (22,3 %), Australia (19,6 %), China (15,1 %), India (11,1 %), Russia (7,4 %)
Coverage by top 5 - 10 nations	Top 5: 75,5 %, Top 10: 91,8 %
Main producers by companies	CVRD (Brazil, 18,5 %), Rio Tinto (Great Britain, 9,4 %), BHP Billition (Australia, 8,6 %), Cleveland Cliffs (USA, 2,5 %), Anglo American (Great Britain, 2,4 %)
Coverage by top 10 companies	Top 5: 41,4 %, Top 10: 48,8 %
Problematic	None of relevance

Data source: German Federal Agency for geosciences and resources, 2007

5.4.1. Balance of the substance “Iron”

The biggest anthropogenic iron or steel flow is the production of steel which is then used to produce products of steel. The most important inflow for the production of steel is the pig iron from the production of iron process with nearly 700 kilograms per capita and the import of scrap iron with 215 kilograms per capita. Other inflows are the scrap iron from the waste management process (28 kg/c) and imported pi iron (5 kg/c). To mention is for that in this process 3,5% of the amount of produced crude steel is lost by the reduction of carbon during the transformation of iron into steel.

The second biggest flow is the export of semi finished and finished goods with 856 kilograms per person, which is nearly twice as much as used within the system (484 kg/c). These products are either produced with the crude steel or imported from abroad. The amount of imported steel products is by about 13 kilogram per capita bigger than the amount of products used within the system. Therefore is the production of semi and finished steel products which amount to 843 kilogram per person slightly lower than the export flows. The smallest flow is given by the losses which are in the range of 7% in comparison to the crude steel used.

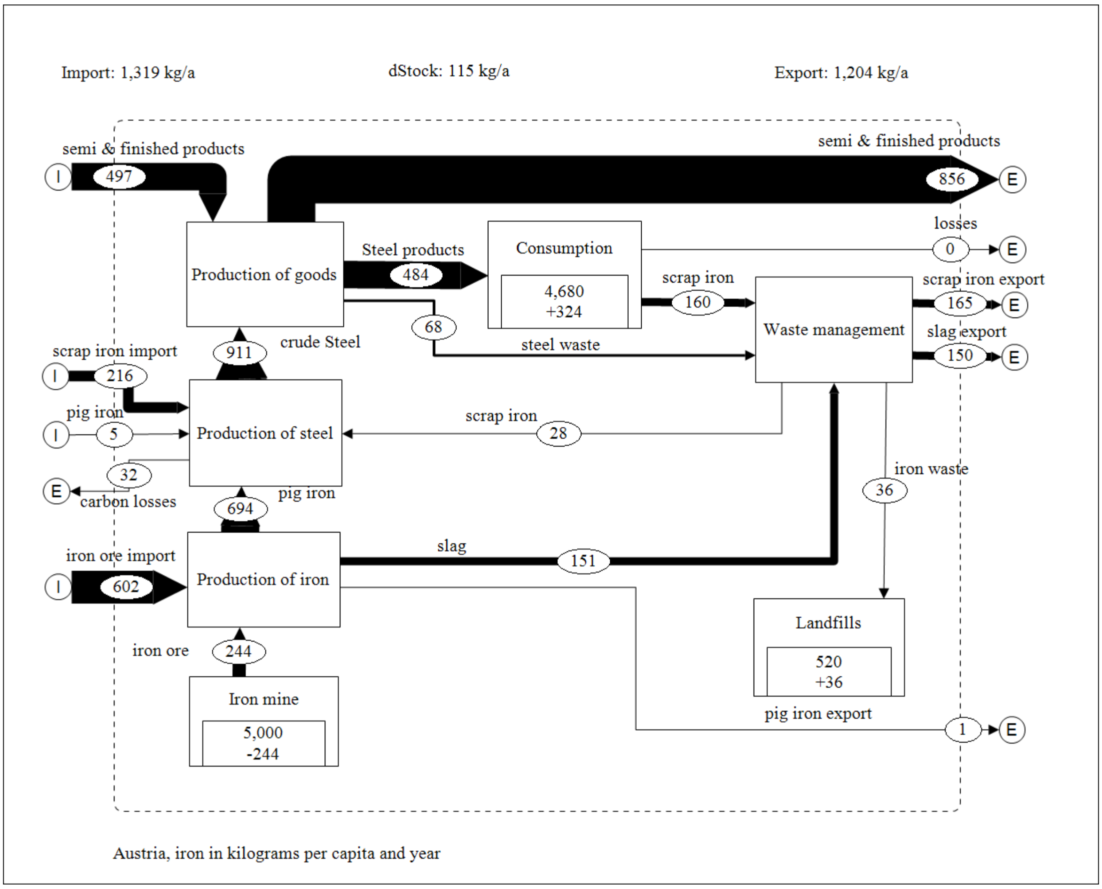
The third biggest flow is consists of the produce iron pig, which is made out of 70% of imported iron ore, the rest is coming from Styria.

Apart of the stocks are the stock deltas the next biggest amounts in this system. In the city the stocks increase by nearly 360 kilograms per person and year. 90% of it is in the stock consumption the rest is landfilled. The ore mine instead decreases each year by 243 kilogram iron per person. With the end of this year the anthropogenic stock will therefore be bigger than the natural one, considering today’s economical rentable resources.

The scrap iron flow from the consumption process to the waste management process is nearly as big as the export of scrap iron. The rest and the amount of scrap iron delivered to the steel production process is covered by the steel waste from the production of goods.

The losses are with 200 grams per person and year relatively small, but as it is an uncontrolled flow it brings the greatest environmental risk with it.

Graph 5.4.1.: System “Iron”



5.4.2. Dissipation and final sinks

It was assumed that about 200 grams of iron are lost per year (see calculations and assumptions in chapter 4.2.4.). A part of these losses will remain within the system and not leave it entirely as shown in the previous chapters. A part will remain in the urban soil or groundwater; others will be transported by water trough the sewer system into the waste water treatment plant. As Iron is a heavy metal (high density) it will then partially remain in the sewage sludge which is subsequently burned. The resulting iron enriched slag from the waste incineration plant is then landfilled[6].

Landfills however are no final sinks as they cannot guarantee final sink quality [Fellner, 2010]. The losses which leave the system can follow different pathways. They either reach waters which do not pass the waste water treatment plant and are

[6] In Germany about 10% of the total losses [German Federal Environmental Agency, 2005]

transported away, they stay in the water which is release from the waste water treatment plant or leave the system via the atmosphere when the iron enriched slug is burned. The transfer coefficients of these amounts using different pathways are not assessed in this thesis.

The diffusive losses will finally end up, whether within the system or not, in the soil, in the groundwater or in the ocean (via the Danube to the Black Sea). Before reaching these final sinks they can be intermediately stored in landfills, cities (buildings), humans, animals or other waters (e.g. rivers). As iron is an essential element for some animals, naturally present in the environment and no data on excessive emissions of iron was found, it was assumed that the amounts of emitted iron do not threat the environment.

This may also be the reason why not much research was done on this emissions and regulations are not as complete as for the hazardous copper and zinc concentrations (Community Legislation on copper and zinc in the EUROVOC categories 'Environment', 'Transport' and 'Agriculture, forestry and fisheries' [Vos, Janssen])

5.5. System "Copper":

The worldwide copper production, resources, and consume is shown in the following table:

Table 5.5.: Copper worldwide

	COPPER
Production worldwide	15,1 million tons
Resources	470 million tons
Consume worldwide	16,6 million tons
Application	Electro industry, construction industry, machines, coins
Main producers by nations	Chile (35,3 %), USA (7,6 %), Indonesia (7,1 %), Peru (6,7 %) Australia (6,2 %)
Coverage by top 5 - 10 nations	Top 5: 62,9 % , Top 10: 83,0 %
Main producer by companies	Codelco (Chile, 12,5 %), BHP Billiton (Australien, 8,6 %), Phelps Dodge (USA, 6,8 %), Grupo Mexico (Mexico, 5,8 %), Rio Tinto (Großbritannien, 5,4 %)
Coverage by top 10 companies	Top 5: 39,1 % , Top 10: 58,1 %
Problematic	Great demand of copper iron and scrap iron by the BRIC nations.

Data source: German Federal Agency for geosciences and resources, 2007

5.5.1. Balance of the substance "Copper"

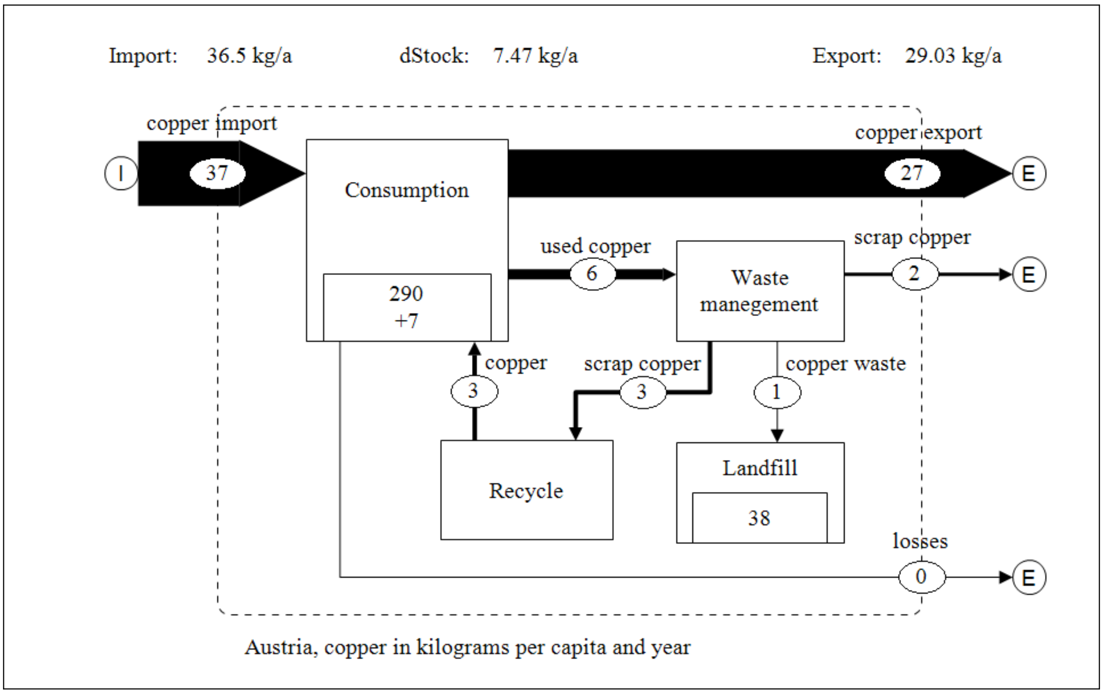
The biggest anthropogenic copper is the import of copper with 37 kilograms per person followed by the export of copper with 27 kilograms. All other flows are less than 20% of the biggest flow and the stock increase of the consumption process is the third biggest amount with nearly 7 kilograms per person. The discharged used copper is the third biggest flow in this system with approximate 6 kilograms per person. About 55% of this flow is recycled within the system, 35% is recycled abroad and the remaining 10% is landfilled.

As 35% of the total used copper is exported it leaves the system and therefore it reduces the copper resources of the system. The same could be said about the landfilled copper, which is stored and a reuse is not foreseen. This although could change in the future when it will be economical more attractive to recover the landfilled copper.

To mention are the stocks which together are nearly ten times as big as the copper import flow, or more than 50 times as big as the yearly discharged copper. The increase of the stocks is about eleven times bigger within the city than in the landfills, the relative increase of the stocks is by about 50% bigger in the city than in the landfills.

The by far smallest flow is represented by the losses. Each person in Vienna "loses" about 26 grams of copper a year. This amount may be very small but due to the fact that it is an uncontrolled flow it contains the greatest risk for the environment.

Graph 5.5.1.: System “Copper”



5.5.2. Dissipation and final sinks

The diffusive losses of copper amount to 26 grams per person and year. 8,9 grams are emitted by buildings, 2 grams are emitted by the activities to nourish and clean, 14 grams are lost by the traffic (vehicles), 0,02 grams are emitted by the waste incineration plant and 1,4 grams is emitted by the wwtp [Obernosterer et al.,2003].

A part of these losses will remain within the system and not leave it entirely as shown in the previous chapters. A part will remain in the urban soil or groundwater; others will be transported by water trough the sewer system into the waste water treatment plant. As copper is a heavy metal (high density) it will then partially remain in the sewage sludge which is subsequently burned. The resulting copper enriched slag from the waste incineration plant is then landfilled[7].

Landfills however are no final sinks as they cannot guarantee final sink quality [Fellner, 2010]. The losses which leave the system can follow different pathways. They either reach waters which don’t pass the waste water treatment plant and are

[7] In Germany about 10% of the total losses [German Federal Environmental Agency, 2005]

transported away, they stay in the water which is release from the waste water treatment plant or leave the system via the atmosphere when the copper enriched slug is burned. The transfer coefficients of these amounts using different pathways are not assessed in this thesis. The diffusive losses will finally end up, whether within the system or not, in the soil, in the groundwater or in the ocean (via the Danube to the Black Sea).

Before reaching these final sinks they can be intermediately stored in landfills, cities (buildings), humans, animals or other waters (e.g. rivers). As copper is an essential element for some animals, naturally present in the environment and no data on excessive emissions of copper was found (high concentration of copper are harmful for the environment [Vos, Janssen, 2008]), it was assumed that the amounts of emitted copper do not threat the environment.

5.6. System "Zinc":

The worldwide zinc production, resources, and consume is shown in the following table:

Table 5.6.: Zinc worldwide

	ZINC
Production worldwide	10,1 million tons
Resources	220 million tons
Consume worldwide	10,6 million tons
Application	Electroplating (car, construction industry, non ferrous alloys (brass), pharmaceutical preparations, dry-cell batteries, pigments
Main producers by nations	China (25%), Australia (13,5%), Peru (11,9%), USA (7,4%), Kanada (6,6%)
Coverage by top 5 - 10 nations	Top 5: 64,4% Top 10: 84,2%
Main producer by companies	Teck Cominco, Canada, 6,6%), Zinifex (Australia, 5,9 %), Glencore (Swiss, 5,7 %), China (4,8 %), Vedanta Resources Great Britain 4,6 %)
Coverage by top 10 companies	Top 5: 27,6% Top 10: 45,7%
Problematic	China is the biggest producer, but together with the other BRIC it is countries one of the biggest consumers.

Data source: German Federal Agency for geosciences and resources, 2007

5.6.1. Balance of the substance "Zinc"

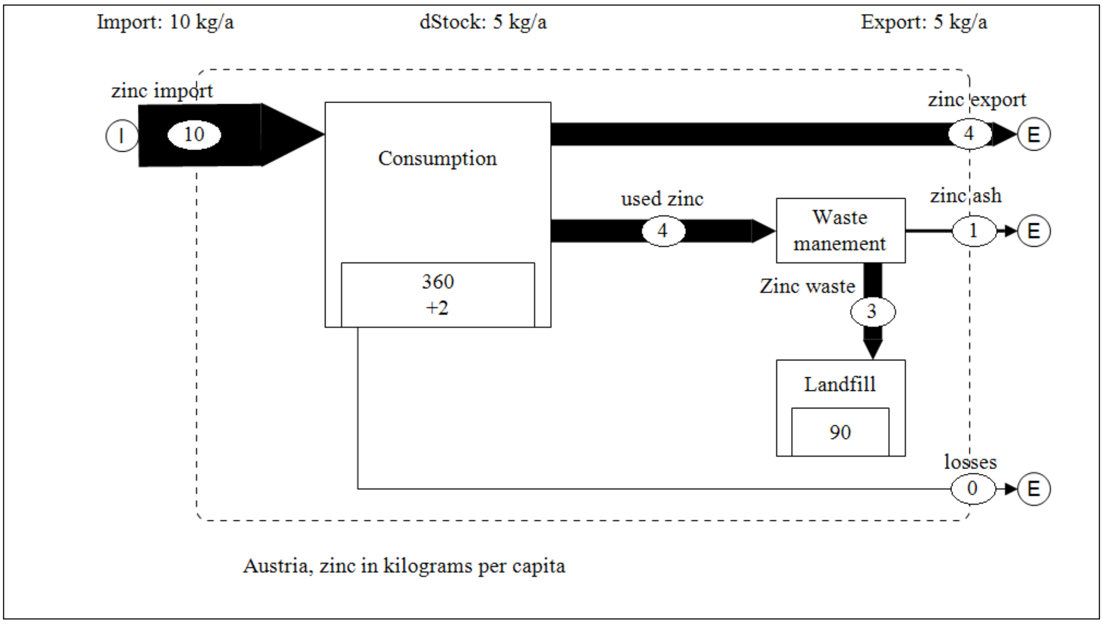
The biggest anthropogenic zinc is the import of zinc with10 kilograms per person followed by the export of zinc with 4 kilograms. The discharged used zinc is the third biggest flow in this system which is approximate as big as the exported zinc (4 kilograms per person). Nearly 20% of this flow is exported as zinc ash for recycling, the rest, 3 kilograms per person, is landfilled.

As more than 30% of the zinc import and more than 80% of the used zinc is landfilled and a reuse is not foreseen, it reduces the amount of zinc available significantly. This although could change in the future when it will be economical more attractive to recover the landfilled zinc.

To mention are the stocks which together are nearly 50 times as big as the zinc import flow, or more than 100 times as big as the yearly discharged zinc. The increase of the stocks in the consumption process is about 50% smaller than in the landfilled process.

The by far smallest flow is represented by the losses. Each person in Vienna "loses" about 82 grams of zinc a year. This amount may be very small but due to the fact that it is an uncontrolled flow it contains the greatest risk for the environment.

Graph 5.6.1.: System "Zinc"



5.6.2. Dissipation and final sinks

The diffusive losses of zinc amount to 82 grams per person and year. 44 grams are emitted by buildings, 10 grams are emitted by the activities to nourish and clean, 18 grams are lost by the traffic (vehicles), 0,08 grams are emitted by the waste incineration plant and 10 grams is emitted by the wwtp [Obernosterer et al.,2003].

A part of these losses will remain within the system and not leave it entirely as shown in the previous chapters. A part will remain in the urban soil or groundwater; others will be transported by water trough the sewer system into the waste water treatment plant. As Zinc is a heavy metal (high density) it will then partially remain in the sewage sludge which is subsequently burned. The resulting zinc enriched slag from the waste incineration plant is then landfilled[8].

Landfills however are no final sinks as they cannot guarantee final sink quality [Fellner, 2010]. The losses which leave the system can follow different pathways. They either reach waters which don't pass the waste water treatment plant and are transported away, they stay in the water which is release from the waste water treatment plant or leave the system via the atmosphere when the zinc enriched slug is burned. The transfer coefficients of these amounts using different pathways are not assessed in this thesis. The diffusive losses will finally end up, whether within the system or not, in the soil, in the groundwater or in the ocean (via the Danube to the Black Sea).

Before reaching these final sinks they can be intermediately stored in landfills, cities (buildings), humans, animals or other waters (e.g. rivers). As zinc is an essential element for some animals, naturally present in the environment and no data on excessive emissions of zinc was found (high concentration of zinc are harmful for the environment, zinc pigments are very harmful for aquatic life and can pollute waters in the long term [Vos, Janssen, 2008]), it was assumed that the amounts of emitted zinc do not threat the environment. To mention is although that zinc pigments are very harmful for aquatic life and can pollute waters in the long term.

[8] In Germany about 10% of the total losses [German Federal Environmental Agency, 2005]

5.7. Balance of the system "Vienna":

The biggest flow of the system "Vienna" is the water export with about 130 tons followed by the other water flows, where the supplied water is the biggest with about 80 tons, the sewage with about 77 tons is the third biggest flow, the fresh water, 73 tons per capita, is the fourth biggest flow and the rain + rivers water is with about 53 tons the fifth biggest flow. The natural water cycle amount, which refills the aquifer, is far smaller with a bit more than 7 tons.

The second biggest group of flows are the air flows, where the used air is the biggest flow with about 45 tons per capita. The fresh air flow (39 t/c) the offgas flow (38 t/c) and the air import (33 t/c) are the other flows.

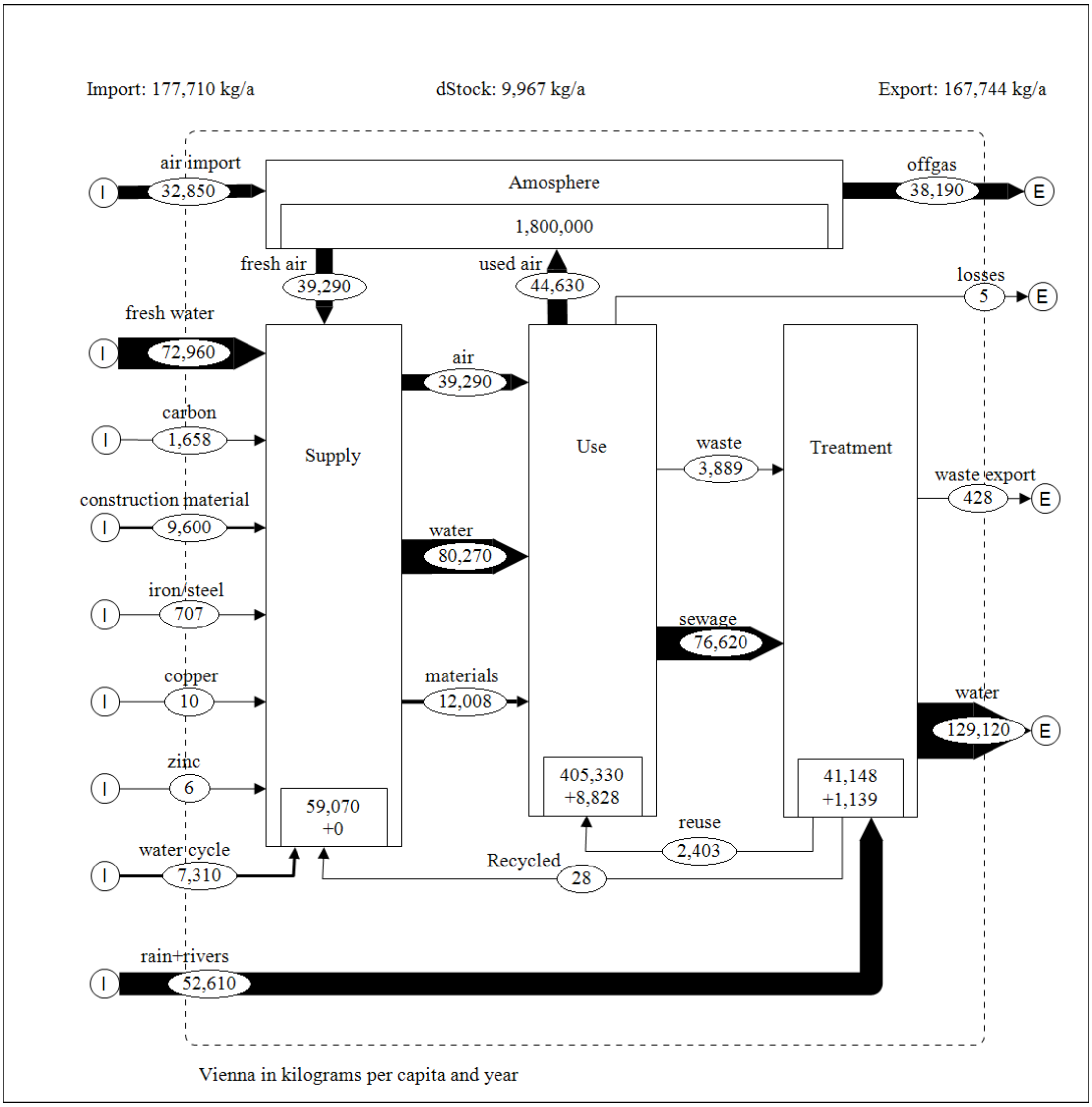
From the side of the imports, in the system "Vienna", the construction materials (9,6 t/c) are with distance on the fourth place. Summed up in the so called goods flow, the imports of carbon (1,7 t/c), iron/steel(0,7t/c), the small amounts of copper and zinc as well as the construction materials built the biggest flow after the water and air flows, with about 12 tons per capita.

Generally, for this system it can be said that about 75% of all import flows and about 77% of all export flows are water flows. A bit more than 18% of the import flows and nearly 23% of all export flows consist of air flows. This difference between air import and offgas export is due to the evapotranspirated water and the burned carbon which are imported as fluid or as solid materials (carbon in food). All other import flows amount to about 7%, where the construction materials are alone responsible for more than 5%. Considering all export flows, the waste export flow amounts to only 0,25%; the losses are, on this scale, negligible small.

The losses flow is the smallest flow of the systems with a bit more than 5 kilogram per person but it has the biggest potential environmental impact as it is an uncontrolled flow.

The total anthropogenic stocks for the system "Vienna" amounts to about 450 tons per capita, the natural aquifer stock does not count for it. The stock increase is significant in the use process with an increase of about 9 tons per capita and year and more than 1 ton per capita and year is stocked in the treatment process, where most of this stock delta is landfilled and a small part is stocked (0,1 ton of construction materials) within the waste management sub-process. In total the stock increase amounts to about 10 tons per capita.

Graph 5.7.1.: System “Vienna”



6. Summary and discussion

Introduction

The planning of the anthropogenic resource use will become more and more important as resources are scarce and their demand is growing.

The high density regions (cities) have a big resource demand and huge stocks considering their superficies. Therefore, it is already now important to coordinate their processes and flows in detail and as the demand is increasing further (apart of new economic crisis), it will remain difficult to uncouple the demand from the population growth, the planning will be even more essential in the future

As the natural stocks of resources decrease by the anthropogenic resource use and the anthropogenic stocks increase, it will become more important to manage this stocks and flows thoughtfully.

To be able to handle these challenges it is essential to understand well the cycles resources undergo during the anthropogenic use. Therefore, this thesis was made. Not with the aim to entirely solve the issues which arise from the anthropogenic resources use, but to show that it is possible to determine the most important flows and stocks of resources to, from and within a city.

For each chosen materials was an own system made. These systems were finally put together into the system “Vienna”, which illustrates the most important flows and process of the mentioned materials for the city of Vienna. The method *Material Flow* Analysis was used to build these systems, which have a temporal border of one year.

Objectives and Research Question

The object of this thesis was to determine the evolvement of the material budget of the city of Vienna during one year. This included quantifying and determining the origins and the imports of the mentioned substances, showing their flows, stocks and processes in an illustrative city (Vienna). Furthermore this thesis tried to detect the dissipation and the final sinks of these substances.

The following questions should have been answered:

- Is it possible to determine the evolvement of the material budget of the six chosen materials for the city of Vienna?
- Which ones are the most important flows and stocks of these materials?
- Can the six materials be presented in one system?
- Is it possible to determine how much materials a Viennese citizen uses in one year and can the results be shown in one comprehensive table?
- Which data is available, which assumptions need to be made?
- How strong influence the assumptions the general results?
- (Can this thesis have practical value?)

Methods

The method Material Flow Analysis was used to compile this thesis. The data input was either used directly or prepared before putting into the systems. For data which was not directly found, or it was not possible to derive it directly from sources some assumption had to be made.

With the help of the STAN software it was possible performing MFA systems with the support of a graphic model, which were made for each explored system with the spatial boarder of Vienna or Austria and the temporal boarder of one year. As base year the year 2011 was chosen; the data input was assumed to be valid for that year or was approximated (stocks).

Generally, with some exemptions (rain, rivers and the water cycle which refills the aquifer), only the anthropogenic flows where considered. For each of the six materials a separate assessment was made to have correct and efficient systems which guarantee the differentiation of these resource cycles.

One further system was put into place which summarizes all other systems in one. This system is defined and elaborated as all the other systems in separate sub-chapters. These sub-chapters follow the ones of the six materials. The results are further discussed and summarized this chapter and illustrated in one table in chapter 7.

The Information retrieval was mainly based on internet research of academic papers, studies and official reports.

Results

The biggest flow of the system “Vienna” is the water export with about 130 tons followed by the other water flows, where the supplied water is the biggest with about 80 tons, the sewage with about 77 tons is the third biggest flow, the fresh water, 73 tons per capita, is the fourth biggest flow and the rain + rivers water is with about 53 tons the fifth biggest flow. The natural water cycle, which refills the aquifer, is far smaller with a bit more than 7 tons.

The second biggest group of flows are the air flows, where the used air is the biggest flow with about 45 tons per capita. The fresh air flow (39 t/c) the offgas flow (38 t/c) and the air import (33 t/c) are the other flows.

From the side of the imports, in the system “Vienna”, the construction materials (9,6 t/c) are with distance on the fourth place. Summed up in the so called goods flow, the the imports of carbon (1,7 t/c), iron/steel(0,7t/c), the small amounts of copper and zinc as well as the construction materials built the biggest flow after the water and air flows, with about 12 tons per capita.

Generally, for this system it can be said that about 75% of all import flows and about 77% of all export flows are water flows. A bit more than 18% of the import flows and nearly 23% of all export flows consist of air flows. This difference between air import and offgas export is due to the evapotranspirated water and the burned carbon which are imported as fluid or as solid materials (carbon in food). All other import flows amount to about 7%, where the construction materials alone are responsible for more than 5%. Considering all export flows, the waste export flow amounts to only 0,25%; the losses are, on this scale, negligible small.

The losses flow is the smallest flow of the systems with a bit more than 5 kilogram per person but it has the biggest potential environmental impact as it is an uncontrolled flow. The final sink for the metals are the soil, the groundwater and the ocean. For construction materials, which represent the main part of these losses, it was assumed that they find their final sink in the soil.

The total anthropogenic stocks for the system “Vienna” amounts to about 450 tons per capita. The stock increase is significant in the use process with an increase of about 9 tons per capita and year and more than 1 ton per capita and year is stocked in the treatment process, mainly landfilled. The total use of the six materials per person and lifetime (8o) is shown in the following table:

Table 6-: Total material consumption per person and 80 years

	Total consumption per person in 80 years
Air	3.100 tons
Water	7.000 tons
Construction materials	1.000 tons
Iron	59 tons
Copper	1 ton
Zinc	0,5 tons
TOTAL	11.190 tons[1]

Data source: Table 7., amounts of total use times 80

[1]this amount is calculated on basis of the data of table 7.

Discussion

The thesis was able to **answer most of the research questions**. It was possible to determine the evolvement of the material budget of the six chosen materials for the city of Vienna. The most important flows and stocks of these materials were defined, explored and presented in weight per capita in one system and summarized in one conclusive table.

Generally it can be stated that most data which was needed to develop these systems was available.

The data was generally from recent years (mainly 2009 or 2008), but also older data was used to compile the systems (data for the system “zinc). Some assumptions had to be made, like the air use for the ventilation of workplaces, the excess air of the burned fuels (carbon), and the assumption that an Austrian citizen would be equal to a Viennese citizen. These assumptions were made conscientious and are considered to not have influence the general results significantly, because:

The **air used for ventilation** is not consumed or enriched by gasses and therefore is this amount changed back and forward from the atmosphere without getting used or exported from the system. The amount of this flow and the high insecurity of its true value make it necessary to mention the possible repercussions a different estimation would have: If not 50% of the work places are ventilated, as it was assumed, but 80%, the flows of this process would be nearly as big as the air need for the process "Human activities", amounting to 10,31 tons per capita and year. If only 20% of the workplace would be ventilated 2,58 tons per capita and year would be needed, which is smaller than the amount of evapotranspirated water. However, as mentioned above, the imports and exports of the system would not change, as this amount of air does not get used and it is only changed back and forward from and to the atmosphere. Therefore, the overall repercussions of this estimate do not affect the overall balance of the system "Vienna" and also for the system "Air" only the process "Atmosphere" and "Ventilation" would have repercussions, which are reflected by bigger or smaller flows and nothing else.

The amount of average **excess air** by fuel combustion is the right one for coal power plants and not far away (smaller and bigger amounts are needed for other combustion from the other combustion processes as illustrated in table 3.2.1.A.). Small errors in this assumption have though big effects as the total amount of exported offgas amounts, with this assumption, to more than 60%. As the amounts of non-GHG were are relatively small, less than 2% off all emission by fuel combustion, they would, even if wrong assumptions were made, not influence significantly the system "air" or the system "Vienna".

To **treat a Viennese citizen like an Austrian** citizen as equivalent is a common practise, but would require a detailed analysis of the material and flows under question to derive the actual differences. This was not analyzed in this thesis.

It is not clear how strong the **divergence of the relative old data** to the actual data is. However are the repercussions for the system "Vienna" negligible small, as only the material zinc is affected by data retrieved from not recent sources [Brunner et al., 1998] and its import amount to less than 0,01% of the total imports. Also the extrapolated stock of zinc amounts to only 0,1% of the total stock of the system of Vienna. The system “Zinc” though, may differs significantly from the actual values.

The recent data though should not divergence significantly to the actual data for the following reasons:

- The stocks are extrapolated to the year 2011.
- Most data sources for the flows are coming from the year 2009 and 2008, which are recent years with similar economic activity.
- The two resources which amount together to more than 90% of the anthropogenic resource flows of the explored resources are not expected to change at individual level as long as the behaviour of individuals does not change (significantly)[9]..

The **last question** though, the one in brackets, cannot yet be answered.

Generally is to mention that the total anthropogenic flows are bigger than shown in these systems, as certain materials were not considered in this thesis. Especially the energy flows would take an important stake in the total anthropogenic material flows of mineral resources.

Furthermore, results and calculations were **influenced** by the above average rainfall. In 2009 the rainwater was 49% above the 30 year average (Statistics Austria, 2011) which increased the treated waste water by about 11 tons per capita.

Some of the findings, which give reasons for further discussions, are listed below:

- The waste which is exported could be a potential source of resources. The exported iron and copper scrap as well as the zinc ash are recycled abroad and leave the system. If these materials would be recycled within the system, fewer imports of materials would be necessary. Furthermore is, in economic terms, material with economic value exported below the price.

[9] New technology can reduce the use of resource use as well, but none significant were put in place the last years

- Landfills are no final sinks. Final storage capacity is not yet reached and the search of appropriate final sinks is going on.
- The amounts of stored materials in the landfills as well as in the city are possible future resources. The concentration of these materials in these stocks is comparable to natural deposits and as soon as it will be economical compatible they may be recovered.
- As the biggest part of construction materials is recycled, more than 60 %, the regulation 2008/98/EG [Klafflet al., 2011], which requires a recycling rate of 70% by 2020, is already nearly fulfilled
- In the system “zinc” more zinc was landfilled than stored in the city. This leads to the assumption that the treatment of waste containing zinc needs to be improved.
- The amount of construction materials which is stored in cities is equal to the whole which is left in the hinterland (approx. 30 km around Vienna) by extracting them. This leads to the problem that more and more material of the hinterland is transferred to the city and is not replaced. This is well illustrated by the two different stock deltas of the systems “Vienna plus hinterland” (delta approximate 0) and “Vienna without hinterland (delta nearly 10 tons).
- From the stock delta and the total stock it is clear that if the same amounts of iron ore are extracted each year it will be finished in the next 20 years. From then on the recycling of iron, as it is already for copper and zinc, will be the only Austrian source of iron. This may change if raw material prices go up or new techniques are developed to make it economic attractable to extract metals from places which today are not economical compatible.
- To mention is that the extraction of one ton of iron, 15 tons of other resources are needed or result as waste. For copper there are even 500 tons of different resources used to extract one ton.

7. Conclusion

The conclusions are illustrated in a final table where the results and findings are summarized and put together. The table consists of the most important flows and stocks of the six explored materials.

On the vertical axes are the three goods (air, water and construction materials) and the three substances (iron, copper and zinc) as well as the total amounts and locations of all six materials shown.

On the horizontal axis are the flows and stocks (import, export, origins, stocks and stock deltas, total use, losses, recycle and final sinks) shown. In the cross section of the table the amounts or locations of the stocks and flows are shown for each material. In the last row the total amounts as well as the main final sinks for the six materials are added together.

The values refer always to weight per Viennese citizen and year. The data from the system “Vienna” (chapter 5.7) was used to compile this table were possible, if this system did not provide detailed enough information data from the other six systems was used. Due to this table it is possible to gain an overview of the explored material budget on one sheet.

Table 7.: Conclusive table

Amounts refer to c&a	**Import**	**Export**	**Origins**	**Stocks + stock deltas**	**Total use** (import+ recycled)	**Losses**	**Recycle**	**Final Sinks**
Air	32,85t	38,19 t	Global / atmosphere	1.800t. +0	39,29t [10]	/	/	/
Water	132,88t [11]	129,12t	pipeline & aquifer	59,07t +0	86,32t[12]	6,05t	6,05t (= losses)	/ (aquifer)
Construction mat.	9,6t	0	Austria & import	440t +9,6	12t	5kg	2,4t	soil
Iron	707kg	315kg	Import & Austria.	5,2t +360kg	735kg	200g	28 kg	Soil, g.water, ocean
Copper	10kg	2kg	import	328kg +8kg	13kg	26,3g	3kg	Soil, g.water, ocean
Zinc	6kg	1kg	import	450kg +5kg	6kg	81g/	0	Soil, g.water, ocean
Total	176.053 kg	167.628 kg	Austria & import	1.909.048 kg +19.946 kg	138.363 kg	6.055 kg	8.481 kg	Soil, g.water, ocean

Data source: see system “Vienna”

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[10] = 32,85t (air import) plus 6,44t (air used by Ventilation)
[11]= 72,96 t (fresh water) plus 52,61t (rain and river water) plus7,31t (water cycle)
[12] = Total import minus rain and river water(80.27t) plus recycled (6,05t)

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9. List of abbreviations:

MFA: Material Flow Analysis

IWA: Institute für Wassergüte und Abfallwirtschaft.(eng.Institute for water quality and waste management**)**

t: tons

kg: kilogramms

c: capita

a: annum

d: day

Wwtp: waste water treatment plant

GHG: Greenhouse gases

c.m.: Construction materials

TOC: Total organic carbon

Ntot: Total nitrogen share

BOD_5: Amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter.

COD: Chemical oxygen demand

g.water: groundwater