MSc Program
Environmental Technology & International Affairs

Is a Central European city without carbon dioxide emissions feasible?
By Analysing the substance flow of carbon and the carbon dioxide emissions in Vienna

A Master's Thesis submitted for the degree of
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supervised by
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Affidavit

I, **TESSA QUANDT**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IS A CENTRAL EUROPEAN CITY WITHOUT CARBON DIOXIDE EMISSIONS FEASIBLE? BY ANALYSING THE SUBSTANCE FLOW OF CARBON AND THE CARBON DIOXIDE EMISSIONS IN VIENNA ", 65 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.

Vienna, 14.06.2011

Signature

Abstract

In order to answer the question whether a Central European city without carbon dioxide emission is feasible this study attempts to determine the quantities of Carbon Dioxide emissions according to the four activities for a Central European city on the example of the City of Vienna. Furthermore, this study assesses how carbon dioxide emissions can be minimized by substituting or compensating the application of best available technologies.

Two different scenarios are investigated for Vienna: The carbon cycle in 1991 as well as the most important carbon flows and carbon dioxide emissions in 2008 are determined with the aid of substance flow analysis and the software STAN. The most important material flows, processes, and stocks within the investigated systems are identified and quantified using statistical data, calculations and assumptions published elsewhere. However, due to the large uncertainties of data and, thereof in part lack of methodology, too, the results have to be interpreted with caution.

The results point out that that the sector with the biggest optimisation potential is the energy and transport sector, allocated to the activity “to transport and communicate”. However, it is not feasible to assume that an existing city with 1, 6 million citizens could be carbon dioxide emission free. Nevertheless, if advanced technologies were to be implemented fully in the transport sector, and gas power plants were to be modernised, around 40 per cent of carbon dioxide emission could be prevented.

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1 Introduction

Global warming has become one of the biggest world issues in the present age because it is causing a lot of problems. With the increase in temperature, more and more glaciers are melting away every year and this water pours into rivers and seas. The resulting increase in the sea level is the main cause of the frequent and severe hurricanes, cyclones and tsunamis. The rise in temperature of water on the surface of sea facilitates in the building up of tsunamis. Natural disasters have blanketed the world in the recent years. Every year, many areas are flooded with water which is a potential threat to the life of humans and animals. Consequently, many people even lose their lives in tsunamis and glaciers that are melting away are depriving many animal species of their habitat. Glaciers are the primary source of food and shelter for polar bears. The rate at which glaciers are melting away presently will soon make the polar bears extinct from earth completely. Also, thousands of cattle are drowned in floods whenever they occur. In addition to that, many people die of severe heat in the summer season every year because temperature is steadily increasing every summer season in comparison to the preceding one. Furthermore, air pollution has made people acquire many diseases. Thus, taking all this facts into account global warming is a big threat to life on earth in many ways. The increase in the concentration of carbon dioxide in the atmosphere is the fundamental cause of global warming. Carbon dioxide is the fundamental greenhouse gas that causes the temperature to rise. In order to reduce the global warming, it is imperative that the level of carbon dioxide emissions is reduced.

Two-thirds of the total electricity in the world is produced from fossil fuels which, while doing this job, make one-third of the total carbon dioxide emission in the world. Along with carbon dioxide, other greenhouse gases are also produced from the fossil fuels that include but are not limited to methane and carbon monoxide. Nature provided us with organic biomass that consume carbon dioxide to produce oxygen, however due to deforestation, organic biomass is also decreasing in number with every passing day as more products are being made of wood. It takes much more time for a tree to grow than the rate at which they are being cut. As a result of this, the fundamental and natural sink for carbon dioxide and therefore the reduction of its level in the atmosphere is readily vanishing. Thus, the level of carbon dioxide in the atmosphere is increasing. Owing to the consequences of the increased levels of carbon dioxide in the atmosphere as discussed above, there is dire need to reduce its level. In order to make the world a habitable place for the future generations and thus more sustainable, measures need to be taken before the situation of no return is reached. This can fundamentally be achieved by reducing the emission of CO2 which requires a combined effort from all countries starting at reduction at the individual sources.

One of the major sources of carbon dioxide emissions are urban settlements. This is due to the accumulated need for electricity, heat, and transport. Although in recent years the energy sector and the transport sector have undergone some dramatic changes which reduced emissions, the level of carbon dioxide emission is still too high. Central Europe has started to implement several different strategies in order to combat climate change and in order to stay committed to the Kyoto protocol.

This thesis will tackle the question whether a carbon dioxide emission free Central European city is feasible by approaching the problem bottom up. It will approach the question by analysing the carbon cycle as most of the carbon is transformed into carbon dioxide, and the sources of carbon dioxide emissions. In chapter 5 the analysis is looking at the carbon dioxide emissions in 2008 in context of advanced technologies and reduction of emissions in a rather creative way. In order to collect comprehensive data the city of Vienna with 1.6 million inhabitants has been chosen as a case study for this thesis.

2 Objectives and Questions

In order to answer the question whether a Central European city without carbon dioxide emission is feasible this study will attempt to determine the quantities of carbon dioxide emissions according to the four activities *to clean, to nourish, to reside and work,* and *to transport and communicate* for a Central European city on the example of the City of Vienna. Furthermore, this study will assess how carbon dioxide emissions can be minimized by substituting or compensating the application of best available technology.

3 Methodology

3.1 General Information

"Anthropogenic systems can be defined by processes, good and materials. Their metabolic process, i.e. the flow of materials through these systems, is characterized by individually selected indicator materials." (Baccini and Brunner, 1991) In order to show the complexity of the regional distribution of the substance carbon and carbon dioxide, this study will use substance flow analysis as described in "Metabolism of the Anthroposphere" by Baccini and Brunner, 1991 and "Material Flow Analysis" by Brunner and Rechberger, 2004. The Substance Flow Analysis will aid to identify and quantify the most important flows, processes, and stocks within a system and show firstly the carbon balance on regional level, secondly identify the transformation of carbon to carbon dioxide in a second Substance Flow Analysis, and thirdly identify the maximum optimisation values of carbon dioxide emissions in a regional system. Furthermore, the spatial and temporal system boundaries for a Central European city have been defined below. Due to the accessibility of empirical data the City of Vienna has been chosen for this study.

3.2 Literature Review

The empirical studies which this study is based on, are Maier et al's work "Ökosystem Großstadt Wien" (1995), the study " Der anthropogene Stoffhaushalt der Stadt Wien" by Daxbeck et al (1996), and the 'Bundesländer Luftschadstoffinventur 1990- 2008' by Anderl et al (2010) for the Austrian ministry of environment. However, this study is an innovative approach towards a topic which has been widely discussed. Such a study has not been conducted before as not only the carbon cycle but also the carbon dioxide emissions and its optimisation possibilities are applied to one city in one study.

3.3 Substance Flow Analysis

"*Mass Flow Analysis (MFA) has been created to "design processes and systems that facilitate careful resource management… Emphasis is placed on the linkage between sources, pathways, and sinks of material, always observing the law of conservation of matter*" (Brunner and Rechberger, 2004). For this reason this research paper is based mainly upon the Mass Flow Analysis. The software tool which has been used in order to design the Mass Flow Analysis and calculate some flows is STAN according to ÖNORM S 2096, an Austrian standard. Following definitions, therefore, are needed for this study regarding Mass Flow Analysis's.

Substance

"*A substance is any chemical element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogenous*." (Sax and Lewis, 1987) Therefore this Mass Flow Analysis can be also called a Substance Flow Analysis as carbon is a chemical element and carbon dioxide is a chemical compound. (Brunner and Rechberger, 2004)

Process

A process here is defined as the transformation and transport of carbon. The transport of carbon through a process simply means that the incoming flow enters the process and then might either be stored or leaves the system in the same form as it enters. In this research paper it would be i.e. carbon in the form of waste water entering the waste water treatment plant and exiting the process waste water treatment plant in the same form but leaving into the Danube. Whereas transformation takes places in processes such as traffic where carbon in form of fuel (liquid) enters the process traffic and leaves being transformed to carbon dioxide in the aggregate state of gaseous emissions of a car.

Flow

"*A flow is defined as a "mass flow rate." This is the ratio of mass per time that flows through a conductor, e.g. a water pipe*." (Brunner and Rechberger 2004) In this study due to the large amounts transported the physical unit of all flows is 1,000 tons per year and the flows are adjusted upwards and downwards in order to make the Substance Flow Analysis clearer. Generally it is differentiated between an input flow and an output flow.

System boundaries

System boundaries are boundaries which define the system in space and time. Substance flows crossing the boundaries are called import flows if entering the system and if exiting the system flows are called export flows.

Activities

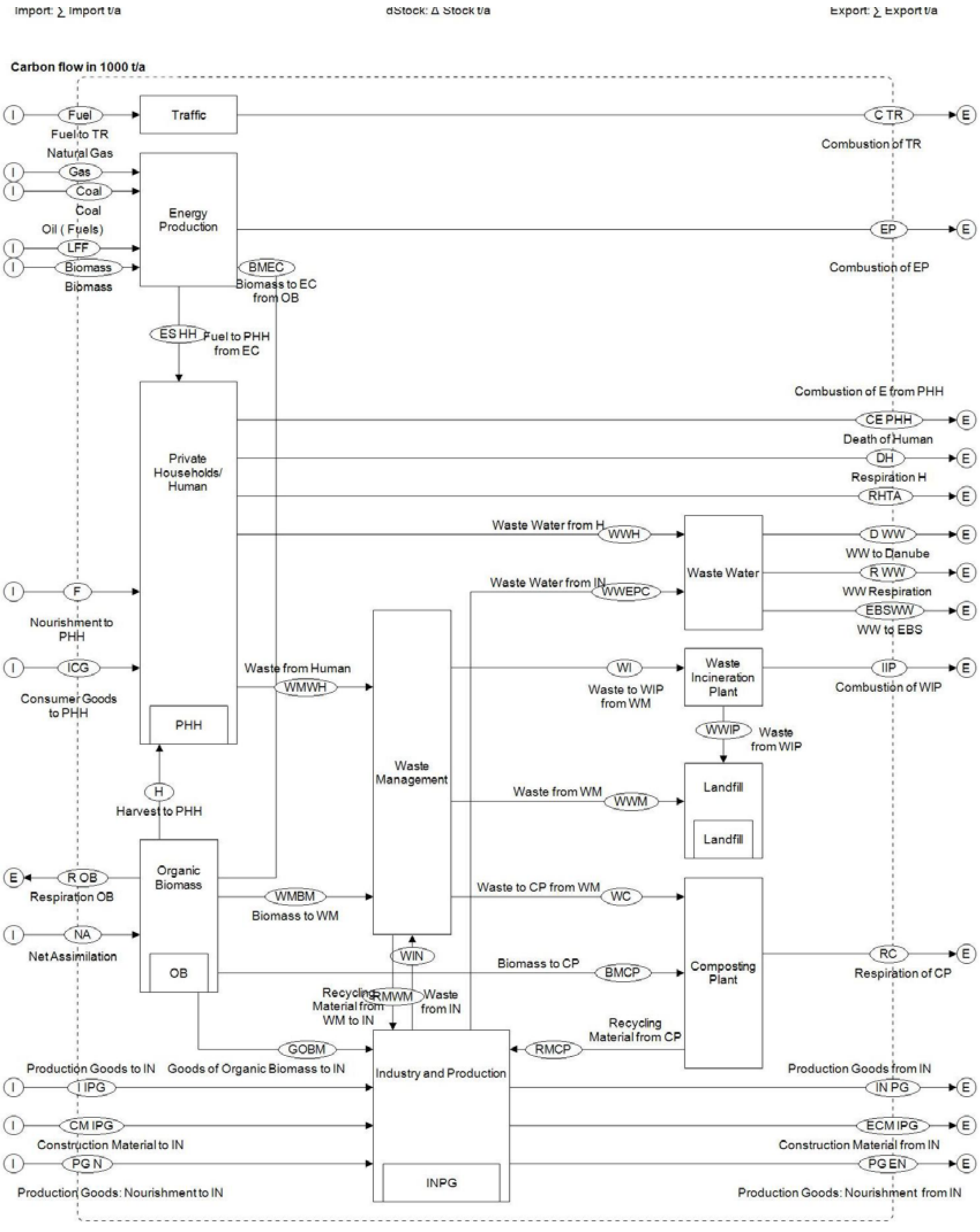
Brunner and Rechberger (2004) have identified activities like human needs which are indispensable such as eating, breathing, and residing. "*An activity is defined as comprising all relevant processes, flows and stocks of goods and substances that are necessary to carry out and maintain a certain human need*" (Brunner and Rechberger, 2004) The adequate activities for this study are the four essential activities: to clean, to nourish, to reside and work, and to transport and communicate. As this thesis is later divided into these four activities, a brief description of the four activities is given in chapter 3.3.4

3.3.1 Identification of the System

This subsection is going to define the geopolitical, spatial, and temporal system boundaries as well as describing the six main processes *Energy Production, Organic Biomass, Private Household, Traffic* and *Waste Management* (including its sub-processes) within the system.

3.3.1.1 System Boundaries

The horizontal system boundary is the geopolitical border of the city of Vienna excluding the Hinterland and commuters from the Hinterland. The temporal system boundary for the carbon balance is the year of 1991 as used by Maier et al (1995) due to the lack of data of a more recent analysis. For the substance flow analysis of the Carbon Dioxide the time period varies from 2007 to 2009 according to the 'Bundesländer Luftschadstoffinventur 1990- 2008' by Anderl et al (2010). More accurate explanations for data collection and uncertainty values will be explained later throughout the analysis of each Substance Flow Analysis.



Carbon Cycle, 1991

Abreviations:

CM	Construction Material	t/a	Tonnes per year
CP	Composting Plant	TR	Traffic
EP	Energy Production	WIP	Waste Incineration Plant
IN	Industry and Production	WM	Waste Management
LF	Landfill	WW	Waste Water
OB	Organic Biomass	WWTP	Waste Water Treatment Plant
PHH	Private Household		

Figure 1: System with its system boundary: Carbon Balance of the City of Vienna

3.3.1.2 Description of Processes

Any urban system consists of a natural and anthropogenic flow of substances. This section will define the most important processes and their input and output flows. The export flow as in Fig.2 will be representing only Carbon whereas in Fig. 3 will show either carbon or carbon dioxide.

Process Traffic (TR)

This process shows the carbon import flow, and carbon/ carbon dioxide export flow needed and emitted by the compressors of pipelines, public transport, rail, and traffic (all automobiles). The import flow of traffic is *fuel to Traffic*. Due to time constraints this process does not include any other alternative fuel but oil. The export flow is *Combustion of Traffic* or *CO2 Emissions of traffic* depending on the Substance Flow Analysis it will be carbon or carbon dioxide.

Table 1: Traffic: Input flows with its Source Processes and Output flows with its Destination Processes

Source process	**Input flow**		**Output flow**	**Destination Process**
Import	Fuel	**Process**	Combustion of Traffic/CO2 Emission Traffic	Export

Process Energy Production (EP)

This process in the carbon cycle is the transport of carbon through the coal, gas, and biomass power plants as the energy producers and in the carbon dioxide analysis it illustrates the transformation of carbon to carbon dioxide within these power plants. The import flows are *biomass*, *coal*, *oil*, and *gas*. The export flow is *Emissions Energy Production* depending on the Substance Flow Analysis it will be carbon or carbon dioxide.

Table 2: Energy Production: Input flows with its Source Processes and Output flows with its Destination Processes

Source process	Input flow		Output flow	Destination Process
Import	Liquid Fuels (oil)	**Process Energy Product-ion**	Combustion of Energy Production/ CO2 Emission Energy Production	Export
	Biomass			
	Natural Gas			
	Coal			

Process Private Household/ Human (PHH)

This process stands for the carbon import flow and carbon, and carbon dioxide export flow needed and emitted by mainly the energy production for spatial and water heating as defined in 'Bundesländer Luftschadstoffinventur 1990- 2008' by Anderl et al (2010) and the food processing and consumption as described by Maier et al (1995). The import flows of *Private Household/ Human* are *Consumer Goods* in Fig. 1 and *Nourishment* for all Substance Flow Analysis's. The export flows are *Respiration Private Household* depending on the Substance Flow Analysis it will be carbon or carbon dioxide. The export flow of *Combustion of Energy Private Household* is carbon in Fig.1 but the same flow in Fig.2 and Fig.3 is called *CO2 Emissions Private Household* and is carbon dioxide.

Table 3: Private Household: Input flows with its Source Processes, and Output flow with its Destination Processes

Source process	Input flow		Output flow	Destination Process
Import	Nourishment	**Process Private Household / Human**	CO2 Respiration Private Household	Export
Organic Biomass	Harvest		Waste Water	Waste Water Treatment Plant
Import	Consumer Goods		Death of Human	Export
			Waste	Waste Management
			CO2 Emission Private Household	Export

Process Organic Biomass (OB)

The process Organic Biomass includes all arable areas, water surfaces, soil, and vegetation. The import flow is net assimilation and export flow is net primary production here called *Respiration Biomass* in Fig.1 and Fig.2 or *CO2 Respiration Biomass* in Fig. 3. This flow for this study is the least important one as the carbon dioxide emissions from biomass are seen as Carbon neutral. For this reason this process will be represented but not analysed in this study.

Table 4: Organic Biomass: Input flows with its Source Processes and Output flows with its Destination Processes

Source process	**Input flow**		**Output flow**	**Destination Process**
Import	Net Assimilation	**Process Organic Biomass**	Harvest	Private Household
			Waste Biomass	Composting Plant
			Goods of Organic Biomass	Industry and Production
			Waste Biomass	Waste Management
			CO2 Respiration Organic Biomass	Export
			Biomass	Energy Production

Process Industry and Production (IN)

The process of industry and production includes as in the Daxbeck study the three economical sectors. One being services and public administration, the others being agriculture and industry (production processes).

Production Goods, Construction Material, and *Production Goods: Nourishment* are the import flows for all Substance Flow Analysis's. However, export flows are named differently as products are being exported in the Carbon balance in the form of carbon and therefore are named the same as the import flows. Whereas the export flows in Fig. 2, and Fig 3 are transformed to carbon dioxide in the aggregate state of gaseous emissions and are hence called *CO2 Emissions Industry* and *CO2 Emissions services.*

Table 5: Industry and Production: Input flows with its Source Processes and Output flows with its Destination Processes

Source process	Input flow		Output flow	Destination Process
Composting Plant	Recycling Material	**Process Industry and Production**	CO2 Emissions Services	Export
Organic Biomass	Goods of Organic Biomass		Waste Water	Waste Water Treatment Plant
Waste Management	Recycling Material		Waste	Waste Management
Import	Construction Material		CO2 Emission Industry	Export
Import	Production Goods Nourishment			
Import	Production Goods			

Process Waste Management (WM)

The process waste management is the main process of the following four processes *Waste Water Treatment Plant (WWTP), Waste Incineration Plant (WIP), Landfill (LF),* and *Composting Plant (CP)*. These processes together include all waste but do not have import flows but only input from within the system. Each system has export flows namely *Waste Water to Danube, Waste Water to EBS/ Waste Incineration Plant, Waste Water Respiration, Combustion of Waste Incineration Plant/ CO2 Emission Waste Incineration Plant, CO2 Emission Landfill* (with stock not available for Carbon Balance), and *Respiration Composting Plant.*

Table 6: Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfill, Composting Plant: Input flows with its Source Processes and Output flows with its Destination Processes

Source process	Input flow		Output flow	Destination Process
Industry and Production	Waste	**Process Waste Management**	Waste	Waste Incineration Plant
Private Household	Waste		Waste	Composting Plant
Organic Biomass	Waste		Waste	Landfill
			Recycling Material	Industry and Production
Organic Biomass	Waste	**Process Composting Plant**	Respiration of Composting Plant	Export
Waste Management	Waste		Recycling Material	Industry and Production
Waste Incineration Plant	Waste	**Process Landfill**	Respiration CO2 Emissions	Export
Waste Management	Waste			
Waste Management	Waste	**Process Waste Incineration Plant**	Combustion/ CO2 Emissions	Export
Waste Waster Treatment Plant	Waste Water		Waste	Landfill
Industry and Production	Waste Water from Industry and Production	**Process Waste Waster Treatment Plant**	Waste Water	Waste Incineration Plant
Private Household	Waste Water from Private Household		CO2 Waste Water Respiration	Export
			Waste Water to Danube	Export

3.3.1.3 Description of Activities

As already mentioned before, this study will divide the entire system into the four activities. This is due to the fact that for some activities a substitution or reduction in carbon or carbon dioxide is not possible as for example for the activity to nourish. Its flows such as the import flow nourishment and the export flow “respiration of a human being” cannot be replaced or decreased. Therefore, find below the definition for each activity in this study.

To clean

This is a purely anthropogenically caused activity. Due to the behaviour of humans waste is created and has to be disposed of. This activity dedicates itself to processes in broad terms to waste management such as waste disposal but also to the supply and disposal of water. The following processes and flows of the Mass Flow Analysis’s belong to this activity: *Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfills*, and the *Composting Plant*. Flows belonging to “to clean” are *Waste Water from Industry to Waste Water Treatment Plant, Waste from Private Household to Waste Management, Waste Biomass to Waste Management, Waste to Waste Incineration Plant from Waste Management, Waste from Waste Incineration Plant to Landfill* (in Carbon Balance to EBS), *Waste from Waste Management to Landfill, Waste to Composting Plant from Waste Management, Waste Biomass to Composting Plant, Recycling Material from Waste Management to Industry and Production, Recycling Material from Waste Management to Industry and Production, Recycling Material from Composting Plant to Industry and Production, Waste Water to Danube, Waste Water Respiration, Combustion of Waste Incineration Plant/ CO2 Emission Waste Incineration Plant, CO2 Emission Landfill*, and *Respiration Composting Plant*.

To nourish

Generally all flows and processes which process, produce, distribute, and consume any type of nourishment are considered to belong to this activity (Brunner and Rechberger, 2004) such as the agricultural production. The following process belongs and flows of the Mass Flow Analysis’s belong to this activity: *Private Household/ Human* (though only partly as it as well belongs to the activity to reside and work) and flows *Nourishment to Private Household, Production Goods Nourishment to*

Industry and Production, Harvest to Private Household, Goods of Organic Biomass, Respiration Human, Waste Water from Private Household to Waste Water Treatment Plant, and *Goods of Organic Biomass to Industry and Production*.

To reside and work

"This activity comprises all processes that are necessary to build, operate and maintain residential units and working facilities." (Brunner and Rechberger, 2004) The following process belongs and flows of the Mass Flow Analysis's belong to this activity*: Industry and Production* and flows oil *Combustion of Energy from Private Household/ CO2 Emission Private Household*, *Consumer Goods to Private Household, Production Goods to Industry and Production, Construction Material to Industry and Production, Production Goods from Industry and Production* (only in Carbon cycle), *Construction Material from Industry and Production* (only in Carbon Cycle), *Recycling Material from Composting Plant to Industry and Production*, and *Recycling Material from Waste Management to Industry and Production. CO2 Emissions Services* and *CO2 Emissions Industry* are only available for CO2 emissions and optimisation Substance Flow Analysis due to transformation to carbon dioxide in the aggregate state of gaseous emissions within the processes.

To transport and communicate

Transport and communicate includes the traditional sectors of traffic in the following Substance Flow Analysis's but generally it includes everything to transport energy, material, persons and information. The processes comprising in the following Substance Flow Analysis's are *Energy Carrier* and *Traffic*. Flows are the following: *Natural Gas, Coal, Biomass (wood), Biomass to Energy Production from Biomass* (data only available for Carbon cycle*), Fuels to Private Household from Energy Production, Combustion of Energy Production/ CO2 Emission Energy Production, Combustion of Traffic/ CO2 Emissions Traffic*, and *Fuel to Traffic*.

3.4 Collection of Data / Quantification of Data

3.4.1 Quantification of the Carbon Balance of Vienna According to the Main Processes in 1991

The study of the carbon balance of the city of Vienna is of utmost importance and the basis in order to quantify the Carbon Dioxide emission for the city of Vienna. The Carbon Cycle represents not only the anthropogenically caused flows but also the geo-genic stock within the city of Vienna. However due to the lack and inconsistency of the available data some uncertainties will have to be taken into account and assumptions had to be made. Calculations for Mass Flow Analysis are usually either based on input or output. As some data is available for both import and export but may not balance out and other data is only available in form of the import or export value, assumptions had to be made and data may have a variation between input and output of up to 10 per cent. In addition each calculation in the order of processes will be explained in more detail in the section below. The Carbon cycle will be represented in a Substance Flow Analysis in Chapter 4.1.

The data accumulation of this Substance Flow Analysis is a cross reference from the 'Maier et al' Study "Ökosystem Großstadt Wien" (1995) and the study "Der anthropogene Stoffhaushalt der Stadt Wien" by Daxbeck et al (1996) and the 'Bundesländer Luftschadstoffinventur 1990- 2008' by Anderl et al (2010).

Process Traffic (TR)

Due to lack of available data from Maier et al (1995) the data collection for the flow of the process *Traffic* has used by both of the following studies and thus, cross-referenced the Energy Production export flow by Maier et al (1995) from 1991, and the export flow of the carbon dioxide to 'Bundesländer Luftschadstoffinventur 1990-2008'. According to the later traffic produced 2,066,000 t carbon dioxide in 1990. As no data from 1991 is available this amount of carbon dioxide is used in this equation. Therefore this process and its flows calculated from its output. In order to produce 2,066,000 t carbon dioxide (Anderl et al, 2010), 563,000 t carbon is needed using the formula of molecular mass.

CO2 in gram* C molecular mass / CO2 molecular mass= C in gram

2,066,000,000,000* 12/ 44= 563,000,000,000 C

Assuming that import and export should be equal in order to create a balance and supposing that all carbon in the fuel is transferred into emission or combustion, the carbon flow for the import flow and export flow *traffic* is 563,000 t.

Although this data varies to the Daxbeck study (1996) where the entire carbon flow amounts in around 860,000 t emission in 1991 but due for comparability to 2008 this thesis has used the data of the study 'Bundesländer Luftschadstoffinventur 1990-2008' .

Table 7: Mass flow of process Traffic
(Own calculations)

Source Process	**Input Flow**	**Mass Flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Import	Fuel	563	**Process Traffic**	Combustion Traffic	Export	563

Process Energy Production (EP)

The data for the process *Energy Production* has been cross-referenced between the studies Maier et al (1995) and Anderl et al (2010) and Daxbeck et al (1996).

Firstly, assuming that only liquid fuels are the basis for traffic, *Oil (fuel)* (Maier et al, 1996) entering the process would have to be subtracted by the amount of 563,000 t C. This leaves an import of 706,000 t C in oil into the process *Energy Production*. Consequently the number in *Combustion of Energy Production* will be less as there is less input into the process (see below).

The flow *Fuels from Energy Production to Private Household* reaches the total of 579,000 t of Carbon according to Daxbeck et al (1996). Data for the import flows *gas*, *biomass (wood)*, and *coal, Biomass to Energy Production from Organic Biomass* are given by Maier et al (1996). His study also gives the value for the total combustion of carbon for the process *Traffic* and *Energy Production*. As shown in the equation above in process *Traffic*, *Traffic* export has to be subtracted from the total amount. In addition the export flow *combustion of Traffic* has to be reduced by the flow *Fuels to Private Household from Energy Production.* Anderl et al (2010) has also calculated the export flow for 1990 in carbon dioxide, his results differ greatly from the results from the study of by Maier et al (1996). Whereas, the data from the Daxbeck study has a very similar carbon flow for the *Energy Production* process and therefore Anderl's study is counted as insignificant for this process.

Table 8: Mass flow of process Energy Production
(Own calculations, Daxbeck et al, 1996 and Maier et al, 1996, Anderl et al, 2010)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Import	Liquid Fuels (oil)	563	**Process Energy Product-ion**	Combustion of Energy Production	Export	1209
	Biomass	18				
	Natural Gas	934				
	Coal	128		Fuels	Private Household	579
Organic Biomass	Biomass	3				

Process Private Household/ Human (PHH)

The data collection for the flows *Nourishment to Private Household*, *Harvest to Private Household*, and *Respiration of Private Household, Waste Water from Private Household to Waste Water Treatment Plant*, *Death of Human*, and *Waste from Human to Waste Management* is based on the work of Maier et al (1995) for 1991. Whereas the flow *Consumer Goods to Private Household* with the maximum assumed carbon flow and *Fuels Energy Production to Private Household* are based according to the Daxbeck study, 1996 and the *Bundesländerschadstofinventur 1990-2008* has contributed the data for the flow *Combustion of Energy from Private Household*.

The stock of *Private Household* with 520,000 t has been calculated by the STAN and is just above the upper boundary of the Daxbeck study (1996) of an estimated *Private Household* stock between 100,000 t and 500,000 t.

Table 9: Mass flow of process Private Household
(Daxbeck et al., 1995 and Maier et al, 1996, Anderl et al, 2010)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Import	Nourishment	212	**Process Private House-hold**	Respiration Private Household	Export	193
Organic Biomass	Harvest	22		Waste Water	Waste Water Treatment Plant	18
Import	Consumer Goods	522		Death of Human	Export	0.3
Energy Production	Fuels	579		Waste	Waste Management	22
				Combustion of Energy	Export	581

Process Industry and Production (IN)

In Maier et al work from 1995 this process was called economy and private consumption, and only output flows were available. Therefore, the imports and exports of this process were not quantified. For this reason data has been used from the Daxbeck et al (1996) study. More specifically, the maximum carbon import and export for construction material from that study has been assumed meaning that about 1.5 million tonnes are being imported to the city and about 806,000 t of Carbon are being exported again.

The data collection for the import and export flows *Production Goods: Nourishment*, *Production Goods*, Construction Material, the stock for *Industry and Production* are based on the carbon flow according to the Daxbeck study, 1996. The stock when calculated for *Industry and Production* has an additional yearly stock of 934,000 t not shown in the table below. The figures for the flows *Goods of Organic Biomass*, *Recycling Material from Waste Management to Industry and Production, Waste from Industry and Production, Recycling Material from Composting Plant* and *Waste Water from Industry and Production* are based on the study of Maier et al (1995).

Differently to the study of Daxbeck et al. (1996) this research paper needs to consider the flows *Production Goods: Nourishment*, and *Production Goods* separately in order to later define the activities easily. As *Production Goods: Nourishment* only considers food production, whereas *Production Goods* considers chemical industry, graphic and paper processing, processing of wood, textile industry and non- metal processing, and glass processing. According to Daxbeck et al the difference in imports and exports is mainly in the chemical and food industry, and thirdly in the paper processing sector.

Table 10: Mass flow of process Industry and Production
(Daxbeck et al, 1995 and Maier et al, 1995, Anderl et al, 2010)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Compos-ting Plant	Recycling Material from CP to IN	2	**Process Industry and Production**	Production Goods Nourishment	Export	220
Organic Biomass	Goods of Organic Biomass	7		Waste Water	Waste Water Treatment Plant	19
Waste Manage ment	Recycling Material	34		Waste	Waste Management	163
Import	Construction Material	1500		Construction Material	Export	190
	Production Goods Nourishment	159		Production Goods	Export	480
	Production Goods	303				

Process Organic Biomass (OB)

The data collection for the process *Organic Biomass* is completely based on the work of Maier et al (1995) from 1991.

Table 11: Mass flow of process Organic Biomass
(Maier et al, 1995)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Import	Net Assimilation	210	**Process Organic Biomas**	Harvest to PHH	PHH	22
				Waste Biomass to CP	CP	1
				Goods of Organic Biomass	IN	7
				Waste Biomass to WM	WM	2
				Respiration OB	Export	166
				Biomass to EC from OB	EC	3

Process Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfill, Composting Plant

The data collection for the processes *Waste Water Treatment Plant (WWTP), Waste Incineration Plant (WIP), Landfill (LF),* and *Composting Plant (CP)* are based on the work of Maier et al (1995) for 1991. Due to lack of available data an export flow of the carbon in the emissions of landfills is not possible and therefore illustrated as a stock on the landfills. Moreover, no study was done on the already existing stock of carbon on landfills, which accounts for an uncertainty in this carbon balance.

Maier et al (1995) have in detail described all data for the following. The process waste management is the main process of the following four processes

Table 12: Mass flow of processes Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfill, Composting Plant
(Maier et.al., 1995)

Source process	Input flow	Mass flow in 1000 t/a	Process	Output flow	Destination Process	Mass flow in 1000 t/a
Industry and Production	Waste	163	**Process Waste Management**	Waste to WIP from WM	Waste Incineration Plant	115
Private Household	Waste	22		Waste	Composting Plant	3
Organic Biomass	Waste	2		Waste	Landfill	34
				Recycling Material	Industry and Production	34
Organic Biomass	Waste	1	**Process Composting Plant**	Respiration of Composting Plant	Export	2
Waste Management	Waste	3		Recycling Material	Industry and Production	2
Waste Incineration Plant	Waste	1	**Process Landfill**	Respiration/ CO2 Emissions	Export	n/a
Waste Management	Waste	34				
Waste Management	Waste	115	**Process Waste Incineration Plant**	Combustion/ CO2 Emissions	Export	114
Waste Water Treatment Plant	Waste Water	21		Waste	Landfill	1
Industry and Production	Waste Water	19	**Process Waste Water Treatment Plant**	Waste Water	Waste Incineration Plant	21
Private Household	Waste Water	18		CO2 WW Respiration	Export	7
				WW to Danube	Export	9

3.4.2 Quantification of the Carbon dioxide Emissions in Vienna According to Main Processes in 2008

Chapter 3.4.2 will assess the quantities of Carbon dioxide emissions according to the processes on the case study of the city of Vienna.

However, due to the lack and inconsistency of the available data some uncertainties will have to be taken into account and assumptions had to be made. Calculations for Mass Flow Analysis are usually either based on input or output. In the case of quantifying the carbon dioxide emissions in Vienna, the data is mostly available for output and import are calculated backwards from the output scenario. In cases where only 1991 numbers for the carbon balance have been available data will mainly be altered by an exponential increase according to population such as the respiration of human being. As the data is based on export flows only, assumptions had to be made and uncertainties will have to be taken into account for all import data as they only show the carbon import for the carbon dioxide production only and thus are source emission in carbon value. The data quantification will be explained in more detail in the section below for the most import flows and each export flow. It has to be added though that not all import flows mentioned in chapter 3.2 are The Substance Flow Analysis and the four activities will be illustrated in a Substance Flow Analysis in Chapter 4.2.

The data accumulation of the quantification of carbon dioxide emissions is based on the 'Bundesländer Luftschadstoffinventur 1990- 2008' for the ministry of environment by Anderl et al (2010).

Process Traffic (TR)

The data collection for the export flows combustion of fuel is based on the study 'Bundesländer Luftschadstoffinventur 1990-2008' by Anderl et al (2010).

As this study only assumes carbon dioxide emissions, the carbon import is calculation by calculating carbon with the aid of molecular mass.

CO2 in gram* C molecular mass / CO2 molecular mass= C in gram

3,319,000,000,000* 12/ 44= 905,000,000,000 C

Assuming that import and export should be equal in order to create a balance and supposing that all carbon in the fuel is transferred into emission, the carbon flow for the import flow traffic is 905,000 t and the carbon dioxide of the export flow amounts in 3,319,000 t.

Table 13: Mass flow of process Traffic
(Anderl et al, 2010 and own calculations)

Source Process	Input Flow	Mass Flow in C 1000 t/a		Output flow	Destination Process	Mass flow 1000 t/a
Import	Fuel	905	**Process Traffic**	CO2 Combustion Traffic	Export	3319

Process Energy Production (EP)

The import values for oil (assuming all liquid fuels are oil), natural gas, and coal have been calculated by a different method by assuming the following:

Natural gas: 14.4 metric tonnes carbon/TJ

Oil: 19.9 metric tonnes carbon/TJ

Coal: 25.4 metric tonnes carbon/TJ

(http://www.greenrationbook.org.uk/resources/biomass-energy/, 2011)

This then has been cross-referenced with the data of the *Gasbilanz, Erdölbilanz,, Fernwärmebilanz* and *Kohlebilanz* from Statistik Austria for the year 2008. In addition the oil import for Energy Production has been calculated by subtracting the carbon import of oil for the process *Traffic* from the data from *Statisik Austria*. For the calculation of biomass though it has been assumed it is 100 per cent wood and after Daxbeck (1996) wood contains 50 per cent carbon. 190 000 t of biomass are imported annually for the Biomass plant in Vienna, thus 95 000 t of carbon are needed in order to generate district heating and electricity.

Resulting in a total carbon import flow for the process of the energy carrier of 685 963 t C. Due to different sources of import and output this figure is fairly uncertain and if off by approximately 50 000 t carbon.

As there was no data to be found on the amount of district heating from *Energy Production to Private Household*, the flow was not accounted for in this section.

The total carbon dioxide emissions from the process *Energy Production* comes to 2,683,000 tons. However, there is a difference between import and export of carbon of approximately 168,000 t CO_2 as the carbon import is calculated separately from the carbon dioxide export. The carbon import would account for 2,515,333 t of carbon dioxide emissions, this would be a variation from the actual export of around 6 per cent.

Table 14: Mass flow of process Energy Production
(Own calculations, Anderl et al, 2010, and Daxbeck et al., 1996)

Source process	Input flow	Mass flow 1000 t/a		Output flow	Destination Process	Mass flow 1000 t/a
Import	Liquid Fuels (oil)	141	**Process Energy Production**	CO_2 Combustion	Export	2 683
	Biomass (Wood)	95				
	Natural Gas	448				
	Coal	2				

Process Private Household/ Human (PHH)

The data collection for the flows *Harvest to Private Household*, and *Respiration of Private Household, Waste Water from Private Household to Waste Water Treatment Plant*, *Death of Human*, and *Waste from Human to Waste Management* is based on the work of Maier et al (1995) for 1991. The "*Bundesländerschadstofinventur 1990-2008"* has contributed the data for the flow *CO_2 Emission Private Household.* Whereas the flow *Consumer Goods to Private Household* is not accounted for as it is not included in the carbon dioxide emission of *Private Household*.

The import flow *Nourishment to Private Household* is based upon the study of Maier et al (1995) and has been adjusted to the population increase by divided the carbon import from 1991 by the number of citizen and then multiplying the result by the number of inhabitants in December 2007 (Stadt Wien, Wien.gv.at, 2011a) . This has resulted in an increase of carbon in food from 212 000 t to 230 594 t. However, it has to be added here that it is assumed that the content of nourishment stayed the same as in 1991, for the year for which the study had been conducted. The export flow of the *CO_2 Respiration of Private Household* is based also based on Maier (1995) and has been also been adjusted to the population increase by dividing the carbon export from 1991 by the number of citizen and then multiplying the result by the number of inhabitants in December 2007 (Stadt Wien, Wien.gv.at, 2011). This has resulted in an increase of carbon in respiration from 193 000 t to 209 931 t. However, it has to be added here that it is assumed that Viennese population pyramid and therefore the average weight has not changed since 1991 when the study has been conducted. This could not be calculated in such depths due to time constraints. In a second step, it is assumed that the carbon respiration is 100 per cent transferred into carbon dioxide and therefore results in 769,749 t of carbon dioxide by applying the following formula:

C in gram* CO_2 molecular mass/ C Molecular mass in gram= CO_2

Harvest to Private Household from within the city is assumed to have stayed the same as Vienna only has limited arable land within city boundaries.

It has been assumed that the flow *Waste Water from Private Household* increased exponentially with the increase in population. Therefore, following calculation has been conducted:

Waste Water divided by citizen in 1991 (according to Maier et al.)= waste water/ c

18,000 t / 1,539,848 = 0.00001169 t/c

The result multiplied by population in December 2007 according to Stadt Wien 1,674,909 which amounts in waste water with a total carbon content of 19,578.791 t.

Due to lack of data the same calculation has been conducted for *Waste from Private Household* whereas it has to be assumed that amount of waste per capita and carbon content in waste products is equal to the carbon content in 1991. Therefore:

22,000 t / 1,539,848= 0,014287t/c

Then the result multiplied by 1,674,909 inhabitants' amounts in 23,930 t for the system boundary.

Also due to the lack of data the flow of death of human has been assumed to have not increased during the given time period from 1991 to 2008. However, this does not change the end result of the total carbon dioxide emissions of *Private Household*.

The total carbon dioxide emissions for the process *Private Household* amount in 2,063,000 t.

Table 15: Mass flow of process Private Household
(Daxbeck et al, 1995 and Maier et al, 1995, Anderl et al, 2010)

Source process	**Input flow**	**Mass flow 1000 t/a**
Import	Nourishment	230
Organic Biomass	Harvest	22
Import	Consumer Goods	n/a

Process Private Household

Output flow	**Destination Process**	**Mass flow 1000 t/a**
CO2 Respiration Private Household	Export	770
Waste Water	Waste Water Treatment Plant	20
Death of Human	Export	0.3
Waste	Waste Management	24
CO2 Emission Private Houshold	Export	1 293

Process Industry and Production (IN)

Due to the lack of data and due to the fact that in this section only direct emissions are of importance, data for the input has not been calculated. However, the data collection for the export flows *CO_2 Emission Industry*, *CO_2 emissions services* is based on the study 'Bundesländer Luftschadstoffinventur 1990-2008' by Anderl et al (2010). The calculation for export flow CO_2 Emission Services is cross-referenced and explained below.

In order to calculate the carbon dioxide emissions for services, sector "Kleinverbrauch" (Anderl et al, 2010) has been split into 1 293 000 t Carbon Dioxide emission for households, whereas the rest of the sector is to be assumed pure services therefore 1,692,000 t CO_2 minus 1,293,000 t CO_2 will result in 399,000 t carbon dioxide emissions for the sector services.

Table 16: Mass flow of process Industry and Production
(Own calculations, Anderl et al, 2010)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Composting Plant	Recycling Material	n/a	**Process Industry and Production**	CO_2 Emissions Services	Export	399
Organic Biomass	Goods	n/a		Waste Water	Waste Water Treatment Plant	19
Waste Management	Recycling Material	n/a		Waste	Waste Management	n/a
Import	Construction Material	n/a		CO_2 Emission Industry	Export	532
	Production Goods: Nourishment	n/a				
	Production Goods	n/a				

Process Organic Biomass (OB)

The data collection for the process *Organic Biomass* is completely based on the work of Maier et al (1995) from 1991 and the flows quantified below are assumed to have approximately stayed the same.

In order to quantify the carbon dioxide emissions for *CO_2 Respiration of Organic Biomass* following equation has been applied:

C in gram* CO_2 molecular mass/ C Molecular mass in gram= CO_2

This amount is 770 000 t carbon dioxide respiration of organic biomass. However this is Carbon neutral and will not be explained further.

Table 17: Mass flow of process Organic Biomass
(Own calculations and Maier et al, 1995)

Source process	**Input flow**	**Mass flow 1000 t/a**		**Output flow**	**Destination Process**	**Mass flow 1000 t/a**
Import	Net Assimilation	210	**Process Organic Biomass**	Harvest	Private Household	22
				Waste	Composting Plant	n/a
				Goods	Industry and Production	n/a
				Waste	Waste Management	n/a
				CO_2 Respiration Organic Biomass	Export	770

Process Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfill, Composting Plant

As already done in section 3.4.1 the quantification of processes *Waste Water Treatment Plant (WWTP), Waste Incineration Plant (WIP), Landfill (LF),* and *Composting Plant (CP)* are described all at once due to their interconnectivity. The data collection for the processes *Waste Water Treatment Plant, Waste Incineration Plant,* and *Composting Plant* are based on the work of Maier et al from 1995, and on the basis that according to *ebswien hauptkläranlage* waste water is 50 % from *Industry and Production* and 50 % from households.

Due to lack of available data of the process *Landfill* from the literature already mentioned before Fellner, 2011 has provided the following information. Stock of carbon in waste on *Landfill* is approximately 2,3 million tons, whereas carbon neutral emissions amount in approximately 30,000 t carbon dioxide. The methane emissions amount 13,000 t which is equivalent to about 330,000 t CO2. However, due to time constraints the data on carbon dioxide equivalent data has not been taken into account for this thesis. Moreover, it has to be mentioned that landfills in Vienna only receive any pre-treated waste and therefore have very little input compared to 1991. Moreover, due to the advancement of technology the emissions of waste incineration have shifted from the processes accumulating in *Waste Management* to the process *Energy Production*. Waste incineration generates energy and only a very low amount of carbon dioxide is produced by pure waste incineration without generating energy and as it is difficult to make assumptions on the amount of carbon dioxide emissions without energy production, it is not accounted for in Waste Incineration Plant and assumed to be negligible. It has been assumed that the input into *Waste Water Treatment Plant* has increased proportionally to the increase in population (see process *Private Household*).

Therefore, according to *ebswien hauptkläranlage* waste water is equally coming from *Industry and Production* and *Private Household* it is believed that around 20,000 t of carbon enter the *Waste Water Treatment Plant* from *Industry and Production* and another 20,000 t of carbon from *Private Household.* In order to calculate the Carbon dioxide emission of *Waste Water Treatment Plant* it is assumed that the carbon respiration export flow of the *Waste Water Treatment Plant* converts to 100 per cent into carbon dioxide. Therefore, the following equation has been applied:

C in gram* CO2 molecular mass/ C Molecular mass in gram= CO2

7,568t * 0, 44 / 0, 12 = 27,748 t

Thus, the waste water treatment plant emits 27,748 t of carbon dioxide.

Table 18: Mass flow of processes Waste Management, Waste Water Treatment Plant, Waste Incineration Plant, Landfill, Composting Plant
(own calculations; Fellner, 2011; Maier et al, 1995)

Source Process	Input Flow	Mass flow In 1000 t/a	Process	Output Flow	Destination Process	Mass flow In 1000 t/a
Industry and Production	Waste	n/a	**Process Waste Manage-ment**	Waste	Waste Incineration Plant	n/a
Private Household	Waste	22		Waste	Composting Plant	n/a
Organic Biomass	Waste	n/a		Waste	Landfill	n/a
				Recycling Material	Industry and Production	n/a
Organic Biomass	Waste	n/a	**Process Composting Plant**	Respiration of Composting Plant	Export	2
Waste Management	Waste	n/a		Recycling Material	Industry and Production	2
Waste Incineration Plant	Waste	1	**Process Landfill**	CO_2 Emissions Landfill	Export	30
Waste Management	Waste	0				
Waste Management	Waste to WIP from WM	n/a	**Process Waste Incineration Plant**	CO_2 Emissions WIP	Export	negligible
Waste Water Treatment Plant	Waste Water	21		Waste from WIP	Landfill	n/a
Industry and Production	Waste Water	20	**Process Waste Water Treatment Plant**	Waste Water	Waste Incineration Plant	23
Private Household	Waste Water	20		CO_2 Respiration of Waste Water	Export	28
				Waste Water to Danube	Export	10

4 Results

This section summarises the quantification from chapter 3.4.1 and 3.4.2. In a first step it will determine and quantify the total carbon flows according to the four activities *to clean, to nourish, to reside and work, and to transport and communicate* within the system boundaries. In a second step it will assess the quantities of carbon dioxide emissions according to the same four activities.

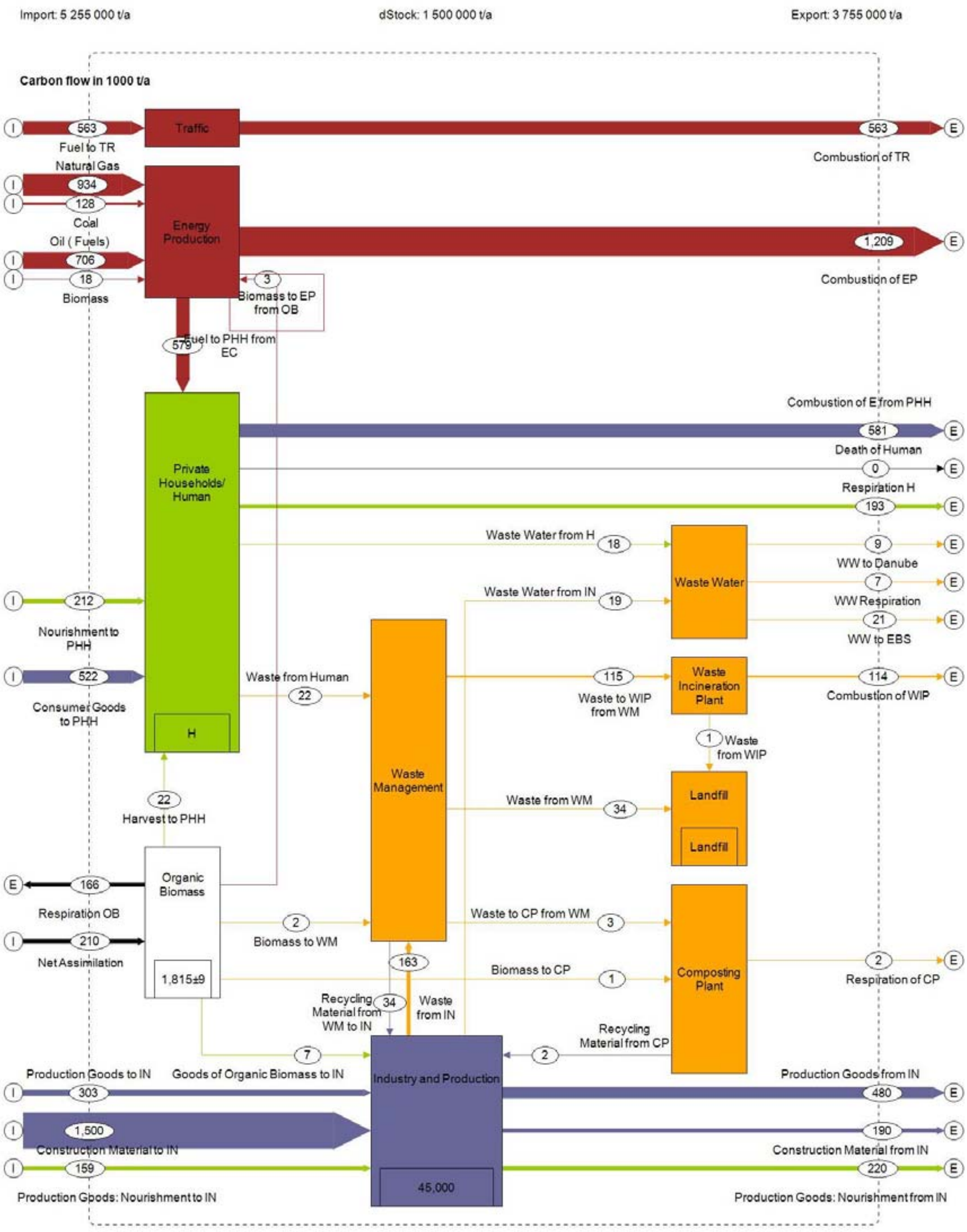
4.1 Carbon Balance of Vienna According to the Four Activities in 1991

The carbon cycle of the city of Vienna consists of the following six main processes *Traffic, Energy Production, Private Household/ Human, Organic Biomass, Industry and Production,* and *Waste Management* (with all sub processes). High uncertainties have to be taken into account for the import flows *Consumer and Production Goods* and the import flows into *Energy Production* and *Private Household.*

The largest flows pass through the process of *Energy Production* with an import flow of around 1.8 million t of carbon and an export flow with around 1.2 million t of carbon and the import and export flows of *Industry and Production* with an input of around 2 million t and an output of around 900,000 t of carbon. The input flows into the processes of waste management sum up to around 225,000 t of carbon. The biggest export flow of waste management is the emission produced by the incineration of waste. Around 36,000 t of carbon as recycling material which make up around 16 per cent of the total input of waste management, are further processed in *Industry and Production*.

Altogether around 5.3 million t of carbon are imported in the year 1991 into the city of Vienna of which 1.5 million are added to Viennese stock and 3.8 million t are exported again. More than 50 per cent (2.7 million t) of the total carbon export flows are directly emitted to the atmosphere by the flows *Combustion of Traffic, Combustion of Energy Production, Combustion of Energy from Private Household, Combustion of Waste Incineration Process, Respiration Human, Waste Water Respiration* and *Respiration of Composting Plant.* Whereas the other major carbon export flow is in form of goods with around 890,000 t C.

This section will divide the entire carbon cycle into the four activities *to clean, to nourish, to work* and *reside, to transport and to communicate*. The Substance Flow Analysis bellow illustrates the Carbon cycle of 1990 and 1991 of the city of Vienna. The colours represent the four activities *to clean, to nourish, to reside and work,* and *to transport and communicate*. The blue greyish colour illustrates *to reside and work*, whereas green visualises *to nourish* and orange is the activity of *to clean*. *To transport and communicate* is shown in brown colour.



Carbon Cycle 1991 according to studies by Punz, Daxbeck, and Anderl, 2011

Activities:

To clean
To reside and work
To nourish
To transport and communicate

CM	Construction Material	t/a	Tonnes per year
CP	Composting Plant	TR	Traffic
EP	Energy Production	WIP	Waste Incineration Plant
IN	Industry and Production	WM	Waste Management
LF	Landfill	WW	Waste Water
OB	Organic Biomass	WWTP	Waste Water Treatment Plant
PHH	Private Household		

Figure 2: Carbon Balance of the City of Vienna in 1990/1991

4.1.1 To Clean: Supply and Disposal of Waste, Waste Management

Table 19: Carbon flows and stocks of activity to clean

Input Name	Input Quantity in t	Name of Flows within Waste Management	Quantity of Flows within Waste Management	Stock in t	Output Name	Output Quantity in t
Waste from Human to Waste Management	22,000	Waste from Waste Management to Composting Plant	3,000	Landfill 35,000 t	Respiration of Waste Water	7,000
Waste from Biomass	1,800	Waste from Waste Management to Waste Incineration Plant	115,000	Composting Plant n/a	Waste Water to Danube	9,000
Waste from Industry and Production	163,000	Waste from Waste Incineration Plant to Landfill	1,000		Waste Water to EBS	21,000
Waste Water from Industry and Production	19,000	Waste from Waste Management to Landfill	34,000		Combustion of WIP	114,000
Biomass to Composting Plant	900				Respiration of Composting Plant	1,600
Total	**206,700**		**153,000**	**35,000**		**152,600**

The total carbon import flow for the activity *to clean* amounts in approximately 187,000 t. This includes the flows *Waste from Human to Waste Management*, *Waste from Biomass,* and *Waste from Industry and Production.* Table 20 shows that less than 12 per cent of the carbon input into waste management comes from *Private Household* whereas about 87 per cent of the carbon in waste is produced by *Industry and Production.* In 1991 about 18 per cent of carbon in waste would be stored on landfills and around 82 per cent would leave the city in different forms of carbon. The major export flow is represented by the emission of a waste incineration plant which makes up three quarters of the total carbon export of around 152,600t. Around 80 per cent of the export is emitted in gaseous state into the atmosphere.

This activity does not take into consideration the import of waste water from *Private Household* as this is accounted for in the activity *to reside and work* in this work.

4.1.2 To Nourish: Transport, Preparation and Digestion of Food

Table 20: Carbon flows and stocks of activity to nourish

Input Name	Input Quantity in t	Stock Name	Stock in t	Output Name	Output Quantity in t
Nourishment to Private Household	212,000	n/a	n/a	Respiration of Human	193,000
Production Goods: Nourishment to Industry and Production	159,341	n/a	n/a	Production Goods: Nourishment from Industry and Production	220,000
Harvest to Private Household	22,000			Waste Water from Private Household	18,000
Goods of Organic Biomass to Industry and Production	7,000				
Total	**400,341**				**431,000**

The total carbon import flow for the activity *to nourish* totals in approximately 400,000 t which includes the flows *Nourishment to Private Household*, and *Production Goods: Nourishment, Harvest,* and *Goods of Organic Biomass.* Around 58 per cent of the activity's import enters the *Private Household* whereas the other 42 per cent go into the process *Industry and Production*. Table 21 shows that nearly half of it is directly emitted again through respiration of a human body. The other 53 per cent of carbon export flows is exiting the system in forms of goods.

The difference in import and export flow (export flow being bigger than import flow) is assumed to be in flow of the production of goods; however no explicit data is available.

4.1.3 To Reside and Work: Fuel for AC and Construction

Table 21: Carbon flows and stocks of activity to reside and work

Input Name	Input Quantity in t	Stock Name	Stock in t	Output Name	Output Quantity in t
Consumer Goods	522,252	Private Household	520,000	Combustion of Private Household	581,000
Production Goods	303,273	Industry and Production	45,000,000	Production Goods	480,000
Construction Material	1,500,000			Construction Material	190,000
Recycling Material from Waste Management to Industry and Production	34,000				
Recycling Material from Composting Plant to Industry and Production	2,300				
Fuels to Private Household	579,000				
Total	**2,940,825**		**45,520,000**		**1,251,000**

The total carbon import flow for the activity *to reside and work* amounts in approximately 2,940,825 t. This includes the flows *Consumer Goods*, *Production Goods, Recycling Material from Waste Management to Industry and Production, Recycling Material from Composting Plant to Industry and Production, Fuels to Private Household,* and *Construction Material.* The later being the biggest import flow with approximately 51 per cent of the activity's import. Moreover about 63 per cent of the carbon import enters the *Industry and Production* and are processed further. *Industry and Production* has an approximate stock of 45 million t of carbon which includes building and geological material of Vienna (Daxbeck, 1996). Table 22 shows that only more than half of the carbon is leaving the system again due to the construction material being used within the city. The major export flow with 46 per cent is combustion of energy from *Private Household* which also means that 46 per cent of carbon is emitted to the atmosphere. The rest (54 per cent) of carbon export flows is exiting the system in forms of *Production Goods,* and *Construction Material*.

The stock of *Private Household* has been calculated by STAN. However, it has to be noted here that it is only an assumption which coincides with the Daxbeck study (1996).

4.1.4 To Transport and Communicate: Fuel for Transport and for Supply of Infrastructure

Table 22: Carbon flows and stocks of activity to transport and communicate

Input Name	**Input Quantity in t**	**Stock Name**	**Stock**	**Output Name**	**Output Quantity in t**
Fuel	563,000	n/a	n/a	Combustion of Fuel	563,000
Natural Gas	934,000			Combustion of Energy Production	1,208,545
Coal	128,000				
Oil (fuels)	706,000				
Wood	18,000				
Biomass to Energy Production	3,000				
Total	**2,352,000**				**1,771,545**

This process is entirely caused anthropogenically. The total carbon import flow for the activity *to transport and communicate* amounts in approximately 2,352,000 t and therefore is the biggest carbon import flow. This includes the flows *Fuel*, *Natural Gas, Coal, Oil (fuels), Biomass to Energy Production,* and *Wood. Natural Gas* is the biggest import flow making up about 40 per cent of the carbon of the activity's import. Furthermore 1,786,000 t of the carbon import enters the *Energy Production* and most of it is emitted directly in a gaseous state of carbon into the atmosphere. Table 22 shows that 1,771,545 t of carbon are emitted by the flows *Combustion of Energy Production* and *Combustion of Fuel*. It has to be added though that these flows only represent the energy produced and the traffic within the boundaries of Vienna not including the Hinterland.

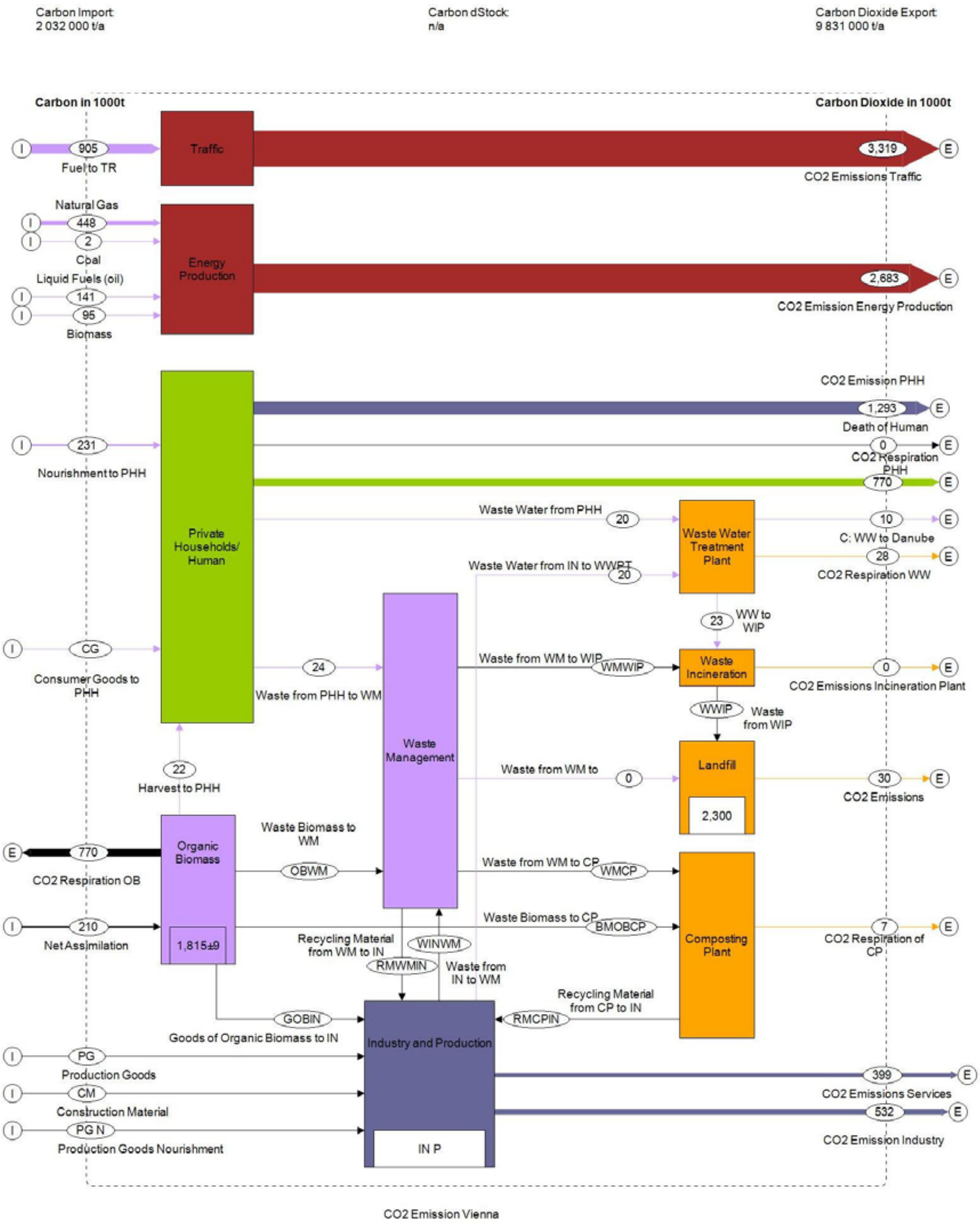
4.2 Carbon Dioxide Emissions in Vienna According to the Four Activities in 2008

The carbon dioxide emissions of the city of Vienna are based on the following six main source processes *Traffic, Energy Carrier, Private Household/ Human, Organic Biomass, Industry and Production* and *Waste Management* (with all sub processes). Uncertainties for carbon have to be taken into account for all input and output flows as many of them are assumption as described in chapter 3.4.2.

The biggest flow of carbon dioxide emissions are the export flows of *Traffic* with a total sum of around 3.3 million t of CO2 emissions followed by the emission from the *Private Household /Human* (2 million t CO2) and *Energy Production* (2.7 million t CO2). The most important carbon import flows as a source to carbon dioxide are the flows entering the processes *Traffic* and *Energy Production* amounting in about 1.7 million t of carbon dioxide. The emissions from *Energy Production* by the biomass plant are considered carbon neutral and reduce the carbon dioxide emissions by around 350,000t which decreases the total emissions of *Energy Production* to 2,35 million carbon dioxide.

This section will again divide the entire carbon cycle into the four activities *to clean, to nourish, to work* and *reside, to transport and to communicate*.

The Substance Flow Analysis below illustrates the Carbon Dioxide emission for the time period from 2007 to 2009. The colours represent the carbon sources of carbon dioxide as well as the four activities *to clean, to nourish, to reside and work, and to transport and communicate*. As above, the blue greyish colour represents *to reside and work*, whereas green represents to nourish and orange is the activity of *to clean*. *To transport and communicate* is shown in brown colour. As carbon dioxide is not imported the light purple colour represents the carbon import, therefore the source of carbon dioxide for all processes and the black flows represent flows insignificant for the final carbon dioxide emissions.



Activities:

To clean	To nourish	Carbon Flows
To reside and work	To transport and communicate	Data insignificant

Abbreviations :

CM	Construction Material	t/a	Tonnes per year
CP	Composting Plant	TR	Traffic
EP	Energy Production	WIP	Waste Incineration Plant
IN	Industry and Production	WM	Waste Management
LF	Landfill	WW	Waste Water
OB	Organic Biomass	WWTP	Waste Water Treatment Plant
PHH	Private Household		

Figure 3: Carbon import and sources of Carbon Dioxide Emission

4.2.1 To Clean: Supply and Disposal of Waste, Waste Management

Table 23: Carbon Dioxide emissions of activity to clean

Export Name	Export Quantity in t
Respiration of Waste Water	27,748
Combustion of WIP	n/a
Emissions of Landfill	30,000
Emissions of Waste CP	7,333
Total CO2 Emissions	**65,081**

The total carbon dioxide emissions for the activity *to clean* amount in 59,348 t include the flows *Respiration of Waste Water, Emissions of Landfill* and *Emissions of Waste Composting Plant. Combustion of Waste Incineration Plant* has been moved to the activity to transport and communicate as it produces energy and the emissions from pure waste incineration without energy are insignificant. Table 24 also includes the flow of emissions of *Composting Plant*. Although the data is from 1991 it is assumed to have stayed constant and as it only makes up around 11 per cent of the total carbon dioxide emissions. However, it has to be mentioned that these are all carbon emissions from the composting plants and assumed to be fully transferred into carbon dioxide. In reality however some of it will be transferred into methane (CH4).

Concluding, the main sources for carbon dioxide emissions in the activity *to clean* are emissions of landfills, whereas most of it is will be carbon neutral and therefore not hazardous to the environment.

4.2.2 To Nourish: Transport, Preparation and Digestion of Food

Table 24: Carbon Dioxide emissions of activity to nourish

Export Name	**Export Quantity in t**
Respiration of Human	769,749
Production Goods: Nourishment	n/a
Total CO2 Emission	**769,749**

All carbon dioxide emissions for the activity *to nourish* total in approximately 769,749 t which consists only of the flow *Nourishment to Private Household*. As the flow *Production Goods: Nourishment* only is a carbon export flow and does not directly emit carbon dioxide, it has been assumed to be insignificant in this section.

Moreover, the respiration of carbon dioxide by humans is not only a necessity but also it is not possible to change the carbon dioxide respiration into another substance and therefore will not be pursued further in this thesis.

4.2.3 To Reside and Work: Fuel for AC and Construction

Table 25: Carbon Dioxide emissions of activity to reside and work

Export Name	**Export Quantity in t**
Combustion of PHH	1,293,000
CO2 Emission Services	399,000
CO2 Emission Industry	532,000
Total CO2 Emission	**2,224,000**

The total carbon dioxide export flow for the activity *to reside and work* amounts in approximately 2,224,000 t. This includes the export flows *Combustion of Private Household*, *CO2 Emission Services,* and *CO2 Emission Industry.* These export flows should include all emissions caused by the economy. Combustion of *Private Household* is the biggest import flow with approximately 58 per cent of the activity's export.

4.2.4 To Transport and Communicate: Fuel for Transport and for Supply of Infrastructure

Table 26: Carbon Dioxide emissions of activity to transport and communicate

Export Name	**Export Quantity in t**
Combustion of Fuel	3,319,000
Combustion of EC	2,683,000
Total CO2 Emission	**6,002,000**

The activity with the biggest share of carbon dioxide emission however is still the activity *to transport and communicate.* The total carbon import flow amounts in approximately 1,591,000 t in forms of the flows *Fuel*, *Natural Gas, Coal, Oil (fuels),* and *Biomass (Wood).* The two export flows Combustion of *Fuel* and *Combustion of Energy Production* add together to carbon dioxide emissions of around 6 million t per year. Nevertheless, the carbon dioxide emissions from the biomass plant are considered to be carbon neutral and would decrease the 'bad' carbon dioxide emissions by 348,333 t per year and therefore this activity's carbon dioxide emission would result in about 5.65 million t. As these emissions are entirely caused anthropogenically, it also has the biggest potential of being reduced as elaborated upon in the next chapter.

5 Optimisation Processes / Main Means to Reduce Urban Carbon Dioxide Emissions for Each Activity

In this chapter a comparative literature analysis of already existing methods and technologies in order to reduce CO2 emissions will be conducted. In addition, this section will assess ways in order to eliminate or minimize carbon dioxide emissions by substituting or compensating applying best available technology according to the four activities. Furthermore, it will look at secondary sources for compensation and structural changes in case carbon dioxide emission can only be reduced.

5.1 General Information

In order to control the carbon dioxide emissions, objects of everyday use should be recycled and reused. For instance, the reliance on oil and coal should be minimized. Use of Heating, Ventilation and Air condition (HVAC) should also be minimized. Moreover, cars should be replaced with bicycles. As bicycles do not consume fuel and this is an environment friendly means of transport. Overall, the population should make use of energy efficient products. The use of material in construction that is rich in carbon content should be minimized as well. Not only should the use of wood for production purposes be banned, but also should planting be increased immensely. These measures, if taken, can cause a considerable decrease in the global warming and let earth remain a sustainable place in the future. *“We show that it’s critical to have both technology and land-use policies to deal with CO2 because we won’t be able to reach Kyoto [Protocol]-like targets without [both]”* (Stone cited in Chatterjee). Therefore, rational policies need to be implemented in order to reduce the carbon dioxide emissions. To lower the carbon dioxide emissions, such public policies should be taken which tend to minimize the obstacles in the way of implementation of carbon dioxide reducing strategies and which empower avenues of commerce, creativity and discovery so that progress can be made real and quantifiable. Carbon dioxide emissions have no single way of reduction. Formulation and implementation of policies which result in decreased carbon life-cycle emissions need such strategies which would address the lifecycle characteristics of the resources of energy like natural gas, coal and other renewable sources, formulation of systems of low carbon propulsion and transformation to the energy carriers like hydrogen, electricity, and fuels. According to *ASME 25*, carbon dioxide emissions can be minimized by developing a policy framework which includes:

- Mandatory and progressive goals for reducing the carbon dioxide emissions from all primary sectors of energy that include but are not limited to transportation, power generation, residential and commercial buildings, manufacturing. The goals should be realized with respect to the near term, midterm, and long-term timeframes.
- The approaches for increasing the motivation among the various economic sectors to limit the carbon dioxide emissions should be made flexible as the limits vary from one sector to another. The approaches may include as per the requirements of a particular sector, guarantees of governmental loan, performance standards, market based incentives, tax reform, performance criteria, deployment, research and development, and several other policy tools.

- More money should be invested in the research and development so that newer and cost effective methods of making energy efficient technologies can be identified. Research should explore ways to enhance the efficiency of carbon energy systems.

- Government should pay great attention towards increasing the competency of workforce working for the advanced energy technologies. Their education and training is vital for their improved productivity.

- The infrastructures need to be improved in accordance with the demands of the technologies selected for the reduction of carbon emissions.

ASME has sufficiently highlighted all areas that need to be taken into consideration while introducing the policy for reduction of CO_2 emissions. These areas largely cover all aspects of the story and proper measures, if taken, can greatly reduce the carbon dioxide emissions and also make the process effective and cost efficient.

An example of a city where carbon dioxide emissions are far below national average according to the records maintained by the International Council for Local Environmental Initiatives (ICLEI) (The Times of India) is Ahmedabad in India . In the same report issued by The Times of India, it is mentioned that research was conducted between 2007 and 2008 which investigated 40 cities of India with respect to their level of carbon dioxide emission. Among all 40 of them, Ahmedabad was found to be the greenest with the least level of emission of CO_2. As a result of the research the total amount of carbon dioxide emissions in Ahmedabad was found to be 6,780,752 t. Of these, 1.97 lakh tonnes were released by the Ahmedabad Municipal Corporation (AMC's) activities. Carbon dioxide emissions resulting from the community activities of the citizens of Ahmedabad were found to be 65.83 lakh tonnes. However, this analysis is only about the area limited within AMC. Many industries that are located on the outskirts of the city as well as the thermal and captive power plants were not included in the study. If those had been included in the research, the level of CO2 emission determined would have increased manifolds. According to municipal commissioner IP Gautam, AMC has implemented numerous carbon emission reducing processes in Ahmedabad. Some of these processes include use of the methane gas which is released from the sewerage plant about 180 million litres per day (MLD). AMC has established a complete landfill site in Gyaspur. The waste-beads are burnt in order to generate electricity. All of these measures serve to reduce the emission of carbon dioxide into the atmosphere. Various technologies have also been employed to cut down the consumption of electricity that include use of BRTS mass transit system, LED lighting source, e-governance and other kinds of green technologies. "AMC has agreements with the three companies with a 60 per cent to 40 per cent profit sharing arrangement for carbon credit trade. Gujarat Urban Development Corporation is the main agency for the carbon credit trade in Gujarat. We would even put our BRTS project for carbon credit trade." (Gautam cited in The Times of India) This may be an example of a city where carbon dioxide emissions are relatively low but not only due to policies but rather due to the geopolitical system boundary made for the study itself which biases the whole picture.

Concluding, cities should have to make use of technology to reduce carbon dioxide emissions and, hence, improve the environment by the power of federal policies. In the contemporary age, the top most priority in all developing cities worldwide in general, and in high-income economies in particular, is to make the cities green by implementing such urban planning techniques that the living becomes sustainable and the city becomes greener. In order to achieve these purposes, many techniques are being implemented; some of which have been discussed before and some of which will be discussed accordingly to the four activities in the following.

5.2 To Clean

The “City of Vienna” has already successfully implemented new technologies in the sector of waste management over the time period of the last 20 years and is a forerunner in this sector with approximately 65,000 t carbon dioxide emissions. Vienna has implemented state-of-the-art waste incineration plants (generate electricity) which are used as examples in that field for many other cities and countries.

Although short distances to waste incineration plant among others are already put into practice, regarding the waste collection transport system it would be of even more value if the transportation system for waste could be revised as it accounts not only for most of the expenses of waste management but also since collected by waste trucks running on conventional fuel, emit carbon dioxide emissions. Therefore, the question arises as to what new innovative possibilities exist in order to eliminate or reduce the carbon dioxide emissions and reduce the financial burden in this field by manifold.

What would illustrate an alternative to avoid or minimise the transportation of waste by trucks? Bearing in mind that theoretically sewage is being transported by pipes, the question arises as to why waste is not transported the same way. However, this may be possible to implement for some specific kind of waste such as residential, non-hazardous, residual waste but would be impossible to design this for construction waste or similar. Furthermore, in an already existing city such as Vienna it would be very difficult to implement an entirely new underground system. Therefore, an alternative would be to create more waste collection point throughout the city and abandon individual pick up for each household. This implies though that citizens will change their behaviour in regards to the luxury of ‘pick up waste collection’ to ‘drop off waste collection’. Due to time constraints this cannot be further discussed in this thesis as it would require more data on emissions only by waste collection trucks which are expected to be extremely high due to stop and go transport.

5.3 To Nourish

The activity to nourish is the activity with the least potential of reduction in carbon dioxide emission although its total emissions are 770,000 t of carbon dioxide. The reason for the least potential is due to the fact that respiration of carbon dioxide by humans cannot be changed into a different substance. The only possibility to reduce emissions in this sector would be in the transportation, production and delivery of goods themselves. Hence, one of the possibilities can be seen again in the transportation sector which would require the human behaviour to change for instance to only buying local goods. However, as this thesis does not include the Hinterland transportation, this aspect is negligible.

5.4 To Reside and Work

In order to find substitutions for or eliminate the carbon dioxide emissions from the activity to reside and work, first the import flows will have to be looked at. The processes and therefore the sources of this activity are *Industry and Production* and *Private Household*.

Firstly, looking at the process of *Industry and Production*, many successful companies have taken measures to make the businesses green. One such company is the Japanese Company INAX, which manufactures bath, kitchen and toilet fixtures. This Company has used ceramics technology as a means to reduce the carbon dioxide emissions. INAX has made low-carbon products and business practices through creativity in the manufacturing, utilization and recycling of products. INAX considers the individualistic features of every stage in the life cycle of products so as to ensure the reduced emission of carbon dioxide during all stages. With a view to making its business greener, INAX plans to alter its ceramic production technologies. In 1990, 89 per cent of the total carbon dioxide emitted by INAX came from the making of such ceramics as bathroom fixtures and tiles (Ohno, 2009). In order to produce the ceramics, INAX used to heat the entire kiln with the help of fossil fuels, whereas no more than 10 per cent of the total energy produced was actually utilized in making the ceramics inside the kiln. This was undoubtedly a very inefficient process. INAX is currently using research and development to create a new production system in which the thermal conductivity would be unusually high and more heat would be directed to the ceramics instead of the surroundings. *"To achieve an 80 percent reduction in its carbon dioxide emissions by 2050, the company estimates that it will need to cut emissions by 33 percent by introducing high-efficiency kilns and by 47 percent by using renewable energy"* (Ohno, 2009).

INAX has generally adopted such practices that are conducive for sustainable living. In addition to reducing the emission of carbon dioxide in the atmosphere, INAX has also developed ways to reduce the consumption of water in its fixtures. In 2006, INAX introduced ECO6, which is a water saving toilet, to the market. It uses no more than 6 liters in one flush and, thus, as compared to the previous models, ECO6 offered a 60 per cent saving in water. Likewise, IAX developed a recycling facility in 2007, which is called the INAX Eco-Center Tokoname. This facility serves to collect and recycle all sorts of used fixtures which constitutes a potential way to minimize the waste as well as carbon content in the environment. Prudent businessmen are taking steps today to have sustained business tomorrow:

> *"I know that environmental issues are not limited to CO2 emissions, but this issue is symbolic of our whole Environmental Declaration. ... It delineates an ideal situation for 2050 with a specific numerical target. You may feel that 2050 is the distant future, but in 2050, today's new employees will be retiring. I asked them at their first training workshop to work together to keep our corporation sustainable even at that time." (Mizuno cited in Ohno).*

Concluding this empirical example of reduction in the sector *Industry and Production* it has to be mentioned here that each single company would have to find different solution for each process producing carbon dioxide emissions.

Regarding the process *Private Household* one of its major contributes to carbon dioxide emission is due to the combustion of resources. In order to reduce these emissions directly emitted by *Private Household* it would be sensible to look at alternatives from the private energy sector. Thus, the main alternative to conservative energy production is solar energy production. Several settlements in Berlin have already built solar panels on the roofs; one example is the settlement in the district of Reinickendorf. The 443 photovoltaic cells produce 92MWh per year. Energy produced by solar panels can either be used directly by the owner of the building or it can be used for district heating. This is not only a solution for residential areas but could also be applied on industrial buildings which generally would have a bigger roof space and therefore could generate a manifold of energy. Furthermore, in a city like Vienna which consists of mainly old building better isolation is necessary in order to make sure that the heating is used most efficiently. However, an analysis of this problem cannot be made due to time constraints.

In conclusion to the activity of *to reside and work* several more detailed studies especially on the potential of solar power in Vienna and its possible implementation will have to be conducted in order to see the possible reduction of carbon dioxide emissions in numbers.

5.5 To Transport and Communicate

In order to find substitutions for or eliminate the carbon dioxide emissions, first the import flows will have to be looked at. The processes and therefore the sources of this activity are *Traffic* and *Energy Production*. The sector *to transport and communicate* has the biggest potential when it comes to carbon dioxide reduction. This is due to the fact that this sector is not only the sector with the highest emission levels, but also the only sector where nearly all carbon dioxide emissions come from combustion of fossil fuels.

In order to reduce the carbon dioxide emissions in the atmosphere, the first and foremost step that needs to be taken is the introduction of renewable energy in the transport sector. Integrating the transport sector into the energy system could yield the maximum effect. Therefore, this section is going to discuss possibilities of the process *Traffic.* In Vienna there are 805,539 vehicles of which around 660,000 are cars (Statistics Austria, 2009, KFZ-Bestand) and each year this number is increasing. Due to improved technology cars can be made more fuel efficient in the last time. As a start Vienna could change all 3,890 taxis into electric cars. Alternatively, hydrogen can be used in place of fuel to drive the electric cars. However, it would not be enough to only change a conservative driven vehicle into an electric car as the electricity needed might be produced in a coal power plant outside the boundaries of the city. Therefore, in order to solve the global energy system, the electric cars should be charged with the help of wind turbines. A parade example of a renewable energy petrol station is a TOTAL petrol station in central Berlin. It is still under construction and is going to be finished in autumn 2011. This petrol station will offer hydrogen in addition to the conservative fuels but the special issue about this certain concept is that the hydrogen is produced by renewable energy only. This joint project of TOTAL and Linde is expected to be very successful (Linde, 2011). For the problem of fuel combustion of vehicles, this would be a long-term solution. Therefore, assuming that all vehicles would be electrical vehicles and the electrical power needed would be produced by renewables, all carbon dioxide emissions from the process *Traffic* would become zero. However, it has to be added that this scenario is fairly unlikely in the close future.

There is need to determine alternatives to the conventional sources of fuel so as to minimize the effect of supply shortages on the transport activities. In the contemporary age, the use of battery technology is not consistent with trucks. However, it is a good idea to make use of small electric vans in order to distribute goods around the city. *“A Georgia Tech City and Regional Planning study on climate* *change, published February 10, 2009 online by Environmental Science and Technology, shows that "smart growth" combined with the use of hybrid vehicle technology could reduce cities' carbon dioxide (CO2) emissions – the principal driver of global warming – significantly by 2050." (Nagel, 2009)*

Road charges such as the ones in London are another way to reduce the carbon dioxide emissions. The congestion charge zone spreads all over central London, including the business district (City) and the Westend. Any vehicles with the exception of electric cars entering the congestion charge zone have to pay road charges. Another, very interesting solution London is offering in order to convince people to use electric cars, is that if living in an area with a residential, on street parking zone the parking permits are for free compared to the usual annual fee. Moreover, charging stations for electric cars are spread all over the inner city. In order to apply the congestion charge zone to Vienna, first the outcome of the referendum would have to be positive. Several attempts of a referendum to create a CC zone in Vienna have failed, although this might decrease central traffic and emissions extremely.

Another attempt is as Brian Stone, who is the associate professor of Georgia Tech City and Regional Planning, put it very nicely: "*In this study we looked at two general approaches on how to deal with the challenge of climate change. One approach is to improve vehicle technology and become more efficient. We can use less gas and reduce tailpipe emissions of CO2. The second approach is to change behavior by changing the way we design cities. We can travel less and take more walking and transit trips" (Nagel, 2009).* Thus, another attempt to decrease emissions by traffic is to encourage people to use emission free transportation such as bicycles or walking. In addition to this, inhabitants of Vienna should be persuaded even more to use public transport, although according to the European Green City Index already 68 per cent of the population walks, cycles, and uses the well designed and easy accessible public transport. Furthermore, all public buses run on liquefied petroleum gas. This results in lower carbon monoxide emissions than diesel would emit. According to the Green City Index, Dublin has successfully introduced a new scheme of financial incentives for people who cycle to work. Employees receive financial benefit on their salary if they can prove that they cycled to work.

Another solution to the problem of road congestion would be the introduction of so-called 'speedy lanes' on which only cars with more than two passengers would be allowed to be driving. Consequently, this will result in car sharing which would reduce the traffic not only within the city but also on the major roads into the city. Similar policies have been implemented on highways around Washington, D.C. in the US .

Last but not least this study will look at the process *Energy Production*. Its carbon dioxide emissions amount in 2,683,000 t. The biomass plant has been very successfully implemented in Vienna. However, there are two sides to generating energy with biomass; on the one hand it is seen as carbon neutral, whereas on the other hand the biomass if considered as forest has a high natural uptake of carbon dioxide and deforestation would therefore cause a decrease of carbon uptake by trees. Therefore, it is debateable whether this is the right solution since although some parties consider it clean energy production, others can contradict if annually more deforestation is taking place than the natural biomass increases. But then again if only considering Vienna as the boundary system and taken into account that the biomass, if coming from up to 250 km outside of Vienna, it would decrease the carbon emissions for the city but potentially increase it for the country. Nevertheless, energy production with biomass is environmentally friendlier than conventional energy production and especially than coal fired power plants such as Dürnrohr coal power plant which produces carbon dioxide emissions of 1,435,406 t in Lower Austria.

Table 27 shows the power plants which nearly produce the entire energy consumed in Vienna in 2008. Discussed in section 2.4 was already the high reliance on natural gas in order to produce energy. Table 27 shows that three out of the four main producer of electrical power are based on natural gas and these three together emit 2,236,219 t Carbon dioxide emissions. Therefore one of the main objectives is to find alternative energy sources which produce the same amount of power but have reduced Carbon Dioxide emissions. However, it will be nearly impossible to build about 100 wind power plant within the city of Vienna in order to substitute the power produced by the power plant in Simmering. Thus, it would be sensible to modernise all natural gas power plants to the most efficient power plant in Vienna. This table already illustrates that the carbon dioxide emissions of each single natural gas power plant differ strongly and that the most efficient power plant regarding carbon dioxide emission per MWh el is the power plant Donaustadt. Thus, it can be concluded that in order to reduce the emissions the gas power plants Simmering and Leopoldau are modernised to the same standard as Donaustadt that would decrease carbon dioxide emissions by 632,484 t assuming that these power plants produce still the same amount of MWh el.

Table 27: Energy production of 97 per cent of Vienna energy consumption 2008 (own calculations, Stadt Wien 2011 *b*, and European Commission "*community transaction log*", 2011)

Name	Type of power plant	Electrical power	Thermal power	CO2 Emissions in t	C Import in t
Wienstrom KW Simmering *3* 1+2	Natural Gas	365 MW el	350 MW th	915,476 268,968	249,675 73,355
Wienstrom KW Leopoldau	Natural Gas	142 MW el	170 MW th	256,284	69,896
FHKW Spittelau Fernwärme Wien	Oil, Natural Gas, Incineration	6 MW el		19,327	5,271
Donaustadt	Natural Gas	499 MW el	250 MW th	795,491	216,952
Biomassekraftwerk Simmering	Biomass Natural gas	16 MW	n/a	300,667 8,687	95,000 2,369
Freudenau	Hydropower	172 MW el	n/a	n/a	n/a
Kleinwasserkraftwerk Nussdorf	Hydropower	4,75 MW el	n/a	n/a	n/a
Deponiegasanlage Rautenweg 22	Biogas	6,5 MW el	n/a	30,000	n/a
Windpark Unterlaa	Windpower	4 MW	n/a	n/a	n/a
Windpark Breitenlee	Windpower	2,55 MW	n/a	n/a	n/a
Total				**2,594,900**	**962,193**
Total excluding BM emissions				2,294,233	962,193

6 Limitation of Study

This study has shown that much more detailed research needs to be done in order to get a conclusive picture of firstly the carbon dioxide emissions and carbon flows, and secondly the optimisation processes. In order to quantify the reductions in the optimisation processes more technical data is needed and would have to be cross-referenced with the already existing data of Vienna. Furthermore, although data had been available for carbon dioxide emission, uncertainties will always have to be taken into account and in order to conduct a more certain study, more detailed data needs to be accessible.

Further studies should be conducted in regards to the methane emissions as due to time constraints this study only discusses the carbon dioxide emission of all Greenhouse gases.

7 Conclusion

In order to answer the question whether a Central European city without carbon dioxide emission is feasible this study determined the quantities of Carbon Dioxide emissions according to the four activities for a Central European city on the example of the City of Vienna.

The results of the carbon cycle in 1991 were that high uncertainties have to be taken into account for some of the import flows *Consumer and Production Goods* and the import flows into *Energy Carrier* and *Private Household.* Altogether around 5,3 million t of carbon are imported in the year 1991 into the city of Vienna of which 1,5 million are added to Viennese stock and 3,8 million t are exported again. More than 70 per cent (2,7 million t) of the total carbon export flows are directly emitted to the atmosphere by the flows *Combustion of Traffic, Combustion of Energy Carrier, Combustion of Energy from Private Household, Combustion of Waste Incineration Plant, Respiration Human, Waste Water Respiration* and *Respiration of Composting Plant.* Whereas the other major carbon export flow is in form of goods with around 890,000 t C.

The Results of the quantification for carbon dioxide emissions are that the biggest flow of carbon dioxide emissions are the export flows of *Traffic* with a total volume of around 3,3 million t of CO2 emissions followed by the emission from the *Private Household/Human* (2 million t CO2) and *Energy Production* (2,7 million t CO2). Whereas the most important carbon dioxide sources, thus the import flows are the flows entering the processes *Traffic* and *Energy Production* with about 1,7 million t of carbon dioxide. The emissions from *Energy Production* by the biomass plant are considered carbon neutral and reduce the carbon dioxide emissions by around 350,000 t which decreases the total emissions of *Energy Production* to 2,35 million t carbon dioxide.

By looking at the optimisation processes it can be stated that the sector with the biggest optimisation opportunity is the energy and transport sector in the activity to *transport and to communicate*. However, it is not feasible to say that an existing city with 1,6 million citizens will be carbon dioxide emission free. But if advanced technologies were to be implemented, differences in millions of tons of carbon dioxide emission could be measured which especially can be seen in regards to modernisation of power plants and vehicle technology. This could reduce the carbon dioxide emissions by around 40 per cent of the total volume of 9,831,000 tons per year.

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9 List of Figures and Tables: