TECHNISCHE
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DRESDEN

Fakultät Forst-, Geo- und Hydrowissenschaften

Institut für Abfallwirtschaft und Altlasten

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Aufgabenstellung für die Diplomarbeit

Diplomand: Sven Schulenburg geb.: 18.02.1983

Thema: Analyse der RDF-Herstellung in Vietnam

Zielstellung:

Mit der wirtschaftlichen Entwicklung Vietnams in den vergangenen Jahren ist auch gleichzeitig ein höherer Bedarf an Energie zu verzeichnen. Durch das wirtschaftliche Wachstum ist auch gleichzeitig eine Veränderung der Abfallzusammensetzung zu verzeichnen.
Um eine ressourcenschonende Abfallverwertung zu etablieren und gleichzeitige Einsparung von Primärenergieträgern zu ermöglichen, sollte eine Nutzung des Abfalls als sog. Ersatzbrennstoff (Refuse Derived Fuel – RDF) in Betracht kommen. Hierbei soll eine biologische Stabilisierung von Haushaltsabfällen aus der Stadt Hanoi stattfinden.
Dafür ist eine Abfallcharakterisierung unerlässlich. Durch die so gewonnen Daten, soll eine Optimierung des Ersatzbrennstoffes hinsichtlich seines Brennwertes stattfinden. Gleichzeitig soll eine Schadstoffreduktion erreicht werden.
Ferner soll eine Treibhausgasminderung durch die Subsituierung mittels Ersatzbrennstoffen berechnet werden. Hierbei sollen auch auf den Zertifikatehandel mit CO2 Emissionen einzugehen.

Ziele der Diplomarbeit:
Abfallcharakterisierung und Analyse von Haushaltsabfällen der Stadt Ha Noi erstellen und diese mit vorhandenen Daten in Hinblick auf die Veränderung der Zusammensetzung vergleichen.
Erstellung, Untersuchung und Optimierung eines einfachen Prozesses im Labormaßstab zur Stabilisierung des Abfalls und Herstellung von Ersatzbrennstoffen. Eine Siebanalyse ist durchzuführen. Hierbei kommt eine biologische Trocknung in Betracht.
Die biologische Trocknung soll detailliert untersucht werden, dies beinhaltet auch eine Betrachtung des Prozesses mittels Massenbilanzen.
Untersuchung und Analyse der Ersatzbrennstoffe in Hinblick auf ihre Tauglichkeit.
Treibhausgasminderungspotential und Kostensenkungspotential berechnen auf Grundlage des intern. Zertifikatehandel für CO2-Emissionen.

Anlage zur Aufgabenstellung für die Diplomarbeit von Herrn Sven Schulenburg

Betreuer:	Prof. Dr. Nguyen Thi Diem Trang	Hanoi University of Science, Vietnam
	Prof. Dr.-Ing. habil. Dr. h. c. Bernd Bilitewski	TU Dresden, Institut für Abfallwirtschaft und Altlasten
Ausgehändigt:	23.12.2009	
Einzureichen:	23.05.2010	

Prof. Dr.-Ing. habil. Dr. h.c. B. Bilitewski

Verantwortlicher Hochschullehrer

Detaillierte Aufgabenstellung

- Die Abfallzusammensetzung und Behandlung durch biologische Stabilisierung lässt eine Nutzung als Ersatzbrennstoff zu.
- Durch eine Klassifizierung ist eine Anreicherung des Energiegehalts möglich bei gleichzeitiger Reduktion des Schadstoffanteils.
- Der erzeugte Ersatzbrennstoff erfüllt die Kriterien der Substitution von Primärenergieträgern, auch im Hinblick auf die zu erwartenden Schadstoffeinträge und z.T. bestehenden Grenzwerte / Richtlinien.
- Durch den Einsatz von RDF lässt sich sowohl ein ökonomischer als auch ein ökologischer Vorteil ableiten.

Organisatorisches

Die Darstellungen und Untersuchungen sind in ihrem Umfang in Abhängigkeit von der zeitlichen Begrenzung der Arbeit so festzulegen, dass ein abgerundetes Ergebnis vorliegt.
Die Arbeit ist (unbeschadet weiterer Exemplare, die mit den Betreuern vereinbart werden) in zweifacher Ausfertigung bei der TU Dresden einzureichen. Zusätzlich sind die Diplomarbeit und folgende Teile im Dateiformat einzureichen: Autorenreferat, Schlagwörter, Poster, Passfoto (JPG).
Die Ergebnisse der Arbeit sind in Thesen zusammenzufassen. Der Arbeit ist ein Poster mit den Außenmaßen H = 100 cm, B = 70cm beizufügen.
Währen der Bearbeitung sind Konsultationen mit den Betreuern unerlässlich. Die Abschlussverteidigung erfolgt nach Vereinbarung.

ĐAI HOC QUOC GIA HÀ NOI

TRUONG ĐAI HOC KHOA HOC TU NHIÊN

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Sven Schulenburg

Analyze of RDF-production in Vietnam

LUAN VAN THAC SI KHOA HOC

Hà Noi-2010

ĐAI HOC QUOC GIA HÀ NOI

TRUONG ĐAI HOC KHOA HOC TU NHIÊN

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Sven Schulenburg

Analyze of RDF-production in Vietnam

CHUYÊN NGÀNH: QUAN LÝ CHAT THAI VÀ XU LÝ VÙNG Ô NHIEM
(CHUONG TRÌNH ĐÀO TAO QUOC TE)

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TECHNISCHE
UNIVERSITÄT
DRESDEN

Diplomarbeit

Analyse der RDF-Produktion in Vietnam

Vorgelegt von:	Sven Schulenburg
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Dresden, 22.06.2010

I. INDEX

II. ABBREVIATIONS

CEN	Centrum for Standardization
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
DOC	Degradable Organic Carbon
DS	Dry Substance
EU ETS	European Union Emission Trading System
F-AAS	Flame Atomic Absorption Spectroscopy
HV	Heating Value
IET	International Emission Trading
LHV	Lower Heating Value (Hu)old now Hi
MAP	Mean Annual Precipitation
MAT	Mean Annual Temperature
MCF	Methane correction factor
MU	Monetary Unit
MSW	Municipal Solid household Waste
PET	Potential Evapotranspiration
MAP/PET	Ratio between the Mean Annual Precipitation and the Potential Evapotranspiration
RDF	Refuse Derived Fuel
SWDS	Solid Waste Disposal Site
SD	Standard Deviation
TU Dresden	Technical University Dresden
TC	Total carbon content
TIC	Total inorganic carbon content
TOC	Total organic carbon content
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Waste from Electric and Electronic Equipment
WC	Water Content

III. LIST OF TABLES

IV. FIGURES

V. ACKNOWLEDGEMENTS

Special thanks I would like to say to my supervisor Prof. Trang Nguyen Thi Diem for gave me the opportunity to make this thesis at Hanoi University of Science in the Double-Degree-Program between the National University and the Dresden University of Technology. Many thanks also to my German Supervisor Prof Bilitewski.

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Last but not least, but for ever at the first place in my heart, a very very lovely thanks to my Giang for your help, support and a lot more, for that no words exist.

VI. SUMMARY

The thesis deals about analyze of production of RDF from municipal household waste from urban area in Vietnam. A waste samples from Hanoi area, Hoan Kiem District was characterized and used for RDF production. Three experiments were established, two with an active aeration and one without (passive) after the experiments, an sieving-analyzed in to three classes was done. From the three classes, >40mm, 10-40mm and <10mm samples were taken for later analyze. The produced RDF was analyzed on water content, biogenic and fossil carbon content, heavy metals, chloride and sulfur, total carbon content and ash content.

With these data analyze about the usability of the RDF was done, also comparisons about the substitution of primary energy sources like coal was done. Economic comparisons also, together with a calculation of the possible benefit for the environment, because of avoided landfill gases like methane, etc. For that also a possible economic benefit was calculated. From that is was seen, that a economic benefit could be possible, which means a surplus income by using RDF instead of lignite, because of the selling of emission rights by a clean development mechanism.

From the comparison the main result was, that the RDF with active aeration from the class >40mm shows promising results, but more and detailed investigations are necessary. Also improvement of the complete RDF production process is necessary, because the produced RDF shows a high water content, which has a negative influence to the quality and later process steps. The class 10-40 mm could also fulfill the possibility for usage as a substitute. But also for that more investigations seems to be necessary.

1. INTRODUCTION

The Waste generation of Municipal Solid Waste (MSW) in Vietnam is more than 15 mil. tons per year. Hereof is more than 50 % generated in urban areas like Ha Noi or Ho Chi Minh city. It is expected, that through the developing of Vietnam, the composition of MSW will change more to a composition of MSW in developed countries. That means, a higher caloric value, because of an increasing of fractions like plastic, paper, etc.

Currently, the most of the MSW is land filled. A treatment of the waste, like mechanical biological stabilization or incineration like in European Countries, does not happen before land filling. The land filling of untreated MSW cause in the future for a long time period landfill gas, which consist mostly of Methane and Carbon Dioxide. Methane has a negative effect on the global warming potential of 25 in comparison to carbon dioxide.

One solution could be the usage of MSW as a substitute for fuel like coal. Nowadays, the most electric energy in Vietnam is produced by coal-fired-power-plants. The economic growing of Vietnam cause a higher electric energy consumption, which is accompany with an increase of the demand of primary energy resources. The production of Refuse Derived Fuels (RDF) could save the consumption of these primary energy resources like and also prevent the generation of global warming gases like methane.

The history of using RDF is very long, and has it beginning in 1876 with the incineration of waste (Alter, 1987). Later, during the 70s years with the oil crises, a rethinking started, away from primary energy fuels like coal and oil to energy sources, which are independent from these resources. Also a economical benefit should reached. In the beginning a lot of problems existent, but nowadays, especially in the European Union, the production of RDF out of MSW become more and more favorable.

The use of RDF can also bring with it a financial gain through Clean Development Mechanisms (CDM). The CDM are based on individual contracts between companies in developed and developing countries such as Vietnam. The Vietnamese side can join the market for emissions rights with such projects. The basic idea behind this is, that Vietnamese companies use RDF with a renewable content of carbon instead of fossil fuels and avoid also the methane emission from landfill. Companies in developed countries must not buy climate-certificates for their emissions; they pay directly to the Vietnamese Companies. With that, a support in education and technical & financial help will also happen from developed countries to Developing countries.

For that an experiment was established to produce RDF with MSW from Hanoi area. For production should be used a biological stabilization, which should bring different benefits to the produced RDF. Early studies engaged with the efficiency of biological drying (Zhang, He, & Shao, 2009) (VELIS, Longhurst, Drew, Smith, & Pollard, 2009), also for typical Asian MSW. Also (CHÂU, 2009) engaged with the process of biological stabilization of MSW from Hanoi area.

To reach a high quality RDF, which is useable for substitution of primary energy fuels like coal, more investigations seems to be necessary. Also the economical effects and environmental benefits by using RDF are not investigated. But also it must be considered, if the RDF has similarities to the fuel, which should be substitute. These could be for example the content of heavy metals or chloride, which could cause during combustion problems. Investigation hereunto for example by (Rotter, Kost, Winkler, & Bilitewski, 2004).

For that, this thesis should give answer to the following theses:

1st Thesis -	The composition of the waste and the biological stabilization allow a usage as RDF.
2nd Thesis -	By a classification is an enrichment of the energy content possible while reducing the pollutant content
3rd Thesis -	The produced alternative fuel meets the criteria for substitution of primary fuel, also with a view to the expected pollutants and existing limit values.
4th Thesis -	The use of RDF can reach a economic and environmental benefit.

2. MATERIALS AND METHODS

2.1 WASTE COMPOSITION ANALYZE

The composition of the input materials for the RDF process was investigated by a sorting analyze with MSW from the city Hanoi, Vietnam. The waste was collected on 15th January 2010 in the Hoam Kim District. The district has a area of 5.29 km^2, a population of 171,400 and a population density of 32,339 pers/km^2 (Con & al., 2004). The total amount of waste, which was used for the composition analyze was 279.6 kg. Analyze was carried out in two general steps. The first step was a sieving (>40 mm) and hand-sorting of the different fractions. The following fractions were distinct into:

- Organic/Biowaste
- paper
- glass
- plastic
- composite materials
- wood
- textile
- minerals
- nappies and hygienic article
- hazardous materials
- others

During the second step, the screenings with a size lower than 40 mm were manually sorted into the different fractions. The through fraction with a size lower than 10 mm was not further subdivided; it was rather regarded as a separate fraction. Each fraction was weighted. After that, each fraction was mixed manually and samples were taken from the fractions. The complete sampling follows the standard (14899:2005, 2005).

2.2 SAMPLE ANALYZE

From every fraction of the sorted waste, samples were taken. If enough material from the fractions was available, the samples were done in double or triplicate. The size of the fractions was not reduced before taking samples, because no mills / shredders were available. Because of the limited capacity of the drying equipment, some samples were storage in a freezer by -18°C.

2.2.1 WATER CONTENT

To determine the water content (WC) of each fraction and the samples from the RDF, the waste was dried in an oven with a degree of ca. 105 °C. Analyze follows the European standard (CEN/TS 15414-3, 2009). If enough material for determination of the water content was available, the samples were done in triplicate. The samples were storage in the oven until a stable weight was reached. The water content was calculated by equation 1:

$$\boldsymbol{WC = 1 - \frac{m_{dry} - m_{emp}}{m_{wet} - m_{emp}}} \tag{1}$$

WC	*water content*
m_{dry}	*mass of dried sample*
m_{wet}	*mass of undired sample*
m_{emp}	*mass of empty beaker*

2.2.2 SIZE REDUCTION

For the subsequent analysis, the dried samples were size-reduced. The first step was made manually with a shear. In the second step, the so prepared samples were size-reduced with a typical household mixer, in the next following step manual by using a pestle and mortar. The so size reduced samples were used for determination of biogenic/fossil carbon (see 0). The so prepared samples were sieved and particles with a size over 1 mm were size-reduced again. The size reduction for analyze on Heating value (0), Chloride and Sulfur content (0), Heavy metals (2.2.5), Total carbon (2.2.3) was made at the Technical University Dresden, Institute for Waste Management and Contaminated sites Treatment, Pirna. As mill was used a sieving mill *CS2000* from *RETSCH* which reach a size reduction lower than 1 mm.

2.2.3 CARBON CONTENT

The carbon content of the samples was determined following the European Standard (CEN/TS 15104:2005, 2005). It was chosen the indirect methods (methods B of the standard). This method demanded at first a treatment of the samples with acid, to realize the total inorganic carbon (TIC). The organic carbon stays in the sample. With a comparison between untreated and treated samples the TIC could be calculated following equation 2:

$$TOC + TIC = TC \tag{2}$$

TOC *Total organic carbon content (mg/kg)*

TIC *Total inorganic carbon content (mg/kg)*

TC *Total carbon content (mg/kg)*

The carbon content was analyzed with *ELEMENT ANALYZER FOR CARBON-MULTI EA 2000 with CS MODULTE*. The detector works with two gas chambers, one as a reference chamber with CO_2. The sample is burned in the analyze device. Through the detection difference of the CO_2 to the reference chamber, the amount of carbon can be calculated automatically.

Heating value

The heating value was determined with the dried and size reduced samples at the Technical University Dresden. Analyze was carried out in a bomb calorimeter *IKA CALORICMETER SYSTEM C7000* in duplicate and follows the European Standard (CEN/TS 15400:2006, 2006) after Annex C. A defined amount of the dried sample was taken into the caloric-bomb. From the igniter lisle was connected through the sample. The bomb is closed and filled with pure oxygen up to a pressure of 30 bars. The sample inside the caloric-bomb is then burned and through the temperature difference the calorific value is determined. A influences (for example heating value of the lisle, etc.) are automatically taken out by the machine. The result from the machine is given in heat of combustion H_s (in some old literature H_o). This result must be calculated to lower heating value (LHV) H_i (in some old literature H_u).

For that exists a calculation equation following (Kost, 2001). Through this calculation the hydrogen content and water content must be considered. Also the enthalpy of evaporation must be considered. The calculation follows the equation 3:

$$\boldsymbol{H_u(raw) = H_o \cdot (1 - W) - 2441 \cdot (9 \cdot H(raw) + W)} \tag{3}$$

H_u(raw)	*lower heating value (J/g)*
Ho	*heat of combustion (J/g)*
W	*Water content (%)*
H(raw)	*Hydrogen content*

The LHV include the water content and the energy which is necessary for the evaporation of it, also the hydrogen content. With the LHV it is possible to make a comparison about the qualification of the waste and the RDF for example on the criteria for land filling of waste. Also this value is a quality criteria of the usage of RDF as a substitute for primary fuels.

2.2.4 *CHLORIDE AND SULFUR*

Chloride and Sulfur are necessary parameters for the quality of RDF. The digestion is carried out together with analyze of the Heating value (0). This procedure is an advantage, because during the determination of the HV, the sample matrix is destroyed. That means that the contained Chloride and Sulfur content of the sample is laid off. The bomb is afterwards edulcorated and the so attained leachate is analyzed on Chloride and Sulfur concentration. Analyze was carried out with the ion chromatograph from the company *METROHM.*

The knowledge about the content of Chloride and sulfur is necessary for later usage of RDF. Chloride plays an important role in the field of corrosion in combustion chambers. Hereby the corrosion must be divided into high and low temperature chloride corrosion. Also the knowledge about the containing amount of Chloride and Sulfur in the RDF is necessary for later planning of exhaust gas treatment. Chloride become to HCl and Sulfur to SO_2. For both of them are separate cleaning modules required. Also their dimension must be calculated after the maximum content of there both elements.

2.2.5 *HEAVY METALS*

The heavy metals play also an important role in the field of RDF production. This comes from two sites. On the one side plays mercury in the exhaust gas a role. During the HCl removing module Hg is also dislodged. On the other hand the most heavy metals could be found in the ash. Hereby could be caused a damage through the environment – depending on weather the ash is used. Many usages are possible, for example in road construction or as landfill cover liner. Researches hereunto could be found in (Travar, Andreas, Lidelöw, & al., 2009) (Brännvall, Andreas, et.al., & Diener, 2009).

Some organizations and countries in Europe have set limit values for heavy metals and other criteria for the usage of RDF. An overview is shown in (Rotter, Kost, Winkler, & Bilitewski, 2004). Also the European Committee for Standardization (CEN) has developed many Standards about RDF and analyze of it (CEN/TC 343, 2008).

Table 1: Overview about different requirements from different sources for the usage of RDF as a substitute fuel

	(Laga, 1997)	(BUWAL, 1998)	(SFS 5875, 2000)	(dell'ambiente, 1998)	(RAL, 2001)	(Staatliches Umweltamt Münster, 2000)	(Sander, 2000)	**Mean value of all values**
	(mg/MJ)	(mg/MJ)	(mg/MJ)*	(mg/MJ)*	(mg/MJ)*	(mg/MJ)*	(mg/MJ)*	
As	1.9	0.6	-	0.5	0.7	1.1	0.3	**0.9**
Be	0.1	0.2	-	-	0.1	0.1	0.1	**0.1**
Cd	0.3	0.2	0.3	0.4	0.5	0.3	0.6	**0.4**
Co	1.2	0.8	-	-	0.7	0.8	0.6	**0.8**
Cr	3.7	4.0	-	6	14	7	6	**6.8**
Cu	3.7	4	-	17	56	8	56	**24.1**
Hg	0.02	0.02	0.03	-	0.07	0.06	0.08	**0.0**
Ni	3.5	4	-	2	8.9	5.6	5.6	**4.9**
Pb	-	8	-	11	-	5.6	13.9	**9.6**
Sb	0.07	0.2	-	-	3.3	3.3	-	**1.7**
Se	0.2	0.2	-	-	0.3	0.6	1.1	**0.5**
Sn	0.4	0.4	-	-	3.9	2.2	-	**1.7**
Te	0.04		-	-	0.3	1.1	-	**0.5**
Ti	0.15	0.12	-	-	0.11	0.11	0.3	**0.2**
V	6.7	4	-	-	1.4	1.1	-	**3.3**
Zn	8	16	-	28	-	-	55.6	**26.9**
Chloride	1 M.%	-	1.5 M%	0.9 M%	Only declaration	-	1 M.%	**1.1 M %**

*) Basic for conversion from mg/kgDS to mg/MJ: Hi(wf): 18,000

The values were converted for the comparison to (M %) with the following equation 4:

$$\boldsymbol{X\ (M.\%) = X\left(\frac{mg}{MJ}\right) \cdot 1800\frac{MJ}{kg} \cdot\ 10^{-3}} \tag{4}$$

Analyze of the heavy metal content was made with a flame atomic absorption spectroscopy (F-AAS) *PERKIN-ELMER*. All samples were, when it was possible, made in triplicate. Analyze was performed at TU Dresden, Institute for Waste Management and Contaminated Sites Treatment. The complete Analyze follows the Standard (CEN/TS15411:2006, 2006).

2.2.6 *FOSSIL AND BIOGENIC CARBON*

For the determination of the amount of biogenic and fossil carbon exist different methods. The different methods are:

- Selective dissolution method
- Manual sorting method
- ^{14}C method

For this thesis was selected the selective dissolution method following the European Standard (prCEN/TS 15440:2009, 2009). For the other methods could be found a overview with lots of background in (Kneissl & Staber, 2009).

The methods procedure is as follow:

About 5 g of sample material was used for the determination of the biogenic and fossil carbon content. The sample material was dried and size-reduced. For the first step, the samples were treated in a flask for 16 ± 2 hours with 150 ml 78 % (g/g) H_2SO_4 in laboratory quality. After the treatment time of 16 ± 2 hours, 30 ml of 35 % (g/g) H_2O_2 is added. The flask is then storage for 5 ± 1 hour in a fume cupboard. After this treatment, the samples is cleaned in six steps, each with 50 ml demineralised water and a filter. The samples were dried again in an oven by 105 °C. Afterward the samples were determined on their ash content following the standard (CEN/TS 15403:2006, 2006).

The percentage of the biogenic and fossil carbon was calculated by the equation 5.

$$x_B = [1 - \{\frac{m_{residue} - m_{residue-ash}}{m_{SRF}} + \frac{A_{SRF}}{100}\}] \cdot 100 \qquad (5)$$

x_B	*biomass content expressed as a percentage by weight (m.%)*
$m_{residue}$	*remaining dry mass (including filter) after the test portion has been dissolved (g)*
$m_{residue-ash}$	*mass of ash of dissolution residue (including filter), burned according to prEN 15403 (g)*
m_{SRF}	*mass of dry SFR test portion used for dissolution(g)*
A_{SRF}	*ash content of SRF sample according prEN 15403*

The content of the fossil carbon was calculated following the equation 6.

$$X_{NB} = 100 - X_B - A_{SRF} \quad (6)$$

X_{NB} *non-biomass expressed as a percentage by weight (m. %)*

X_B *biomass content expressed as a percentage by weight (m.%)*

A_{SRF} *ash content of SRF sample according prEN 15403*

Therewith a differentiation of the RDF and the waste could happen. A fuel consist of the parts burnable, ash and water. With the determination the part burnable could be distinct into one part, which came from renewable resources – biogenic and on the other side a part which come from fossil recourses. Examples for both can be seen in Table 2:

Table 2: Overview of the different origin from the biogenic and fossil parts of carbon in MSW

Biogenic (renewable)	Fossil
Vegetables	Plastic
Wood	Rubber
Kitchen waste	Composite materials
Yard waste	
paper	

This information is also necessary for the calculation of Carbon dioxide emissions and the avoidance potential (2.4.3).

2.2.7 *ASH CONTENT / LOS OF IGNITION*

The Ash content and the Los of Ignition was determined at the TU Dresden. The Determination of them follows the standards (CEN/TS 15403:2006, 2006). The Ash content shows the unburnable part of a fuel and consists out of minerals. The knowledge about the amount and the composition of the ash is necessary. One the one site for the calculation about the treatment and disposal costs of the ash, on the other hand for a utilization of ash for example in road constructions.

But also about the qualification of an RDF for example in a cement kilt – how much ash and the quality of the ash is possible to create a negotiable product. Also different requirements must reach – for example different limit values like in Table 1. And these Heavy metals are existent mostly in the ash.

2.3 BIOLOGICAL STABILIZATION

The RDF was produced in two different ways. On the one hand with active aeration and on the other hand with passive aeration. The biological stabilization should reach different things with the waste. These are:

- Reduction of the water content
- Preservation of a high carbon content / burnable part
- Improvement of the sieving behavior
- Sanitation for the storage

The reduction of the water content should reach a stop or prevention of the microbiological activity. With that a degradation of the biogenic content is stopped and the biogenic carbon content is conserved. This is necessary to have a high content of burnable fraction in an RDF, which consists mostly out of carbon. Also the renewable part is preserved. Also a possible methanation is avoided during the storage process of the RDF.

Combined with the reduction of the microbiological the heating value will be increase. This can be easily seen, from the conversion H_s to H_i. The Water content plays a major role in that and with a reduction of it, the LHV will increase.

The Improvement of the sieving behavior is also caused through the reduction of the water content. Through the reduction the liming effect between small contains in the waste is reduced. These are mostly mineral part like sand. Also this parts are often found on the surface of the parts of the fractions >40mm and 10-40mm. A later sieving will remove these particles from the surface. With that could reach a increase of the heating value on the fractions >40 mm and 10-40 mm and together with an increase of the ash content of the <10 mm.

2.3.1 *ACTIVE AERATION*

The production-process of RDF with a biological stabilization together with active aeration was performed for two weeks. The experiment started on 16th January 2010 and was finished on 30th January 2010. The experimental set-up is shown in Figure 1. In the low range of a drum was a free space for leachate collection and for spreading the air. This part was separated by a rack with a mesh from the waste. 30.01 kg of fresh, non-separated waste was filled in. The size of the waste was not reduced, because of missing size-reduction equipment. The drum was closed with a cap. On the cap an outlet for the air-flow was fixed.

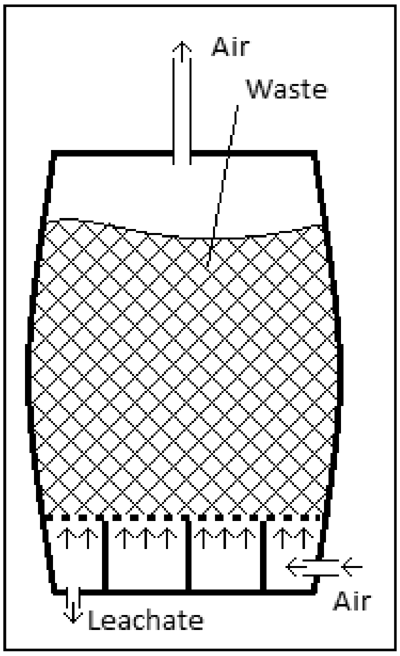

Figure 1: Experimental set-up for a biological stabilization with aeration of MSW for RDF production

After the biological stabilization the so dried waste was taken out and was weighing. The waste was than classified into three different fractions: <10mm, 10-40mm and >40mm. From these fractions samples were taken for analyze.

Also a second experiment with active aeration was realized. This experiment modified in comparison to the two weeks experiment. This experiment was performed for three weeks and the aeration only happens 10 minutes per day. The idea behind this was, that so the heat which is produced by the microorganisms during the biological stabilization stays longer in the waste and can so evaporate more water than the other experiment.

2.3.2 *PASSIVE AERATION*

The experimental setup for the biological stabilization is very similar to the experiment with aeration. The drum for this experiment was larger than in the other experiment. In the ground of the drum was an inlet for the passive aeration. In the waste a rack was installed, to reach a disaggregation of the waste. The total amount of waste, which was filled, was 45.15 kg. The cap of the drum was perforated, to establish aeration. On the drum was installed a rain shield. The test duration was also two weeks.

Also like in the experiment with an active aeration, after the experiment the stabilized waste was classified into three fractions. (<10mm, 10-40mm and >40mm). Samples for later analyze were taken from these fractions.

2.4 CLEAN DEVELOPMENT MECHANISM

2.4.1 KYOTO PROTOCOL

The Clean Development Mechanism (CDM) is a created as a part of the Kyoto Protocol. The Kyoto Protocol should reach a stop and prevention of the global warming through the emission of green house gases. It belongs to the United Nations Framework Convention on Climate Change (UNFCCC) and will end at the end of the year 2012. The emission of greenhouse gases whichever should be reduced are:

- Carbon dioxide – CO_2
- Methane – CH_4
- Nitrous oxide – N_2O
- Sulphur hexafluoride - SF_6
- Hydrofluorocarbons - HFCs
- Perfluorocarbons - PFCs

Carbon Dioxide plays two roles. On the one site it is the reference value for all other gases. That means that the global warming potential of each gas is calculated to an equivalent in CO_2 units. On the other side the emission of CO2 must be considered sophisticated. Only the CO_2 from fossil resources like coal or oil has a negative effect to the global warming. The increases of such gases in the atmosphere cause an increase of the global temperature. Negative effects through this temperature increasing are worldwide. Examples for that are melting of the polls, increase of the sea water level, desertification, etc. This is mainly caused by the heat capacity of the individual gases.

On the other side the usage and emission from biogenic carbon has no negative effect to the environment, because this carbon comes from the carbon cycle of the nature. That means, that the biogenic carbon is / was in usage (conversion of CO2 by photosynthetic to organic biomass; release of CO2 through the consumption of biomass through burning or use as food, etc.). It was heretofore in the environment and it is not an additional gas.

The Kyoto Protocol set different values for the reduction of greenhouse gas emissions in some developed countries. Developing countries are excluded from this reduction goal. It should be avoided, that developing countries are exposed to heavy loads by reducing limits. Higher priorities for these countries are a developing of their economics and establish a gain in prosperity. Inside the developed countries was created a market for the trading with climate certificates and for the developing countries was created the tool Clean Development Mechanism.

2.4.2 *INTERNATIONAL EMISSION TRADING*

The intention of the Kyoto protocol is that together with a minimization of the cost for new technologies the emission of green house gases should also decrease. The International Emission Trading (IET) works simplified so:

During a fixed period all producer of greenhouse gas emissions get a fixed amount of climate certificates. This amount is lower than all producers need on the market. Therewith the producers have a stimulation to invest in new technologies for reducing their emissions. Otherwise they must buy climate certificates on the market. If their own reduction is higher than the amount of certificates they got, they can sell it on the market and got so a benefit. It was expected, that the price for these climate certificates will increase and so a force was established, that the

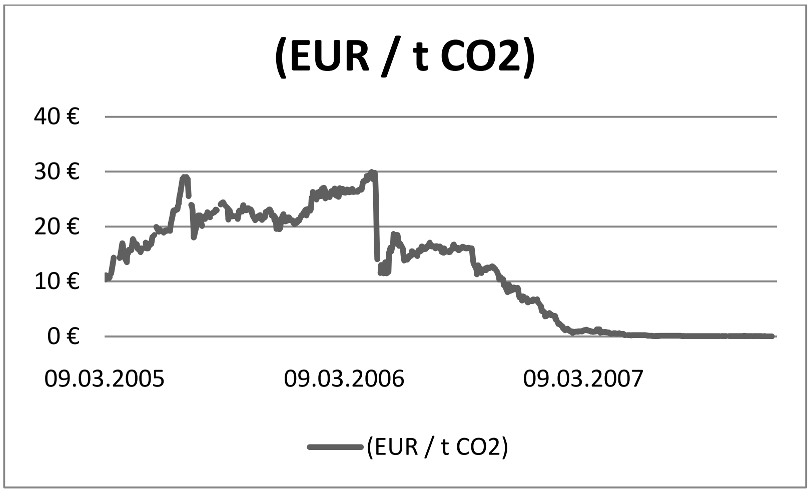

Figure 2: Price for climate certificates at the EXX stock exchange Germany during the first period of IET in the European Union (European Energy Exchange AG, 2005) (European Energy Exchange AG, 2006) (European Energy Exchange AG, 2007)

producers of the greenhouse gases must invest in new technologies, because it is cheaper than buy such certificates on the market.

Inside the European Union was the IET establishes with (Directive 2003/87/EC, 2003) as European Union Emission Trading System (EU ETS). This is the first international market for emission trading and this should also be a role model for a worldwide trading of emissions certificates.

In the reality this hope does not come true. During the first period in Germany for example were given to the market too much certificates, so that the price for them decreased and the market participants have no force to invest in new technologies or reduce their emission. This mistake was fixed for the second period and the prices for CO_2 certificates are now stable.

2.4.3 CLEAN DEVELOPMENT MECHANISM

2.4.3.1 BASICS

The Clean Development Mechanism (CDM) should establish participation for the developing countries to the emission trading market. Due to the planning and the Annex of the Kyoto Protocol, only the Developed countries should establish an IET. The developing countries could not join this market. Therefore was the tool CDM developed. With that tool should also the developing countries have the chance to get benefit through the reduction of greenhouse gas emissions. This mechanism is based on cooperation between companies in developed countries and developing countries. The companies make a contract and the company from the developed country supports the other company with techniques, education, etc. The amount of reduced CO2 equivalents could be used instead of carbon certificates. With that is also a monetary flow to the developing countries established. For the companies it is also a benefit, because the projects could be much cheaper than in developed countries and also, in the case of a high price for the certificates, cheaper than buying these certificates on the IET. For the so saved emissions, the European project partner will get Certified Emission Reductions (CER), which he can use for own processes in the European Union, but they can also sell it to other market participants. There are some limits and regulations with the selling and exchanging CER into certificates for the EU ETS. This special will not be discussed here in more detail. It is assumed, that the CER are equivalent to the certificates for the EU ETS market.

For each project type must be done a calculation of the amount of saved emissions from that project. The amount of so saved emission is only hypothetically, because a scenario is calculated and compared to the realized project. For many types of projects exist nowadays a calculation method and methodological tools from the UNFCCC. In these tools could be found a applicability and parameters for each project and the method for determination and calculation for the emissions avoidance. The calculations must be audited by a national agency.

The emission certificates are only valid during one period. A transfer to the following period could be possible in some special cases. The current period is the second from 2008 to 2012. The first period was from 2006 to 2008. The third period will be from 2012 to 2020.

All values and calculations in this thesis are for the third period. That means, the emissions are calculated for 8 year. This is from the perspective of the author, a plausible assumption, since the establishment and implementation of the CDM project would take some time to complete. (Test on pilot scale, auditing, more investigation, etc.)

2.4.3.2 Methane avoidance potential for RDF usage instead of Land filling

For the calculation of the methane avoidance potential of the used MSW is used (UNFCCC EB41, 2008). With this tool could be calculated the avoided methane from a solid waste disposal site, when the waste is not land filled, because of for example RDF production.

It is assumed that the composition of waste in the nights eight years does not change and also the quantity remains constant. The methane potential is calculated cumulatively, i.e. for the avoided waste from the first year for eight years for the avoided waste from the second year for seven years, etc.

The calculation which was used is shown in equation 7:

$$BE_{CH4,SWDS,y} = \varphi \cdot (1 - f) \cdot GWP_{CH4} \cdot (1 - OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_j W_{j.x} \cdot DOC_j \cdot e^{-k_j \cdot (y-x)} \cdot (1 - e^{-k_j}) \qquad (7)$$

Where:

$BE_{CH4,SWDS,y}$	*Methane emissions avoided during the year y from preventing waste disposal at the solid waste disposal site (SWDS) during the period from the start of the project activity to the end of the year y* (tCO_2e)
φ	*Model correction factor to account for model uncertainties*
f	*Fraction of methane captured at the SWDS and flared, combusted or used in another manner*
GWP_{CH4}	*Global Warming Potential (GWP) of methane, valid for the relevant commitment period*
OX	*Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste*
F	*Fraction of methane in the SWDS gas (volume fraction)*
DOC_f	*Fraction of degradable organic carbon (DOC) that can decompose*
MCF	*Methane correction factor - The methane correction factor (MCF) accounts for the fact that unmanaged SWDS produce less methane from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS*

$W_{j.x}$	*Amount of organic waste type j prevented from disposal in the SWDS in the year x (tons)*
DOC_j	*Fraction of degradable organic carbon (by weight) in the waste type j*
k_j	*Decay rate for the waste type j*
j	*Waste type category (index)*
x	*Year during the crediting period: x runs from the first year of the first crediting period (x=1) to the year y for which avoided emissions are calculated (x=y)*
y	*Year for which methane emissions are calculated*

The following assumptions were made in calculating:

$\varphi = 0.9$	Value was assumed from (UNFCCC EB41, 2008). (Oonk, Weenk, Coops, & Luning, 1994) stated, that value of 0.9 for a model correction is necessary. This is a value for a conservative calculation.
$OX = 0$	This value is adapted from (UNFCCC EB41, 2008) and based on a unmanaged solid waste disposal site which use no oxidation material like soil or compost for covering (also daily covering). (IPCC, 2006a) stated also a value of 0 for the region south-east Asia.
$F = 0.5$	This value is adapted from (UNFCCC EB41, 2008) and follows the (IPCC, 2006a). “The factor reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS.” (UNFCCC EB41, 2008).
$DOC_f = 0.5$	(IPCC, 2006b) stated a value of 0.5 for the decomposition rate of the carbon.
$MCF = 1$	This value was chosen following (UNFCCC EB41, 2008) because it was expected, that an anaerobic managed solid waste disposal site exists. It is assumed, that the landfill is “Nam Son”, which is an anaerobic managed solid waste disposal site, because following the criteria a mechanical compacting and a degree of control of scavenging exist. Also a leveling of the waste happens.
DOC_j	Two Scenarios were created and calculated. The one is based on Table 3 and these values were taken from (UNFCCC EB41, 2008). The other scenario was created after the results of the experiment biogenic and fossil carbon determination (0) see Table 4.

Table 3: DOC_j values for the calculation of the methane avoidance potential, table completely assumed without changes from (UNFCCC EB41, 2008; IPCC, 2006b)

Waste type j	DOCj (% wet waste)	DOCj (% dry waste)
Wood and wood products	43	50
Pulp, paper and cardboard (other than sludge)	40	44
Food, food waste, beverages and tobacco (other than sludge)	15	38
Textiles	24	30
Garden, yard and park waste	20	49
Glass, plastic, metal, other inert waste	0	0

Table 4: DOC_j values from own analyses – determination of biogenic and fossil carbon, DOC_j values are the percentage of biogenic carbon in the fractions

Waste type j	DOCj (% dry waste) >40mm	DOCj (% dry waste) 10-40mm
Paper	19.11	73.80
Plastic	9.22	13.37
Organic/ biowaste	85.85	69.09
Wood	94.25	-*
Textile	29.32	-*
Composite	36.77	45.88
Nappies	87.27	32.61
Other	83.25	83.25
Rubber	23.10	-*
Glass, metal, hazardous, mineral and soil	0	0

*) It was not carried out any sampling

For the fraction <10mm was determined a DOCj value of 58.28%, which was also used for calculation.

k_j The decay rates for different waste types was taken from (UNFCCC EB41, 2008). The values are shown in Table X. It was assumed, that Tropical temperatures were existent and a Wet environment exist with a mean annual precipitation (MAP) of over 1000mm.

y = 10 It is recommended from (IPCC, 2006a), that baseline emissions should only be calculated for th crediting period. There are two options for the credit period. The one option allows a crediting time for 7 years with the option of an extension. The second options run only for ten years without the possibility of an extension. For that is chosen a period of ten years.

Calculation of the potential methane emissions

The Emissions are calculated by the following equation 8. It is a sum calculated for 10 years.

$$\sum_{i=1}^{y}(y+1-i)\cdot BE_{CH4,SWDS,i} \tag{8}$$

Following reasons speak for the use of this calculation, which is based on (IPCC, 2006a). Future-emissions, which are produced outside of the observed trading period, are not in the third period included. Future developments could be considered for later and other projects. It could be possible that in the future a gas collection system is installed. For that an economically and environmentally benefit in comparison to the use of RDF could be possible. Also future legislative changes are unconsidered, just as well as technical developments.

Emission rights could taken into account at the time, when they are incurred. Such a solution would be a long-term duration. A transfer of emission right in a subsequent period could be done easily, problems such as limitations and restrictions on transfer, as today, are eliminated.

Table 5: Decay rated k_j for different waste types and climate zones and different precipitations, table completely assumed without changes from (UNFCCC EB41, 2008), where it was taken from (IPCC, 2006b)

	Waste type j	Boreal and Temperate (MAT<=20°C)		Tropical (MAT>20°C)	
		Dry (MAP/PET<1)	Wet (MAP/PET>1)	Dry (MAP<1000mm)	Wet (Map>1000m)
Slowly degrading	Pulp, paper, cardboard (other than sludge), textiles	0.04	0.06	0.45	0.07
	Wood, wood product and straw	0.02	0.03	0.025	0.035
Moderately degrading	Other (non-food) organic putrescible garden and park waste	0.05	0.1	0.065	0.17
Rapidly degrading	Food, food waste, sewage sludge, beverages and tobacco	0.06	0.185	0.085	0.4

NB: MAT – mean annual temperature, MAP – Mean annual precipitation, PET – potential evapotranspiration. MAP/PET is the ratio between the mean annual precipitatiation and the potential evapotranspiration.

$f = 0$	It is assumed, that no landfill gas is collected and used for special treatment methods like combustion or flared. Also no other utilization exists.
$GWP_{CH4} = 21$	The recommended value of 21 from the (UNFCCC EB41, 2008) is assumed. It based on the decisions under the UNFCCC and the Kyoto Protocol, also when other studies recommended other values like 25 (Forster, Ramaswamy, & al., 2007) or 33 (Shindell, Faluvegi, Koch, Schmidt, & Unger, 2009).

2.4.4 AVOIDANCE POTENTIAL OF EMISSIONS FROM WASTE THROUGH RDF PRODUCTION

For the calculation of the avoided emissions from the organic waste through alternative waste treatment processes is used (AM0025, 2008). With that tool it is possible to calculate the saved emissions through the RDF production process and avoided emissions from land filling without special treatment.

Normally, the following emissions factor should be flow into the calculation:

- Emission from electricity consumption on-site due to the project activity
- Emission on-site due to fuel consumption on-site
- Emission during the composting process
- Emission from the anaerobic digestion process
- Emission from the gasification process
- Emission from the combustion of RDF/stabilized biomass
- Emission from the waste incineration
- Emission from wastewater treatment

One goal of this thesis is the calculation and determination of the avoidance potential through the production of RDF. For that only the following calculation was realized:

- Emission from the combustion of RDF/stabilized biomass

The emissions from the combustion process of RDF / stabilized biomass can be distinct into two base-emissions on the one side from the fossil-based CO_2 emissions ($PE_{r,f,y}$) from the waste and on the other side the N_2O and CH_4 emissions ($PE_{r,s,y}$) from the final stacks from the RDF/stabilized biomass combustion.

For the calculation of $PE_{r,f,y}$ could be used following formula, assumed from (AM0025, 2008):

$$\boldsymbol{PE_{r,f,y} = A_{MSW,y} \cdot FCF_{MSW} \cdot EF \cdot \frac{44}{12}} \tag{9}$$

A_{MSW}	*Amount of waste type I fed into the RDF/stabilized biomass combustor or into the waste incineration plant (t/yr)*
FCF_{MSW}	*Fossil carbon fraction in the MSW (fraction)*
EF	*Combustion efficiency for waste (fraction)*
44/12	*Conversion factor (tCO_2/tC)*

Following assumption was made:

EF – 0.4	The combustion efficiency for waste was taken from (IPCC, 2006a). Normally the value should direct taken from the reviewed project or national values should be used. In this thesis no project is observed and currently no waste incinerator for RDF is in use in Vietnam. For that, the recommended value from IPCC is used.

For the calculation of $PE_{r,s,y}$ is used the following equation 10 assumed from (AM0025, 2008):

$$\boldsymbol{PE_{r,s,y} = Q_{biomass,y} \cdot (EF_{N20} \cdot GWP_{N20} + EF_{CH4} \cdot GWP_{CH4}) \cdot 10^{-3}} \tag{10}$$

$PE_{r,s,y}$	*total emission of N_2O and CH_4 from RDF/stabilized biomass combustion in year y (tCO_2e)*
GWP_{N20}	*Global Warming Potential of nitrous oxide (tCO_2e/tN_2O)*
GWP_{CH4}	*Global Warming Potential of methane (tCO_2e/tCH_4)*
EF_{N2O}	*Aggregate N_2O emission factor for waste combustion (kgN_2O/tonne of waste)*
EF_{CH4}	*Aggregate CH_4 emission factor for waste combustion (kg CH_4/tonne of waste)*

Following assumptions were made:

$GWP_{N20} = 298$	The recommended value of 298 from (IPCC, 2009) for a calculation of over 100 years.
$GWP_{CH4} = 21$	The recommended value of 21 from the (UNFCCC EB41, 2008) is assumed. It based on the decisions under the UNFCCC and the Kyoto Protocol, also when other studies recommended other values like 25 (Forster, Ramaswamy, & al., 2007) or 33 (Shindell, Faluvegi, Koch, Schmidt, & Unger, 2009).
$EF_{N2O} = 47$	Value was taken, as recommended from (AM0025, 2008), from (IPCC, 2006a). All possible and recommended values are shown in Table 6. It is supposed, that a continuous incineration of co-combustion with the RDF occur. It is used a stoker and not a fluidized bed. Also when the use of stoker is not typically for Asian countries, it is chosen to have a conservative calculation.

Table 6: Aggregate N_2O emission factors for different types of waste combustions and from different countries for estimation of N_2O emission. Table was completely assumed from (IPCC, 2006a), Chapter 5, Table 5.4

Country	Type of incineration / Technology		Emission factor for MSW (g N2O/t MSW incinerated)	Weight basis
Japan	Continuous incineration	Stoker	47	wet weight
Japan		Fluidized bed	67	wet weight
Japan	Semi-continuous incineration	Stoker	41	wet weight
Japan		Fluidized bed	68	wet weight
Japan	Batch type incineration	Stoker	56	wet weight
Japan		Fluidized bed	221	wet weight
Germany 2			8	wet weight
Netherlands 3			20	wet weight
Austria 4			12	wet weight

1 (GIO, 2008)

2 (Johnke, 2003)

3 (Spakman, van Loon, van der Auweraert, Gielen, Olivier, & Zonneveld, 2003)

4 (Anderl, et al., 2004)

$EF_{CH4} = 0.2$ Value was taken, as recommended from (AM0025, 2008), from (IPCC, 2006a). All possible and recommended values are shown in Table 7. It is supposed, that a continuous incineration of co-combustion with the RDF occur. It is used a stoker and not a fluidized bed. Also when the use of stoker is not typically for Asian countries, it is chosen to have a conservative calculation.

Table 7: Aggregate CH_4 emission factors for different types of waste combustions and from different countries for estimation of CH_4 emission. Table was completely assumed from (IPCC, 2006a), Chapter 5, Table 5.3

Type of incineration/technology		CH4 Emission Factors (kg/Gg waste incinerated on a wet weight basis)
Continuous incineration	stoker	0.2
	fluidized bed Note1	~0
Semi-continuous incineration	stoker	6
	fluidized bed	188
Batch type incineration	stoker	60
	fluidized bed	237

Note 1: In the study cited for this emission factor, the measured CH4 concentration in the exhaust air was lower than the
concentration in ambient air.
Source: (GOI, 2004)

Towards the recommendation of (AM0025, 2008) the N2O and CH4 emissions from an outside RDF/stabilization process is not taken into account, because in this thesis it is not the subject of consideration.

It is also used a conservativeness factor. The factor should use for uncertainty of the used IPCC default values. It was estimated a uncertainty range less or equal to 10 %. For that, (UNFCCC EB41, 2008) stated a value of 1.02. This value was multiply with the results from the above calculation.

2.5 ECONOMIC CALCULATION

The economic analyze take the price for EU ETS certificates as basis. Even though this project is a clean development mechanism project which only allow a issue of CER certificates. In this thesis it is assumed, that CER certificates are equivalent to EU ETS certificates and that there are no hinders, even if it is aware, that restrictions on the conversion and trading of CER to ETS exist.

For the calculation was used a price of 13.50 €/tCO$_2$e. This was the mean value of the found data from (European Energy Exchange AG, 2010) for the time from 5th November 2009 to 20th May 2010. Three scenarios were considered. One scenario with a linear increase of the price over the entire period. The second scenario with a stable price and the third with a decrease of the price over the time.

For the scenario with decreasing prices, it is assumed, that the reduction rate is 1 €/ year, the same for the opposite scenario, with rising prices. It is also assumed, that the payments be due to the end of each year.

This economic analyze should only show a basic comparison between a changing price and income from a CDM project. The present thesis will no make investigation in detail, because the work is not based on a special project. For that, it is impossible to assume investment cost, credit-amount and other revenues or expenditure which have influence on a detail economic analyze. Also the saved emissions have only been taken into account from the use of RDF, see also (2.4.4).

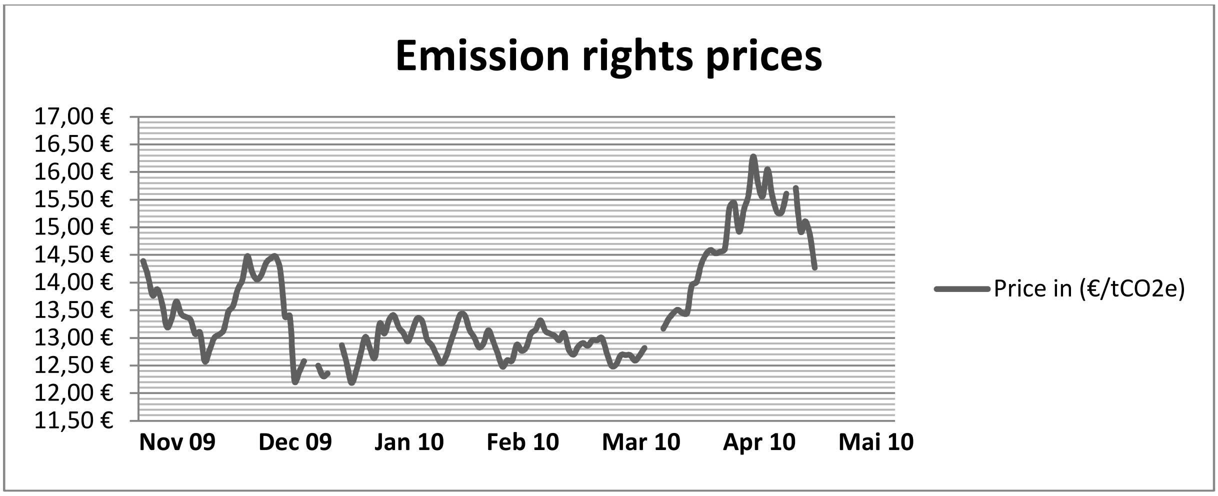

Figure 3: Price history of EU ETS from German stock exchange for climate certificates from 5th Nov 2009 to 20th May 2010. Prices in €/tCO$_2$e (European Energy Exchange AG, 2010)

2.6 COMPARISON TO THE USAGE OF PRIMARY ENERGY SOURCES

Primary energy sources are nowadays used for the generation of heat, electric energy or steam. Coal plays a central role for the Vietnamese energy production with 8.4 million ton coal for electric energy production in the year 2009 and 5.6 million tons for the cement production in the year 2009 (Germany Trade and Invest, 2009). For that, RDF could also play an important role for the substitution of coal during these processes. It is assumed, that through the economic growing of Vietnam, the consumption of coal will increase in the future. Also for that an substitution could be favorable.

The comparison should be show the emission avoidance potential of fossil carbon dioxide in comparison to normal coal. Coal could be divided into two general groups, lignite and bituminous coal.

Investigations about that were made by (Schirmer, 2007) (Eckardt, Schirmer, Bilitewski, & Albers, 2004). These studies take a view to the avoidance potential and the economic benefit of the use of RDF, or substitution, instead of using coal and other primary fossil energy sources.

In this thesis was made a comparison between the RDF and lignite coal and bituminous coal. This is based on the avoidance potential, because of using RDF instead of coal to the view of $CO_{2\text{-fossile}}$ emissions. Because it should only show a simplified potential, it is assumed, that during a combustion process, the oxidation rate is 100 %. In reality the oxidation rate is lower than 100 %, but higher than 95 % for German incineration plants. Also it is not taken into account, the differences and investment costs between a incineration / co-combustion plant and a normal using coal power plants. This could be object for further researches.

For the comparison, the $CO_{2\text{-fossile}}$ emissions are calculated on the results of the fossil and biogenic carbon content. For that, the fractions are re-calculated, that they are only divided into biogenic and fossil content of the burnable fraction. The total CO_2 emission is calculated on the total carbon content. From that, the emission is group into a biogenic part and a fossil part. These parts are then calculated on the LHV (wf), to make a comparison.

For the primary energy sources like coal, literature values for the fossil CO_2 emissions could be found in (Eckardt, Schirmer, Bilitewski, & Albers, 2004) (Schirmer, 2007) and are shown in Table 8.

Table 8: Emission factors and LHV (wf) for selected energy sources

Primary energy source	Emission factor (g CO2 · MJ-1)	LHV (wf)
Lignite	111	8.6 GJ/Mg
Bituminous coal	93	29.7 GJ/Mg

With that calculation, a comparison of the maximum avoidance potential is possible.

The calculation was done following equation 11:

$$\boldsymbol{Emission\ fac._i} = \frac{\boldsymbol{TC_{\ i} \cdot X_{nb,i} \cdot (\frac{44}{12}) \cdot 10^3}}{\boldsymbol{caloric\ value_i}} \tag{11}$$

Emission fac.$_i$	*Emission factor for class i in (gCO$_2$/MJ)*
TC$_i$	*Total carbon content of class in (%)*
X$_{nb,i}$	*Fossil carbon content in (%)*
44/12	*Conversion factor for carbon to carbon dioxide (-)*
10^3	*Conversion factor for weight (g/kg)*
Caloric value$_i$	*Caloric value for class I (MJ/kg)*

3. RESULTS

3.1 WASTE CHARACTERIZATION

The waste characterization shows high similarities between other waste characterizations in Asian countries. The composition is shown in Figure 4. From that is seen a high content of organic fraction, which is the main content of the Hanoi household waste. Also the Table 9 shows a detailed contribution of the Hanoi MSW. From that is could seen clearly, that in both fractions, >40mm and 10-40mm, the organic part was the high-mass part. Plastic and paper plays also a major role in the >40mm fraction of the MSW (11.54 $\%_{>40mm}$; 10.89 $\%_{>40mm}$). Materials with a high economic value could only be found in minimal parts, like metal (0.41 $\%_{total}$), glass (1.97 $\%_{total}$), hazardous (0.54 $\%_{total}$) (comprised batteries, WEEE, medicaments, etc.).

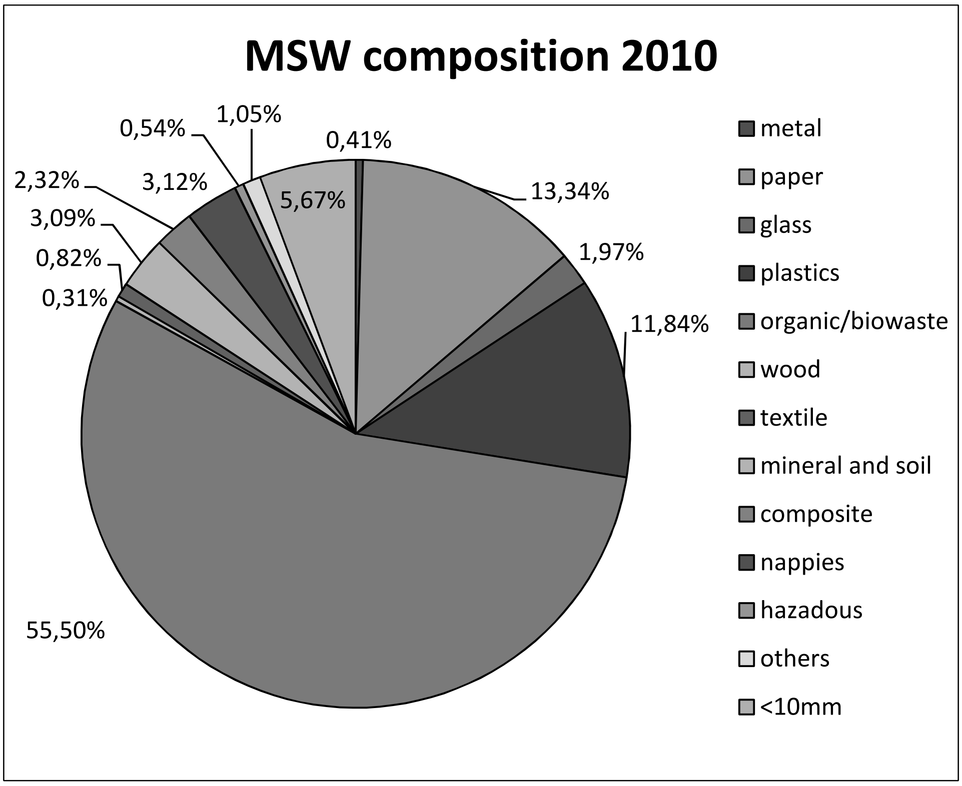

Figure 4: Waste composition of MSW from Hoan Kiem Lake District, Hanoi, 2010, not divided into classifications.

Table 9: Waste composition of the MSW from Hoan Kiem District Hanoi, 2010. Table shows the contribution between the classification of >40mm, 10-40mm and <10mm.The fraction <10mm was not reviewed more detailed.

waste composition	>40mm	10-40mm	<10mm	total
metal	0.33%	0.08%	-	0.41%
paper	10.89%	2.44%	-	13.34%
glass	1.86%	0.11%	-	1.97%
plastics	11.54%	0.30%	-	11.84%
organic/Biowaste	26.69%	28.81%	-	55.50%
wood	0.31%	-	-	0.31%
textile	0.72%	0.10%	-	0.82%
mineral and soil	2.57%	0.53%	-	3.09%
composite	2.22%	0.10%	-	2.32%
nappies	2.32%	0.80%	-	3.12%
hazardous	0.46%	0.08%	-	0.54%
others	0.86%	0.20%	-	1.05%
<10mm	-	-	5.67%	5.67%
total	60.78%	33.54%	5.67%	100.00%

The total contribution of biological waste from the complete MSW-sample was 55.50 %. This is very similar to older researches about the composition of household waste in Asian countries, like shown in Table 10.

Table 10: Waste composition for Vietnamese MSW for the years 1993, 1995, 2003 and 2009. Table assumed from **(World Bank; Monre; CIDA, 2004)**, data there assumed from other sources.

Waste component	19951	20031	20092****	20053	20064
Organic	51.9	49.1	64.30	~47-65	43.5
Paper and textiles	4.2	1.9			
Paper and cardboards			6.34		12.9
Composite			3.51		
Textile			3.9		2.7
Plastic			6.99*		7.2
Plastic, rubber, leather, wood, hair, feathers	4.3	16.5 (Plastics 15.6)		~13-17	0.9
wood					9.9
Metal	0.9	6.0	0.60**	~3	3.3
Glass	0.5	7.2	0.77	~3-13	4.0
Inert matter	38.0	18.4	5.56***	~6-22	
Others	0.2	0.9	-		16.3
Nappies			0.87		
Hazardous waste			0.25		
<10mm			6.91	-	

1) data assumed from (World Bank; Monre; CIDA, 2004) and there from other sources; 2) (CHÂU, 2009); 3) (ISATEC, 2005); 4) (IPCC, 2006a)

*) Plastic was in the original source divided into plastic bags, hard plastics and foils; **) in original source defined as ferrous metal; ***) inert fraction was defined together with others; ****) values are calculated from raw data in Annex of the thesis

All researches show a high content of organic matter in the MSW. The difference between the data could explain by the different amount of analyzed waste. (CHÂU, 2009) Analyzed MSW was in total 128.31 kg. It is assumed, that in the other studies the data base was larger and more broad, so that differences in building structures, economic circumstances, different weather conditions, etc. have found more consideration.

But in general, the studies stated, that Asian waste contains a high amount of organic waste together with a low content of high-energetic matter like plastic, paper or composite. In contrast (ISATEC, 2005) shows a high content of high-caloric content in the waste, together with a high content of biogenic parts.

3.2 MASS BALANCE OF RDF PRODUCTION

The Mass-balances are given in Table 11. It is clearly seen, that the leachate production was not high as expected. For RDF$_{\text{active1st}}$ was a reduction of the weight recorded of: 10.19 %, for RDF$_{\text{active2nd}}$: 8.94 % and RDF$_{\text{passive}}$: 21.49 %. This could not divided and determinate in more detail for all RDF, because of problems with the leachate collection system. Also, especially for the RDF which was produced without active aeration, precipitation could come into the bin, because of a holey cap. It is also seen from Table 11, that the class of >40mm is the major part of the RDF. The <10mm content plays a minor role. This is important in view of other considerations.

Table 11: Mass balances of Input/output for RDF production.

RDF active 1st			
INPUT MSW	30.01	OUTPUT RDF thereof:	26.95
		>40mm 61.34 M.%	
		10-40mm 37.94 M.%	
		<10mm 0.72 M.%	
		LEACHATE	0.05461
		Water evap. / degradation of Carbon	3.00539
	30.01		30.01
RDF active 2nd			
INPUT MSW	26.15	OUTPUT RDF thereof:	23.81
		>40mm 59.19 M.%	
		10-40mm 36.40 M.%	
		<10mm 4.42 M.%	
		LEACHATE*	0*
		Water evap. / degradation of Carbon	2.34
	26.15		26.15
RDF passive			
INPUT MSW	45.15	OUTPUT RDF thereof:	35.45
		>40mm 51.24 M.%	
		10-40mm 45.97 M.%	
		<10mm 2.79 M.%	
		LEACHATE**	0**
		Water evap. / degradation of Carbon	9.70
	45.15		45.15

*) no leachate was collected; **) because of damage at leachate collection system no leachate could be collected

3.3 WATER CONTENT

3.3.1 *WASTE FROM CHARACTERIZATION*

Table 12: Water content, SD and the Contribution of the WC in relation to the different waste classes, calculated on the base of the amount of waste

waste class	WC (%)	SD (±)	Contribution of WC in relation to amount of each waste class (%)
>40mm	66.21	8.18	65.91
10-40mm	51.90	4.92	28.30
<10mm	62.85	1.00	5.79

The analyzed waste had a high water content of 61.24 % (SD ±6.68). Table 12 shows the distribution and the proportion of water content depending on the different classes. It can be assumed, that all classes have high water content, but the class of over 40mm plays a major role in this contribution. That is a typical characteristic for Asian MSW, because of the high content of organic matter. Also the collection method of the waste has a influence on the water content of the household waste. The analyzed waste comes from a street collection, which has a negative effect on the water content in comparison to a bin-/container-collection system. Also is it supposed, that the analyzed waste has a higher WC-value, because the night before waste characterization precipitation was recorded. From that could be assumed, that the normal WC is lower than in the analyzed waste, but it should be recorded, that older researches (CHÂU, 2009) (Tchobanoglous, Theisen, & Vigil, 1993) stated, that the range for the water content is very similar.

3.3.2 RDF

The different contributions, based on the amount of the different classes, and the medians for the WC of the different classes are shown in

Table 13.

Table 13: Median with SD and the contribution of the WC for the different RDF classes, subdivided into the different classes

	>40mm			10-40mm			<10mm		
	Median (%)	SD	Contribution (%)	Median (%)	SD	Contribution (%)	Median (%)	SD	Contribution (%)
RDF active 1st	59.21	8.60	56.22	73.33	3.01	43.07	63.92	1.45	0.71
RDF active 2nd	61.51	7.05	58.55	65.24	1.85	38.19	45.83	0.83	3.26
RDF passive	74.01	2.67	51.49	73.25	6.39	45.71	73.99	1.18	2.80

From this overview it can clearly seen, that the class >40mm plays, like in chapter 3.3.1, plays a major role for the entry of the Water content into the complete mixture. The class of <10mm seems to play a minor role. The total water content of the produced RDF was: $\mathrm{RDF}_{\mathrm{active1st}}$: 64.60% (SD: ±6.43); $\mathrm{RDF}_{\mathrm{active2nd}}$: 62.18% (SD: ±4.88); $\mathrm{RDF}_{\mathrm{passive}}$: 73.66% (SD: ±5.83).

3.4 HEATING VALUE

3.4.1 WASTE FROM CHARACTERIZATION

Table 14: Low heating value LHV (raw) for the different waste classes with the contribution of the LHV in relating to the total HV, based on the wet weight of the waste.

Waste class	LHV (kJ/kg)	Contribution LHV for classes relating to total LHV (%)
>40mm	4154.39	62.50
10-40mm	4934.70	40.66
<10mm	-2269.02	-3.16

Above Table 14 shows the contribution of the LHV in relation to the total LHV (raw) of the waste and the LHV for each class of the waste. What is clearly shown is, that the class <10mm have a negative impact to the total LHV of 4052.274 (kJ/kg). Reason for that is a low heating value of the matter together with high water content. In the two classes >40mm and 10-40mm the LHV was high with over 4000 kJ/kg, caused mostly by the plastic and paper fraction.

3.4.2 RDF

The total LHV (raw) for $RDF_{active1st}$: 4680.026 (kJ/kg), $RDF_{active2nd}$: 4503.752 (kJ/kg), $RDF_{passive}$: 1728.351 (kJ/kg). It is clearly seen, that the fraction >40mm take the major part for this result. The $RDF_{passive}$ has in total a lower LHV (raw) then the other both with active aeration.

Table 15: LHV for different RDF and classes after a sieving analyze and the contribution of the LHVs related to the total LHV of each RDF.

	RDFactive1st		RDFactive2nd		RDFpassive	
	LHV (kJ/kg wet weight)	Contribution (%)	LHV (kJ/kg wet weight)	Contribution (%)	LHV (kJ/kg wet weight)	Contribution (%)
>40mm	6463.835	84.72	5739.522	75.43	2357.734	69.91
10-40 mm	1846.509	14.97	2681.615	21.67	1092.447	29.06
<10 mm	2016.315	0.31	2959.950	2.90	644.122	1.04

3.5 HEAVY METALS

3.5.1 WASTE FROM CHARACTERIZATION

Table 16 shows the contribution of each class and the total amount, calculated after the mean value of each median from the classes. It is clearly seen, that for nearly all heavy metals, except Cadmium, the class of >40mm has the major contribution to the entry of the heavy metals to the MSW. The class <10mm plays a minor role in this contribution of the entry.

Table 16: Heavy metal content for each class of the characterized MSW with the total amount of the waste and the contribution of each class to total amount of each heavy metal

	>40mm	10-40mm	<10mm
Cu (mg/kgDS)	53.8	25.32	27.81
40.31	69.56%	26.32%	4.12%
Ni (mg/kgDS)	23.95	21.48	44.5
24.14	51.70%	37.28%	11.02%
Zn (mg/kgDS)	136.31	132.64	175.94
137.14	51.80%	40.53%	7.67%
Cr (mg/kgDS)	72.26	25.38	76.68
52.88	71.22%	20.11%	8.67%
Cd (mg/kgDS)	0.15	0.65	0.78
0.4	19.71%	68.60%	11.69%
Pb (mg/kgDS)	290.33	38.7	42.73
170.09	88.96%	9.53%	1.50%

3.5.2 RDF

The contribution of the entry of each heavy metal, together with the total amount of each class and the total amount for the complete RDF is shown in Table 17. The results for the $RDF_{active1st}$ and $RDF_{active2nd}$ are in most cases very similar in comparison to $RDF_{passive}$. Here could be found, in some parts, significant changes. Similar to the results for the heavy metals for the MSW plays the class >40mm also a major role in relation to the entry of them. Concomitantly the class <10mm plays a minor role in the entry behavior. $RDF_{active1st}$

Table 17: Heavy metal content for each RDF with the total amount of the waste and the contribution of each class to total amount of each heavy metal

	>40mm	10-40 mm	<10 mm
RDFACTIVE1ST Cu (mg/DS)	50.05	58.21	66.38
52.50	67.38%	31.69%	0.92%
RDFACTIVE2ND Cu (mg/DS)	39.11	46.51	246.80
52.50	43.03%	28.42%	28.54%
RDFpassive Cu (mg/DS)	63.00	78.50	64.82
70.29	45.32%	52.14%	2.54%
RDFACTIVE1ST Ni (mg/DS)	28.80	52.78	67.95
35.94	56.65%	41.98%	1.38%
RDFACTIVE2ND Ni (mg/DS)	35.46	42.17	69.46
39.85	53.58%	35.39%	11.03%
RDFpassive Ni (mg/DS)	32.71	36.83	49.18
35.09	47.13%	49.01%	3.86%
RDFACTIVE1ST Zn (mg/DS)	132.91	188.39	255.45
149.66	62.77%	35.98%	1.25%
RDFACTIVE2ND Zn (mg/DS)	93.37	85.40	89.13
90.44	62.18%	31.58%	6.24%
RDFpassive Zn (mg/DS)	626.12	146.19	176.36
389.69	81.24%	17.51%	1.24%
RDFACTIVE1ST Cr (mg/DS)	14.72	27.48	43.62
18.58	56.00%	42.29%	1.71%
RDFACTIVE2ND Cr (mg/DS)	18.87	27.76	61.63
39.63	39.44%	53.56%	7.01%
RDFpassive Cr (mg/DS)	32.29	42.49	94.29
24.20	49.08%	35.86%	15.06%
RDFACTIVE1ST Cd (mg/DS)	0.14	0.63	0.76
18.58	34.68%	63.38%	1.94%
RDFACTIVE2ND Cd	0.48	0.53	0.78

(mg/DS)			
39.63	47.50%	48.35%	4.15%
RDFpassive Cd (mg/DS)	0.14	0.20	0.21
24.20	50.55%	41.18%	8.27%
RDFACTIVE1ST Pb (mg/DS)	32.37	29.23	35.27
31.50	72.65%	26.53%	0.82%
RDFACTIVE2ND Pb (mg/DS)	27.44	30.07	38.91
32.52	47.87%	48.43%	3.69%
RDFpassive Pb (mg/DS)	34.08	28.95	36.60
28.98	63.11%	29.77%	7.12%

3.6 CHLORIDE AND SULFUR CONTENT

3.6.1 WASTE FROM CHARACTERIZATION

The Chloride and Sulfur content is in context to the other elements like heavy metals, very low. The total amount in percentage is 0.76 % of the total waste, but whereas the contribution of chloride and sulfur is different. This is clearly seen in Table 18. For chlorine a nearly equal contribution of the class >40mm and 10-40mm is observed. This does not apply sulfur. Here are significantly higher contributions of the class 10-40mm in scale. The other classes play a minor role here.

Table 18: Chloride and sulfur content and contribution of each class to the total amount. Values in percentage of dry substance, contribution in percentages.

	>40mm	10-40mm	<10mm
Cl (% DS)	0.75	0.83	0.34
Total 0.76	51.52 %	45.77 %	2.71%
S (% DS)	0.07	0.29	0.16
Total 0.17	22.00 %	72.24 %	5.77 %

3.6.2 *RDF*

For the sulfur content of the RDF, the statement cannot be confirmed. Here has the class >40mm a higher contribution to the total amount of sulfur: $RDF_{active1st}$: 0.09 %DS; $RDF_{active2nd}$: 0.09 %DS; $RDF_{passive}$: 0.23 %DS. The total chloride content was: $RDF_{active1st}$: 0.53 %DS $RDF_{active2nd}$: 0.29 %DS $RDF_{passive}$: 0.38 %DS. The contribution and the amount of each class can be found in Table 19.

Table 19: Chloride and sulfur content and contribution of each class of each RDF to the total amount. Values in percentage of dry substance, contribution in percentages.

		RDFactive1st		RDFactive2nd		RDFpassive	
Cl	>40mm	0.5172	69.23%	0.2705	56.81%	0.3573	48.00%
	10-40 mm	0.5588	30.24%	0.3390	39.55%	0.3981	49.39%
	<10 mm	0.3849	0.53%	0.1650	3.64%	0.3580	2.62%
S	>40mm	0.0853	63.75%	0.0706	46.31%	0.1215	26.79%
	10-40 mm	0.1168	35.31%	0.1207	44.00%	0.3437	69.94%
	<10 mm	0.1224	0.94%	0.1405	9.69%	0.2727	3.27%

3.7 TOTAL CARBON CONTENT

The total carbon content in percentage for each class of MSW and RDFs is shown in Table 20. From the table it is clearly seen, that the class >40 mm has a high content of carbon. For the other classes it is lower. The content of total carbon in the RDFpassive is, in comparison, well below the values from the other RDFs and the MSW.

Table 20: Total carbon content of MSW and RDFs sorted after classes. All values in percentages of dry substance.

	MSW (% DS)	RDFactive1st (% DS)	RDFactive2nd (% DS)	RDFpassive (% DS)
>40 mm	43.19	48.99	45.64	38.43
10-40 mm	37.95	35.98	35.85	19.44
<10 mm	25.29	23.21	27.11	25.10

3.8 BIOGENIC / FOSSIL CARBON CONTENT / ASH

The distribution of the ash and the biogenic and fossil carbon content is shown in Table 21. A high ash content could mostly found in the fraction <10mm, which is normal, because the most components of minerals (like sand, etc.) could be found in this class. RDFactive2nd show an increase in comparison to the MSW, which could be caused by the drying effect. The class >40mm has a high content of fossil carbon, which is not surprising, because the most plastic component have a size larger than 40mm.

Table 21: Distribution of the ash, biogenic and fossil carbon content of the MSW and RDF, distinct to the classes. All values are in % of dry substance.

	Waste			RDFactive1st			RDFactive2nd			RDFpassive		
	>40mm	10-40mm	<10mm	>40mm	10-40mm	<10mm	>40mm	10-40mm	<10mm	>40mm	10-40mm	<10mm
Ash	12.29	16.43	40.41	10.36	22.60	28.69	10.20	24.73	60.93	19.83	27.62	45.49
biogenic C	51.31	66.91	58.28	88.19	64.03	70.88	31.07	65.25	20.91	52.70	61.86	53.51
fossil C	34.69	16.66	1.31	1.45	13.37	0.43	58.74	10.02	18.16	27.47	10.52	1.00

3.9 METHANE AVOIDANCE POTENTIAL

The methane avoidance potential was calculated for 5000 Mg produced MSW per day. (Con & al., 2004) shows the increase over the calculated project time. Through the cumulative character of the calculation is a steady increase recorded which is oppositional to the gas production trend of the MSW for one year. In these cases is a decrease over time reported. This is also consistent with data from relevant literature such like (Bilitewski, Härdtle, & Marek, 2000).

Over a long time period the gas production will stabilize and later decrease. But this behavior is not subject of this thesis.

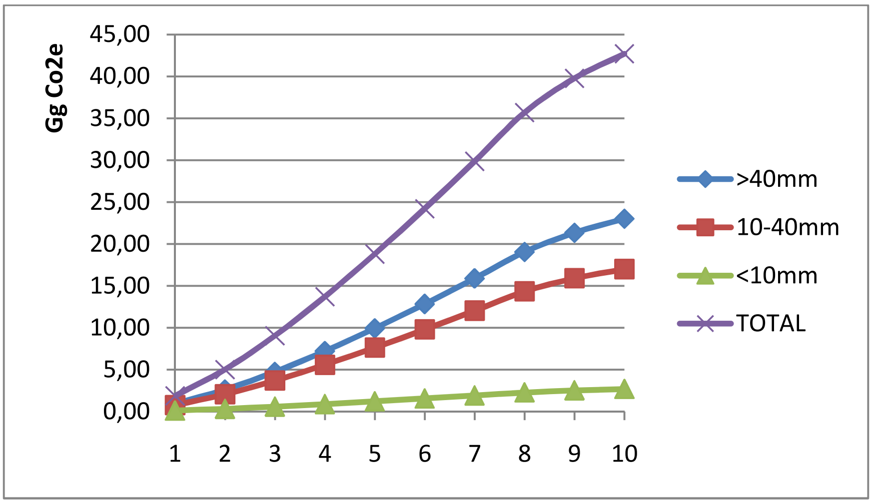

Figure 5: Emission potential of methane in the case of land filling the MSW. For the calculation is assumed, that the project time is ten years and every day is produced 5000 Mg MSW for 365 days per year. The calculations are cumulative, that means, for the MSW which is produced in the first year, the emissions are calculated for eight years, for the MSW of the second year for seven years, etc. All values in million tCO_2e.

With these values can be calculated the reduction potential in the case of avoiding the land filling of MSW and instead use of RDF. For that, the combustion emissions of RDF must calculate.

3.10 CO_2E EMISSION THROUGH RDF USAGE

The equivalent CO2 emission through the combustion process could be seen in Table 22. The calculation does not take into account the emission of CO2 from biogenic carbon, because this is seen as a renewable carbon, which is not relevant for climate change and the greenhouse warming effect. The significant differences between the classes can be explained by the different content of plastics. The class <10mm shows a very low emission in the case of combustion, which is caused by the major content of mineral fraction.

Table 22: Emission potential for RDF combustion in tCO2e. The source of the emissions comes from fossil carbon, N_2O and CH_4, which is produced by the combustion. Values are calculated for 8 years, which is equivalent to the duration of the third period of carbon emission trading.

(tCO2e)	RDFactive1st	RDFactive2nd	RDFpassive
>40mm	22,006,960.82	28,493,563.58	18,314,594.69
10-40 mm	14,581,136.64	13,724,488.81	16,379,658.91
<10 mm	255,223.21	1,743,664.53	991,023.46
TOTAL	36,843,320.66	43,961,716.93	35,685,277.05

3.11 ECONOMIC COMPARISON

A revenue trend is seen in Figure 6 for RDF$_{\text{active1st}}$. The revenue is based on the avoided emissions for three scenarios, with stable, in- and decreasing prices. In this scenario it is calculated, that the other emissions, which were not considered as own calculation like for example emission from leachate treatment, are the same amount like the emissions from the combustion of RDF.

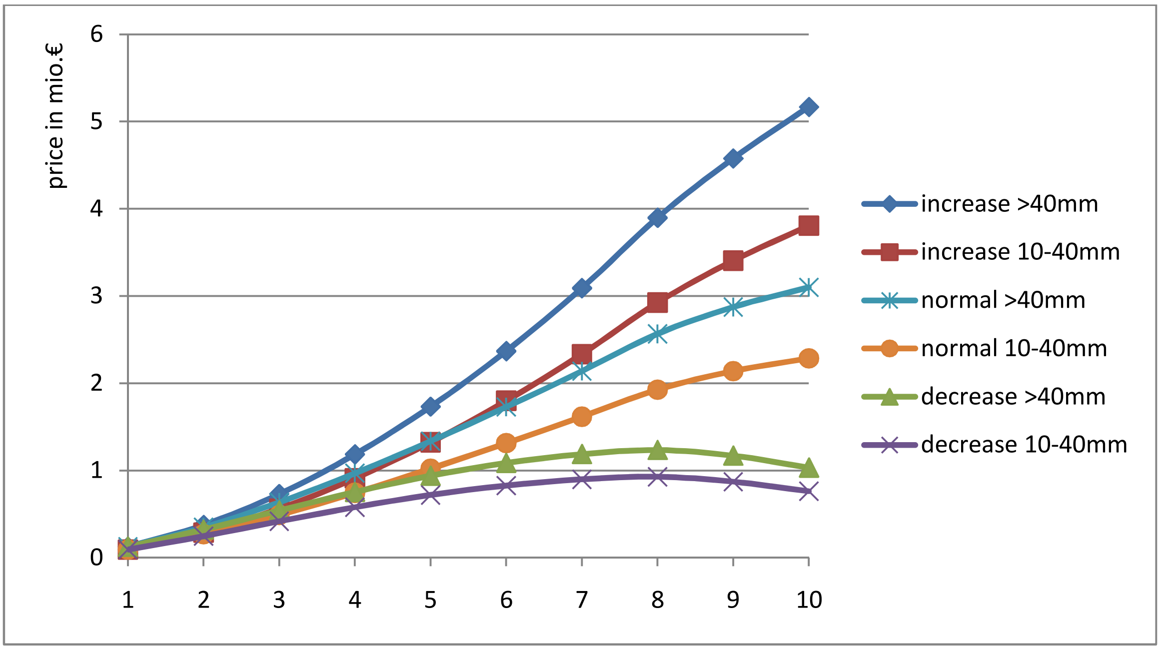

Figure 6: price trend, calculated for the expected avoidance of the emissions for a duration of ten year with stable, increasing and decreasing prices for emission rights, subdivided into the classes >40mm and 10-40mm

It is clearly seen in this figure that the revenue trend for the class >40mm is I all cases, in comparison, higher than the class of 10-40mm.

3.12 COMPARISON TO COAL

The result of the emissions factor for different classes of the RDF could be seen in Table 23.

Table 23: Emission factors of fossil carbon dioxide for selected RDF classes.

Origin	Emission factor (g CO2·MJ-1)
RDFactive1st >40mm	1.4
RDFactive1st 10-40mm	18.5
RDFactive2nd >40mm	57.5
RDFactive2nd 10-40mm	8.8
RDFpassive >40mm	31.7
RDFpassive 10-40mm	14.1
RDF from literature1	18.9

1) (Eckardt, Schirmer, Bilitewski, & Albers, 2004)

The values differ in some cases in a very high range. Reasons for that could be mistakes through the determination of the total carbon content of the biogenic fossil carbon content of the samples. It is assumed, that the variation comes from the determination of the biogenic / fossil carbon content.

But some vales are in a typical range for RDF produced with biological stabilization with 18.9 g CO_2 / MJ, which was taken from literature (Eckardt, Schirmer, Bilitewski, & Albers, 2004). The value for the class >40mm for $RDF_{active1st}$ differ strongly from the value of $RDF_{active2nd}$. The value of the first one should be seen as a outliner and should not taken account for later discussion.

4. DISCUSSION

In this chapter the four thesis of the introduction chapter should be discussed. This is to clarify whether the use of RDF is useful or not.

4.1 1ST THESIS

The composition of the waste and the biological stabilization allow a usage as RDF.

Differences in the characterization of the MSW

The founded data, which were shown in Table 10, show a possibility of the use of MSW as RDF. The energy-rich fractions like plastic, textiles, paper are in huge amounts in the waste. Also when their quota not comply with a typical MSW composition of developed countries, a use of RDF is possible. A list with MSW compositions could be found in table 2.3 from (IPCC, 2006a). From that is could directly seen, that the quota for the energy-rich components like plastic, textile and paper are not so significant different like the quota of organic content in the MSW. The Asian MSW has a high content of organic fractions, which have a high contribute of waster content to the total MSW. A trend of changing in the composition to a typical composition of developed countries could not exactly recorded, because the founded data a too different and shows no clear trend.

In contrast to the founded data from former researches, the analyzed MSW shows a different composition. The organic content is higher than in the founded data with a quota of 55.5%. Paper and plastic have the second and third highest content of the total MSW with 13.34 % and 11.84 %. This makes a use as RDF possible, but not easy, because of the high content of organic matter. The organic matter has a high contribution to the total water content, but later more about that.

Reasons for the differences between the analyzed MSW and the founded data may be too small sample size. Only 279.6 kg MSW was analyzed. Also the area, where the MSW was collected, could not be representative for a complete analyze. Seasonal changes, differences in the development structure and the collection method were disregarded, however when, as known from (Bilitewski, Härdtle, & Marek, 2000), they have a significant influence on the composition of waste.

For the components and their contributions to the total amount of MSW could be said, that a RDF usage is possible, but for a biological stabilization high requirements are necessary, because of the high content of organic matter.

The three experiments about the stabilization of the MSW and production of RDF show differences in their results. One the one site are the experiments with active aeration and on the other side without active aeration (passive).The $RDF_{active1st}$ and $RDF_{active2nd}$ have a weight loss of 10.16 % and 8.95 %. The $RDF_{passive}$ has a higher weight loss of 21.48 %. On the first view, it is expected, that for that comparison the $RDF_{passive}$ shows a higher drying effect, which means a better stabilization effect. A detailed consideration of this argument is untenable.

In two cases, a compilation of a detailed mass balance was not possible for the leachate, because no leachate was collectable. The reasons could be that the experiment-setups were too small and not enough leachate was generated. Also a problem with the collection system avoids the collection of it.

A view to the content of total carbon and the biogenic carbon content, Table 24, shows clearly the differences between the two production methods. A view to the total TC and biogenic carbon content shows for the passive produced RDF a reduction of 26.87 %. The RDF, which were produced with active aeration show an increase. In itself, there should be no increase of the values, because microbiological degradation consumes biogenic carbon. The increase effects can be attributed to a too small sample size. But this can be derived from this is that there has been a reduction in the passive carbon produced RDF and the weight loss is due to this.

Table 24: Ratio between the total carbon content and biogenic carbon content for each class and in total in comparison to the MSW

	>40 mm		10-40 mm		<10 mm		Total	
	TC	Xb	TC	Xb	TC	Xb	TC	Xb
RDFactive1st	35.62%	44.83%	-31.78%	92.56%	-87.80%	1109.37%	12.92%	38.65%
RDFactive2nd	15.55%	-48.98%	-20.18%	96.23%	5.87%	256.69%	3.18%	-24.33%
RDFpassive	-2.99%	-13.45%	11.42%	86.04%	-53.99%	813.00%	-26.87%	0.05%

From the perspective of the TC and biogenic carbon content, the RDFs with active aeration are clear in advantages, because a reduction of biogenic carbon is avoided, which is necessary to produce a quality RDF.

The values of the water content show no clear and stable values. It is recorded an increasing effect for all three RDF.. The value for the passive RDF is the highest with 73.66 %. The standard deviation has also very high values, this is mostly caused by the samples with a large size from the classes >40 mm and 10-40mm. It is expected that the reason for that was, that no size-reducing before sampling happen and because of that a heterogeneous sample exist.

Therefore, no statement can be making here about the total water content reduction of the RDFs. But for some classes and their contribution to the total amount could it be making. Table 12 and

Table 13 shows this clearly, that the contribution for the class >40 mm is lower in comparison to the MSW, on the other side for the class 10-40mm is an increase recorded of the contribution of the WC to the total amount. For the class <10mm is a decreasing effect recorded, for all three RDFs.

Problematic is, that the RDFs were not do dried than expected. The RDF did not fulfill the quality criteria for a RDF. A drying should establish a better storage with avoiding methane production during the storage time; this is also necessary to avoid explosions or fired because of methane inside the storage area of RDFs. (Eckardt, 2004) stated a water content of 7.2 % as a quality requirement for RDF produced out of MSW. All RDF did not reach this value.

Also the heating value should increase because of a biological stabilization. The problem of the non-drying and non-achievement of this requirement could be:

- MSW amount
- Bin-size
- Isolation
- Rain
- Outdoor temperature
- Pre-treatment
- RDF1
- Compressor

MSW amount

The used amount of MSW for the production of RDF seen to be too few. With that, not enough biological activity could create to establish a biological stabilization of the RDF. To generate enough heat, a high amount of waste must be used. Problems were also recorded from the literature, that especially at the outside of a drum, etc. the heat leakage is high. A high core temperature should be reached, to fulfill the production and quality criteria of an RDF.

Bin-size

The used bins seem to be too small for a production of RDF at a small scale. The problems are, that the ratio between the surface and the volume is not optimal. That means, that for the used volume too much surface is available, were the heat can leave the drum to the surrounding environment. This problem accompany together with the too small amount of MSW, which was used.

Isolation

One other problem could be a missing isolation at the used drum. A isolation would prevent the heat loss from the drum to the environment. Other methods, like HERFORD™ use for example containers with isolation.

Rain

One night before the collected MSW was analyzed, raining happen. Because of that it is expected, that the water content increase in comparison to the MSW before, also when the water content in comparative study is nearly in the same range. This problem could also be caused during the collection of the waste, because of the special collection method of MSW in Vietnam.

Outdoor temperature

During the experiment the outdoor temperature change in a range from 8°C to 20°C. Because of the sub-optimal surface-volume-ratio and the too small bin a too high heat loss is expected. Also the time of too low temperature with 8 – 10 °C could hinder and stop all microbiological activity.

No pre-treatment of MSW

The used waste was not pre-treated. To reach a high biological activity, together with a high production of heat, the waste should be pre-treated. The pre-treatment should include a size reduction together with an removal of bulky parts and metals. Because of missing equipment this pre-treatment steps were not possible and with that no homogenization of the MSW possible.

$RDF_{active1st}$

In that experiment the aeration could be too much, because the aeration runs over the complete time. For that the drum was maybe too small and the heat was blowing out and did not stay inside the MSW. The experiment with RDFactive2nd works only for 10 minutes per day, which reach a longer stay of the heat inside the MSW.

Compressor

For aeration was used a normal compressor. Hereby could be the problem, that the compressor work with oil and a noticeable smell was determined. It is assumed, that the oil inside the air cause a inhibition of the microorganisms.

In total it could be said, that the composition of waste fulfill the criteria of a production of RDF out of the MSW, also with the view to the possible change to a composition more like developed countries.

The Mass balances show a good and clear trend, but in a detailed view, the RDFpassive shown no results, which fulfill the criteria for the production of an RDF out of MSW. Only the two RDF with active aeration fulfill it, because of a stable or very low reduction, content of total carbon and biogenic carbon.

All RDF did not reach the criteria for water content, which is given in literature. For all was determined a too high water content, which had a negative influence on the quality of the RDF, because of problems during the storage time and the heating value. This could be caused by several reasons.

4.2 2ND THESIS

By a classification is an enrichment of the energy content possible while reducing the pollutant content.

The heating value was calculated for all RDFs and the MSW to the lower heating value (raw). With that a comparison in consideration of the water content, was possible. The LHV of the MSW was low with 4052.274 kJ/kg. This is cued because of the high water content of the MSW. It was already commented, that the water content of the MSW was very high and also the reasons for that (rain).

Another problem was also the high content of organic matter. The organic matter, which has a high water content with over 83.91% for the class >40mm and 53.46% for the class 10-40mm, has a high contribution to the total amount of water content. This is impact to the total contribution of each class to the total water content. With that, the HV is reduced, which make a usage, for example for incineration, difficult.

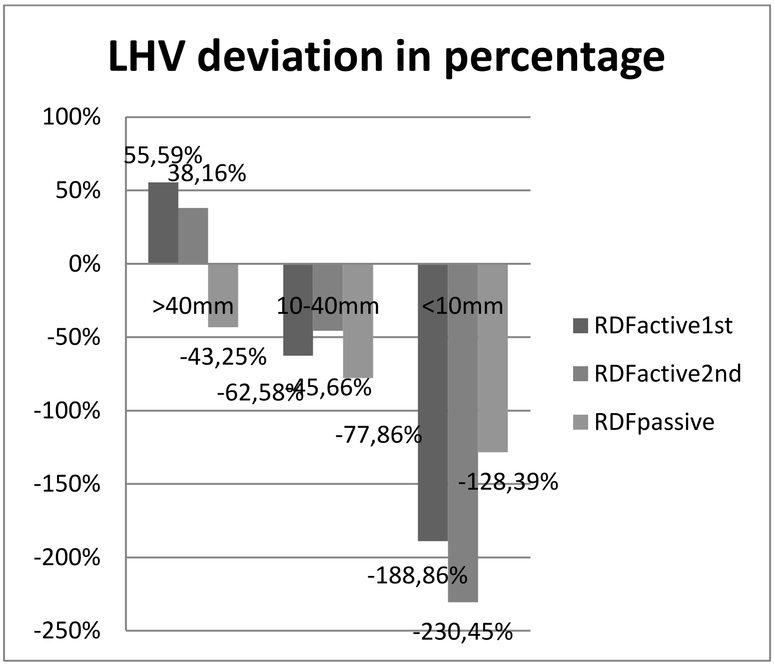

Figure 7: LHV deviation in percentage in comparison to the LHV of the MSW for the different classes

The biological stabilization and classifying of the RDF seems to have a positive influence on the RDF in comparison to the MSW. Like in Table 15 shown, an increasing of the each fraction was recorded. Figure 7 shows this deviation in comparison to the classes of the MSW also clearly. For the class >40mm an increasing of the heating value was recorded of over 55 % for the $\text{RDF}_{\text{active1st}}$. Only for the RDF, which was produced without aeration, a decreasing of the LHV was recorded.

For the class lower 10 mm an decrease for all RDFs was recorded, in one case with over -230 %. Overall, the increase of the LHV should be divided into two causes. First, the increase is based on a reduction of water content, which results as an increase of it. Second, there is a shift between the classes, i.e., low calorific value particles go from the class> 40 mm to lower classes through the stabilization.

This corresponded with the goal a biological stabilization should reach – a increase and transfer of the HV to the large classes. What is also very striking is the increase of the contribution to the total calorific value of the class> 40mm. This applies to both RDF, which were produced with active aeration, too. This effect does not occur for the $RDF_{passive}$. An explanation could be that the MSW / RDF had no drying effect, which removes the adhesion of the water inside the waste. The water in the MSW functions like lime at the different particles, so that on the surface of the particles a lot of mineral components could be found.

The active produced RDF seem to have a drying effect of the components with a size >40mm, which generate a transfer of the mineral fraction to smaller classes and therewith an increasing of the LHV.

Heavy metals

The reduction ratios for the different classes are shown in

Table 25. From here it is clearly seen, that often for the active produced RDFs a reduction is recorded. For example for copper for the class > 40 mm a reduction ratio of 6.98 % and 27.31 %, whereas an increase for the classes 10-40mm and <10mm is noted. This statement does not apply to all heavy metals.

Table 25: Reduction ratio between MSW and the RDFs for the different classes. All values are in percentage.

	>40mm	10-40 mm	<10 mm
RDF1 Cu (%)	-6.98	129.91	138.69
RDF2 Cu (%)	-27.31	83.70	787.44
RDFpas Cu (%)	17.10	210.03	133.09
RDF1 Ni (%)	20.25	145.70	52.69
RDF2 Ni (%)	48.04	96.34	56.09
RDFpas Ni (%)	36.56	71.47	10.51
RDF1 Zn (%)	-2.50	42.03	45.19
RDF2 Zn (%)	-31.50	-35.62	-49.34
RDFpas Zn (%)	359.34	10.21	0.24
RDF1 Cr (%)	-79.63	8.28	-43.11
RDF2 Cr (%)	-73.88	9.39	-19.63
RDFpas Cr (%)	-55.31	67.40	22.96
RDF1 Cd (%)	-7.15	-3.15	-2.98
RDF2 Cd (%)	221.57	-18.19	-0.59
RDFpas Cd (%)	-8.19	-68.91	-72.50
RDF1 Pb (%)	-88.85	-24.46	-17.45
RDF2 Pb (%)	-90.55	-22.31	-8.95
RDFpas Pb (%)	-88.26	-25.20	-14.34

For nickel is recorded in all the classes an increase. Also for the calculation of the total content of nickel, an increase is recorded; for $RDF_{active1st}$: 49 % $RDF_{active2nd}$: 65 %$RDF_{passive}$: 45%. For that is expected, that the amount of used samples were not homogenized enough to got a stable result. For the heavy metals Zinc, chrome, cadmium and lead is a reduction recorded for the class >40mm, but only a partially decrease in the lower classes. Altogether the values show no clear trend of a reduction or transfer to other classes.

This is also clear, with a view to the difference of each contribution. This is shown in

Table 26. For copper the contribution change, what means a reduction for the >40mm class for all RDF, but at the same time an decrease of the other classes.

Table 26: Difference of the contributions of each fraction in percentage points.

	>40mm	10-40 mm	<10 mm
RDF1 Cu (% points)	-2.18	5.37	-3.20
RDF2 Cu (mg/DS)	-26.53	2.10	24.42
RDFpas Cu (mg/DS)	-24.24	25.82	-1.58
RDF1 Ni (mg/DS)	4.95	4.70	-9.64
RDF2 Ni (mg/DS)	1.88	-1.89	0.01
RDFpas Ni (mg/DS)	-4.57	11.73	-7.16
RDF1 Zn (mg/DS)	10.97	-4.55	-6.42
RDF2 Zn (mg/DS)	10.38	-8.95	-1.43
RDFpas Zn (mg/DS)	29.44	-23.02	-6.43
RDF1 Cr (mg/DS)	-15.22	22.18	-6.96
RDF2 Cr (mg/DS)	-31.78	33.45	-1.66
RDFpas Cr (mg/DS)	-22.14	15.75	6.39
RDF1 Cd (mg/DS)	14.97	-5.22	-9.75
RDF2 Cd (mg/DS)	27.79	-20.25	-7.54
RDFpas Cd (mg/DS)	30.84	-27.42	-3.42
RDF1 Pb (mg/DS)	-16.31	17.00	-0.68
RDF2 Pb (mg/DS)	-41.09	38.90	2.19
RDFpas Pb (mg/DS)	-25.85	20.24	5.62

This picture is not valid for all the other heavy metals. Low values show no significant change in the contributions. Therefore it could be said, that so clear trend is seen for a transfer of the heavy metals inside the classes. The main reason could be because the sample size was too small. Also no difference between the different production processes of RDF is seen. Therefore, no clear statement can be made.

Chloride and Sulfur

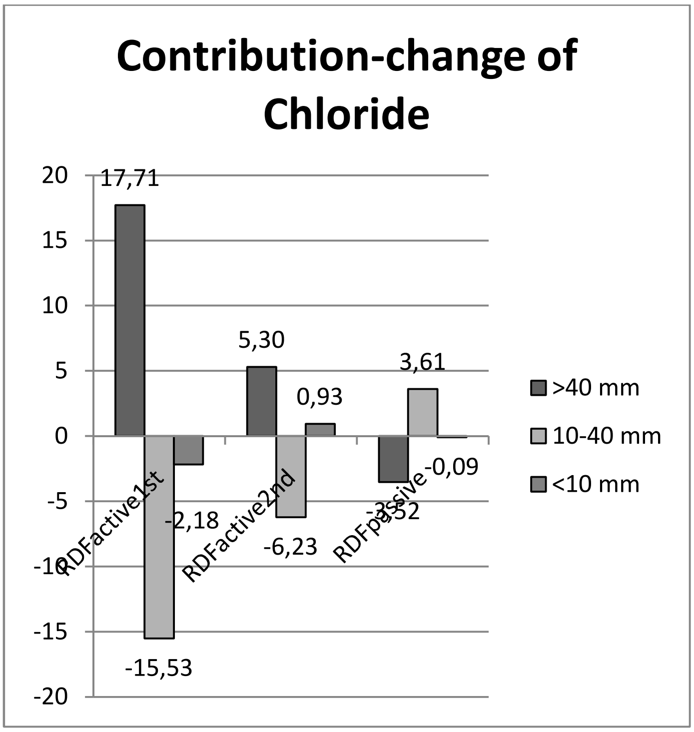

Figure 9: Change of the contribution of each class for the Chloride in comparison to the MSW

For the RDFactive1st and RDFactive2nd was recorded a significant change in the contribution of chloride and sulfur. For the passive produced RDF no significant changes were recorded. For the both active produced RDF, an increase in the contribution of chloride and sulfur for the class > 40 mm happen. This could only explain, that through the drying materials, which contain no chloride, were transferred to the other lower classes. For the absolute amount of Chloride, a decrease was determined, but a comparison is not possible, because of the different total absolute amount of Chloride. The reasons for that could lie at a too small sample size.

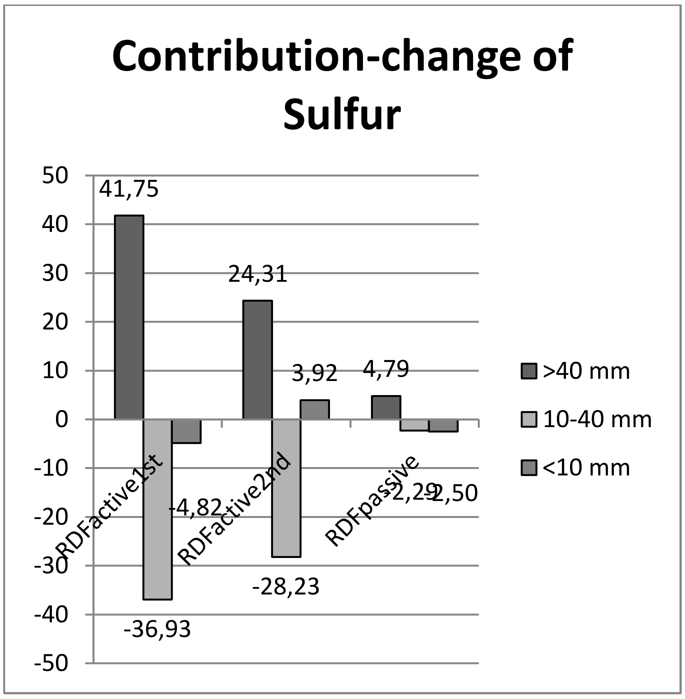

Figure 8: Change of the contribution of each class for the Chloride in comparison to the MSW

Overall, the result is unsatisfactory and a clear statement of chloride reduction is not possible. An increase of the contribution, especially for the classes >40mm and 10-40 mm has a negative effect on the quality of the produced RDF. Through an RDF production process, the amount and contribution of chloride should increase for the useable classes as RDF.

For sulfur is the same valid. An increasing of the class >40mm is recorded for all the RDFs, together with an decreasing for the class 10-40 mm, like in Figure 8 shown. The absolute amount of sulfur was very low with 0.09 % DS for $RDF_{active1st}$ and $RDF_{active2nd.}$. For the passive produced RDF the total amount was higher. 0.23 %. Altogether is here also no clear trend recorded for an increasing or decreasing of the amount of sulfur for the different classes, because of too different amounts in comparison to the MSW.

In general is could be said, that an increasing of the LHV for the useable class of the RDF (>40mm) was recorded. Through the biological stabilization this was reached, mostly based on a drying effect with its aftereffects. These are reduction of the liming effect of the water and a transfer of low energy-rich particles to lower classes.

For the reduction of pollutants like heavy metals and chloride, sulfur, no clear statement could be made, because the data show no clear trend. A comparison with the absolute values was impossible, because of too high differences in the values, which make an comparison impossible. A comparison with the contributions of the classes shows diversity results, which show no clear trend of a reduction of the pollutants. Therefore, no statement can be made.

4.3 3RD THESIS

The produced alternative fuel meets the criteria for substitution of primary fuel, also with a view to the expected pollutants and existing limit values.

For a substitution of primary energy sources like coal must be the produced RDF very similarly, to avoid expensive reconstructions at power plants, etc. For that a comparison between the RDF and for example coal is necessary. The different requirements, the RDf must reach, can be divided into, after (Eckardt, 2004):

- Mechanical requirements
- Caloric requirements
- Chemical requirements

Under the mechanical requirements could be understood:

- Form and kind of delivery
- Particle size
- Bulky density
- Impurity quota

Under the caloric requirements

- Lower heating value water free / raw
- Substitution rate

Under chemical requirements:

- Composition of RDF
- Chloride and Sulfur content
- Ash-content
- Heavy metals

(Eckardt, 2004) stated hereunto investigation about the use of RDF in different plants (power plants for bituminous coal / lignite; cement kilts, etc. in Germany). A complete 1:1 comparison is in this thesis not possible, because for a marketable RDF, some different treatment methods were not fulfilled. These are for example a size reduction, together with a remove of impurities. For that, the thesis cannot take a view to all of the requirements.

4.3.1 MECHANICAL REQUIREMENTS

Form and kind of delivery

Normally, the form and the kind of the RDF should not be too different from the energy source which is uses in a specific plant. The form depends strong of the kind of combustion process, for that the requirements could be totally different, for example for stocker in comparison to fluidized bed. Fluidized bed need a small particle size, were a stocker combustion process also agree with large particle sizes. Because for this thesis no size reduction of the RDF was made and also no equipment was available, and investigation of that behavior was also not carried out. Also no clear project was analyzed, so that it would be impossible to set the different requirements, which are necessary to reach for use in the specific process. Therefore no statement about this requirement could be made.

Particle size

The particle size and the distribution was not made. Particle-size distribution curves are a common tool for estimation the usability and quality of an RDF. These curves were not made in this study, because it was not a goal. Also no size reduction was made with the RDF, which is a necessary pre treatment step of the production of RDF. For that, no statement could be made about that.

Bulky density

The bulky density was also not investigated, because no treatment happens with the RDF. For that, an investigation on it seems to be impossible. Knowledge about the bulky density is necessary, for example for storage behavior estimations or combustions behaviors. For that, no statement could be made about the bulky density.

Impurity quota

What an impurity is depends on the different processes and the different requirements of them. For example in an fluidized bed combustion wood particles, metal, etc. are impurities, but for a stocker combustion they are not. Because no specific process was topic of this thesis, no investigations were made. Also a treatment, for example remove metals, etc, was not happen with the RDF. For that no statement could be made.

4.3.2 CALORIC REQUIREMENTS

Heating value

The produced RDF should substitute some primary sources like coal. Coal exists in two general form, lignite and bituminous coal. These both ones have different compositions and properties. It starts with the heating value, which is different at both ones. Lignite has a LHV (wf) of 8 MJ/kg, whereas bituminous coal has a LHV (wf) of 27 – 32.7 MJ/kg. For a substitution, the RDF should reach these values. Thus, no RDF and also no class of the RDF reach the LHV of the coal. The class >40mm of, with active aeration produced, RDF reach approximately the values of lignite. With these values, 1.23 (1.39) times the $RDF_{active1st}$ >40mm ($RDF_{active2nd}$ >40mm) must used to reach these LHVs. For the other classes a substitution seems not possible, because of too low LHV. For that, it could said, that only the class >40mm is useable for RDF.

Table 27: Substitution rate of different RDF in comparison to lignite with a LHV of 8.7 MJ **(Kaltschmitt & Hartmann, 2009)**

	RDF1	RDF2	RDFpassive
>40mm	44.87%	46.24%	54.29%
10-40mm	63.80%	70.75%	80.79%
<10mm	87.77%	115.54%	92.33%

The poor drying quality of the biological stabilization cause this result, because with a look to the LHV (raw) the results seems better than the results for LHV (wf). Table 27 shows the percentage, how much of the RDF is necessary to reach the LHV (raw) for lignite. For the classes >40mm and also the classes 10-40mm, specially for the active produced ones, are recorded passable results. These results should be seen the highest potential, which could be reached by a effective biological stabilization.

These values are calculated for a 100 % substitution. For that is must be said, that this is not the normal and does not reflect the reality, because the normal case is a co-combustion of RDF together with other energy sources. For that, mixtures of for example coal and RDF are produced. The proportion of RDF to the co-firing varies from plant to plant, therefore, and also because no specific project was investigated, no statement about that could be made.

A nowadays common process in the European Union and especially Germany, are RDF power plants. They use only RDF for the generation of electricity and / or steam. For that it could be said, that a 100 % substitution happen, but here must be considered, that these plants are completely developed for the use of RDF and not of coal or other energy sources.

Therefore, the comparison should be considered with a special care. It was made for a 100 % substitution, but in reality, these values, especially in the case of co-firing, are significant lower. Therefore, the comparison is to be regarded as the maximum possible potential.

4.3.3 CHEMICAL REQUIREMENTS

Composition of RDF

The water content plays a major role for the quality of an RDF. On the one side it is a factor the storage quality and the possibility of treatment processes. For that a low water content through the biological stabilization should reached. With that a methane generation during the storage time is avoided, together with a better separation effect of the wanted and unwanted contents of the RDF.

On the other side, the water content has a influence on the lower heating value, because with an decreasing of the water content in the RDF the lower heating value will increase. With that, more energy can be generated, because this energy must not be used for the evaporation of the water during the combustion. Also the different processes are adjusted to the specific used energy source. That means that for example a plant which uses lignite is constructed for the typical lignite water content (stack gas cleaning, turbine, etc.). For that, the RDF should reach the characteristic of other energy sources very similar in the case of a substitution or mixing. For a single combustion process, the plant must be designed after the characteristic of the RDF, whereas a low water content has also a positive effect, but not at all. Also plants, which work with a low temperature, exist.

The determined water content of the RDF was in all classes and RDFs too high for reach the quality criteria. (Eckardt, 2004) stated, that a water content of different plants for RDF in Germany is located between 7.2 – 30 %. The determined water content of the produced RDF is clearly over these values with over 60 % water content. For that is could said, that a safe storage of the RDF is not possible. Methane generation and heat generation during the storage is expected. Also growing of fungi's, which could cause a hygienic problem and need maybe special treatment of the air. For that, all RDFs in all classes did not reach the criteria for water content.

For the heating value see 4.3.2.

Chloride and Sulfur content

The values for all classes of the RDF under-run the calculated limit value for chloride as mean value of 1.1 M.% of the dry substance. Because of the negative effects and the high treatment cost, the chloride content should be very low. PVC is a mainly problem for RDF usage. It could be found in the MSW and should during a preparation remove. In the analyzed waste, the content seems very low, a reason for that could be a too small sample size, but with the founded values a use as RDF is for all classes and for all RDF possible.

For sulfur the limit values are lower than for chloride. (Eckardt, 2004) stated as a limit value for different plants in Germany a median value of 0.75M. % of the dry substance. Like for chloride, all classes of all RDFs under-run this limit value clearly. Sulfur should also be available in low concentrations, because the treatment of stack gas cleaning is sometimes not available for some plants. This case, and the same is valid for chloride, is often found in plants which for example only use coal as energy source. The reason for that is that coal contains also a low content of chloride and sulfur, for that a stack gas cleaning for chloride and sulfur is not necessary. Sometimes only dust cleaning treatment could be found at plants, for that the amount of chloride and sulfur should be low to avoid emissions.

Because all classes of the RDFs reach the limit value, the RDFs reach this criteria.

Heavy metals

The RDFs were analyses on the heavy metal. Different limit values exist for RDF (Table 1). It was make a comparison between the amount of selected heavy metals and the limit values as a mean value of them. Heavy metals have different negative impacts on the quality and using during combustion of RDF. For that, the amount of them should be low. Also the usage, for example in a cement kilt, should reach different limit values, because these heavy metals could be found later in the products, here cement.

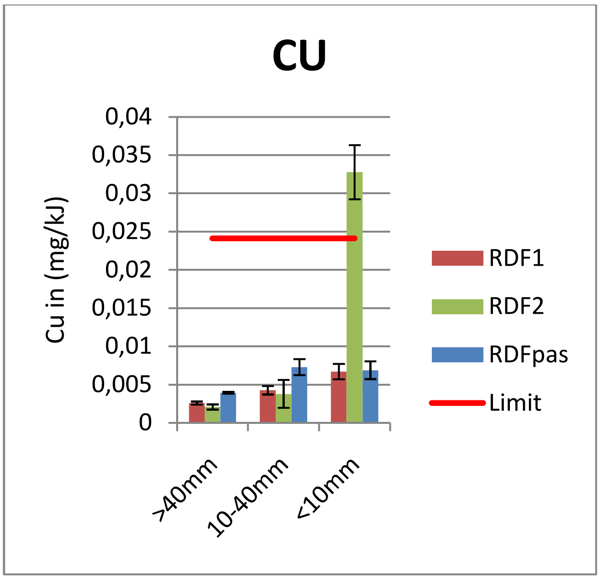

Figure 10: Copper content for the different classes and RDF with mean value of different limit values

Copper

Copper can cause during the combustion problems like promote the generation of dioxin and furan. These ones are under a cloud to be carcinogenic. The founds values could be seen in Figure 10. From this picture it is clearly seen, that for the classes >40mm and 10-40mm the values are lower than the limit value. From that a usage is possible. A different is seen between the active produced ones and the passive one. The passive one shows in these classes a higher content, for the class <10mm RDFactive2nd shows a content, which is over the limit value. A explanation could not be found for that result, but in fact it also does not matter, because the class <10mm seems not useable as a RDF. In total is could be said, that all the RDFs meet the quality criteria for copper content.

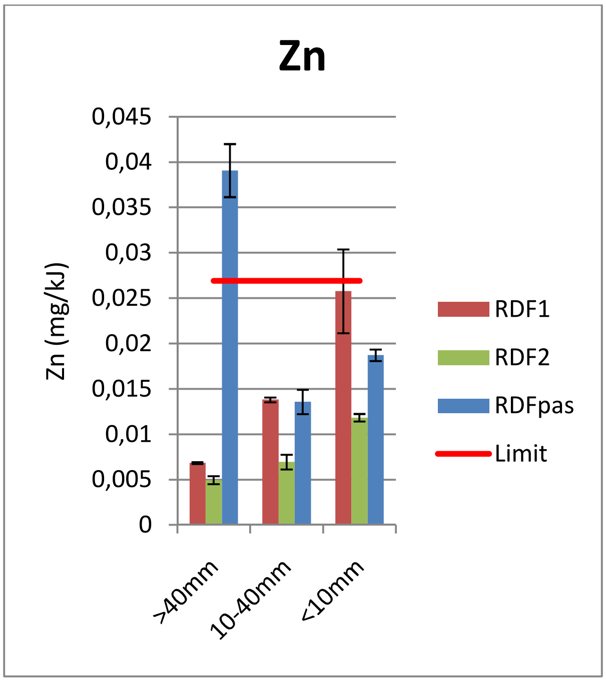

Figure 11: Zinc content for the different classes and RDF with mean value of different limit values

Zinc

For Zinc the image looks different (Figure 11). In the class >40 mm the value for the $RDF_{passive}$ exceed the limit value. The active produced ones under-run the value. For that a usage is possible. Also the class 10-40 mm under-run the limit value. The class <10mm has much higher values, than the other ones. For that is could said, that through the biological stabilization the Zinc content in the considered classes is under the limit value. It is expected, that the zinc content is mostly found in the mineral fraction, which could be found in the class <10mm. It could said, that a use of the both upper classes is possible, because it reach the limit value for zinc.

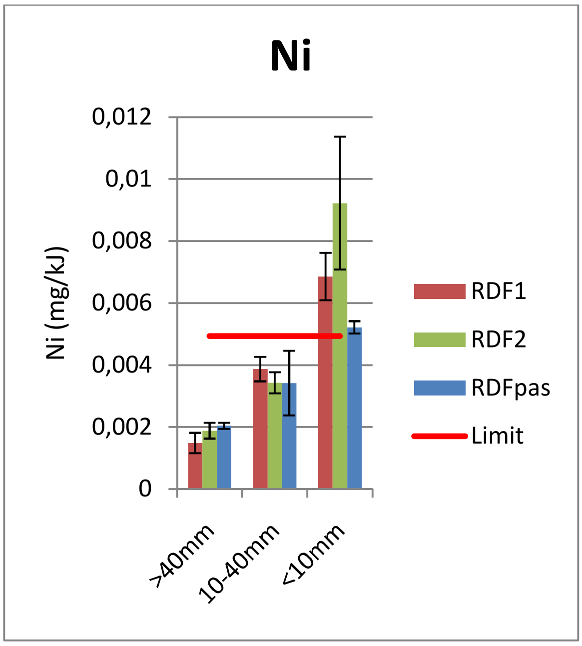

Figure 12: Nickel content for the different classes and RDF with mean value of different limit values

Nickel

The values for nickel lie under the limit value for the classes >40mm and 10-40 mm. The class <10mm exceed the limit value for all RDF. A graphic distribution could be seen in Figure 12. That could mean that the nickel is mostly found in small particles of the waste, maybe in the mineral fraction. With the under-run of the nickel content for the both classes a use as RDF is possible.

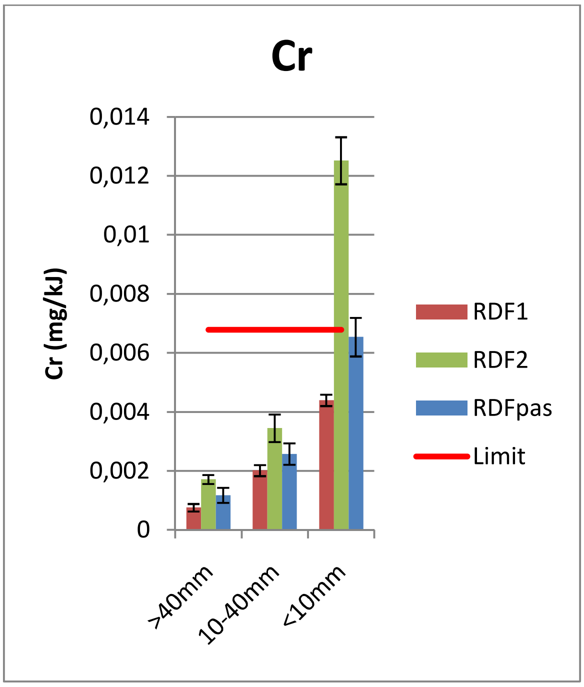

Figure 13: Chrome content for the different classes and RDF with mean value of different limit values

Chrome

Chrome shows the same effects like nickel. The classes >40 mm and 10-40 mm have a low content of chrome, which underline the limit value clearly. For that a use as RDF is possible. A distribution could be seen in Figure 13.

Lead

Lead show low values for all classes (Figure 14). All values are under the limit value of 0.00925 mg/kJ together with an increase through a smaller size. Here class <10mm is recorded. Also, like for the other heavy metals, it is assumed, that the mineral parts of the waste have a high contribution for the amount of lead inside the total MSW / RDF. For that, a biological stabilization and drying has a positive effect on the lead content.

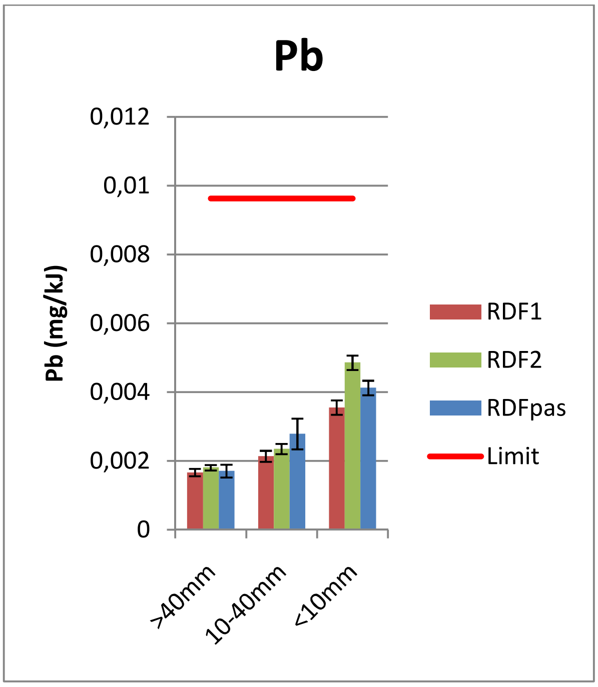

Figure 14: Lead content for the different classes and RDF with mean value of different limit values

Cadmium

Like for lead, also for cadmium all values are totally under the limit value. The $RDF_{active1st}$ and $RDF_{passive}$ show similarities in the classes 10-40mm and <10mm. A reason for that could not be found. The both higher classes shows the lowest values, therewith a usage is possible.

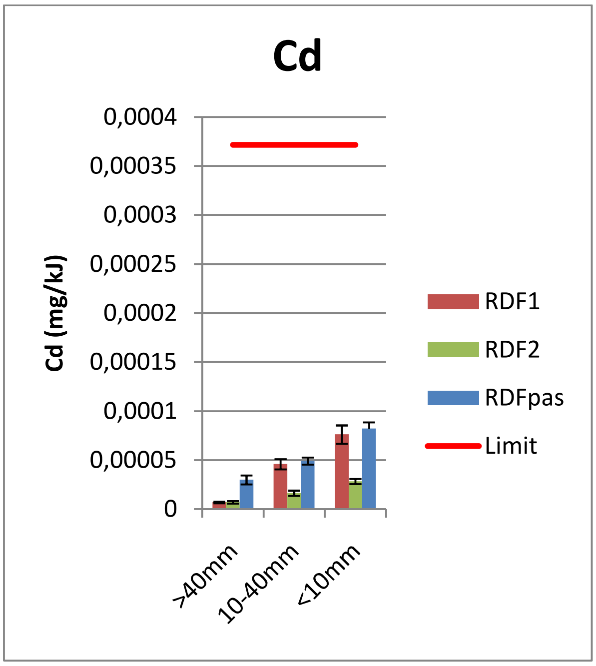

Figure 15: Cadmium content for the different classes and RDF with mean value of different limit values

Ash content

Figure 16 shows the ash content and the contribution to the total ash content for the MSW and the different RDFs. Also the average of ash content for lignite is viewed. From that it is seen, that the Ash content is for all kinds over the content of the lignite. An increasing through the biological stabilization is recorded in comparison to the waste. All RDFs were with that result not completely useable for a substitution of lignite. It is assumed, that the contribution could be reduced through a better drying effect and also the total amount could be reduced.

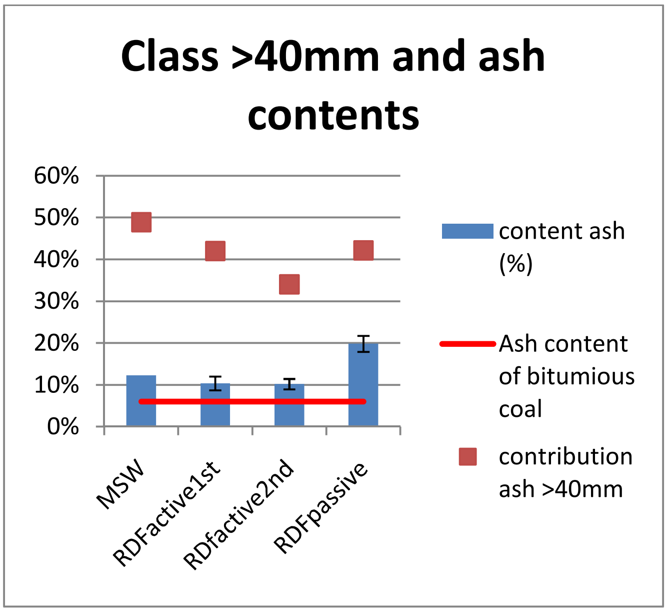

Figure 16: Ash content and contribution for the class >40mm for MSW and RDFs with the ash content of lignite

This clear picture could not be viewed for the ash content and the contribution of the class 10-40mm (Figure 17). The contribution for the high with over 50 % for all three RDF. An increase is recorded in comparison to the MSW. Also the percentage amount of ash is increasing through the biological stabilization. This result is volitional, because of the stabilization process, the mineral parts of the waste should be transferred to the lower classes. For that is could said, that the drying effect has a positive influence on the quality of the RDF.

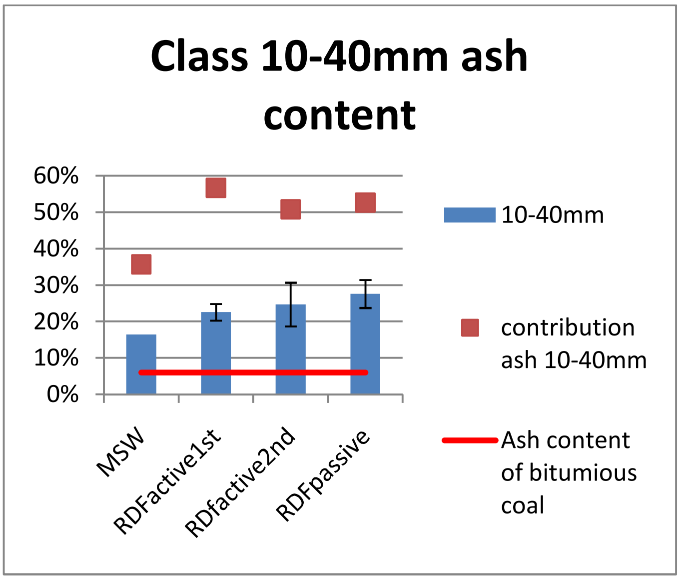

Figure 17: Ash content and contribution for the class 10-40mm for MSW and RDFs in comparison to the ash content of lignite

The picture for the class <10mm not so clear like for the class 10-40mm, because the values in comparison to the MSW change too much. The contribution of the ash after the RDF production shows increasing and decreasing effects for the different RDFs. For that no statement about the changing is possible. Also the content of ash changes in a very high range in comparison to the MSW. But it is assumed, that an increasing of the ash content in this class will happen with a better biological stabilization. A more detailed investigation in relation to the comparison between primary energy fuel and RDF was not done. This was not object of this thesis. Therefore, no statements could be done for example about the bulky density or the combustion behavior.

For the third thesis it could be said, that in some criteria the RDF, especially the RDF which were produced with active aeration, reach the similarities of primary energy fuel, like coal. For the LHV (raw) the RDFactive1st and RDFactive2nd reach nearly the LHV (raw) of lignite. When a drying effect could be improved, then the LHW (wf) could be easily reached, maybe also for bituminous coal.

The heavy metal content underrun the limit values for most cases. A clear effect of a transfer to lower classes could not be determined. For that a statement was not possible.

The ash content is transferred from the class >40 mm to the lower classes, which was determined at the total ash content and the contribution of the ash, also in comparison to the MSW.

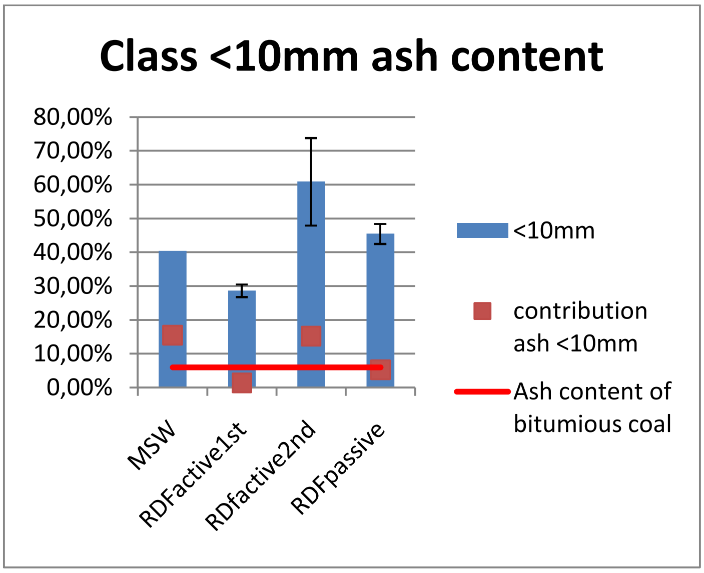

Figure 18: Ash content and contribution for the class <10mm for MSW and RDFs in comparison to the ash content of lignite

For that a substitution of primary energy fuels like coal seems to be possible with the produced active RDFs.

4.4 4TH THESIS

The use of RDF can reach a economic and environmental benefit.

4.4.1 *ENVIRONMENTAL BENEFIT*

Comparison to emission factor

The emissions factor, which were calculated on the results of the biogenic/ fossil carbon test and also on the total carbon analyze with caloric value (LHV(wf)) of each class, shows strongly differences. The factor shows the emission of fossil CO_2 through combustion.

The values are in the same range of former studies, which determine a value for RDF, which were produced at mechanical biological treatment plants in Germany (Eckardt, Schirmer, Bilitewski, & Albers, 2004). What the results show clearly is, that through a use of the RFD, the emission is reduced in a view to primary energy sources like lignite or bituminous coal.

Table 28: Reduction rates of the emission factors for selected RDF in comparison to lignite and bituminous coal, as reference value was taken literature value

Kind of RDF	Reduction in comparison to lignite (%)	Reduction in comparison to bituminous coal (%)
RDFactive1st >40mm	98.70	98.45
RDFactive1st 10-40mm	83.36	80.14
RDFactive2nd >40mm	48.18	38.15
RDFactive2nd 10-40mm	92.07	90.53
RDFpassive >40mm	71.40	65.87
RDFpassive 10-40mm	87.33	84.88
RDF literature1	82.97	79.68

1) (Eckardt, Schirmer, Bilitewski, & Albers, 2004)

Table 28 show the reduction rates clearly in comparison to lignite and bituminous coal. For that is could said, that, under excluding the outliners like $RDF_{active1st}$ >40mm, high reduction rates could be reached. The reduction rates are very high in a view to a substitution of lignite, bituminous coal show not so high reduction values. The other energy is substitute by biogenic carbon, which is not greenhouse effect relevant. For that, it is clearly seen, that the use of RDF instead of primary energy sources will be bring a benefit for the environment.

For that is must be also be said, that this comparison shows only the maximum reduction rate, which is possible. Some circumstances are not considered, these are oxidation factors, LHV (raw) of the energy sources and RDF, substitution rate, etc. For that is assumed, that the emission factor in reality will be lower than the calculated, but is must not be a disadvantages, because it should show the maximal possible emission reduction by substitution.

In general is could be said, that a ecological benefit for substitution of coal through RDF seems to be possible. Emission of fossil Carbon dioxide could be reduced up to 50 % in comparison to lignite. For that, more investigations and basic parameters must be considered, especially for specific projects.

Comparison to landfill and use as RDF

In a comparison to landfill, a hypothetical model was created and used. The land filling of MSW cause, if the waste is untreated, methane emissions over al long-time period up to 30 years (Bilitewski, Härdtle, & Marek, 2000). These emissions could be avoided, if the waste is combusted, or RDF, which were produced out of the waste, were used.

The avoidance potential is based on a model, which calculated the possibility and typical methane emissions from MSW. In this thesis the emissions were calculated only for a maximum project running time of ten years. It is from that clearly seen, that through the usage of RDF instead of land filling the MSW, the hypothetically methane emissions could be reduced clearly.

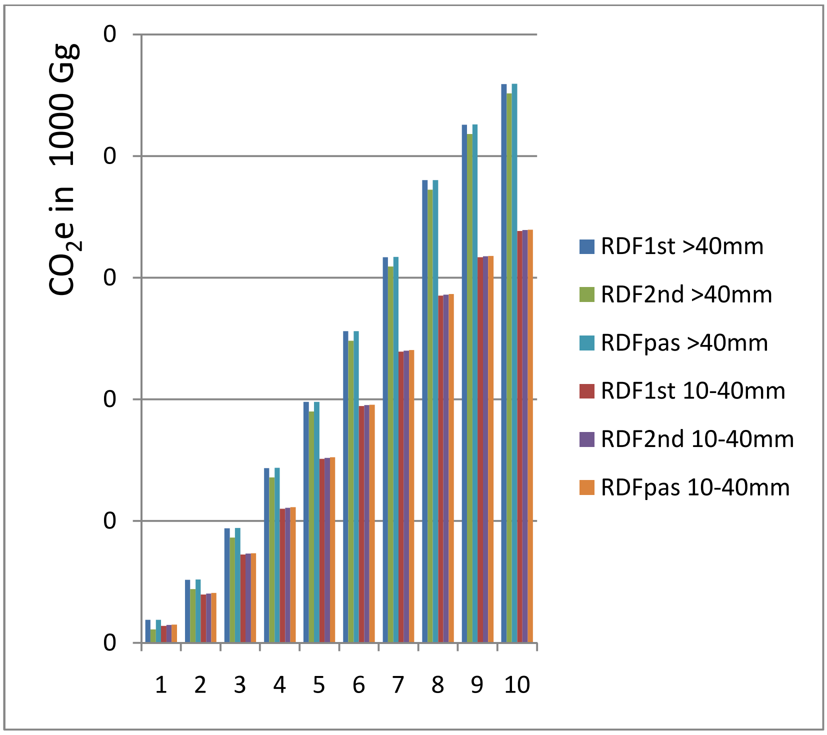

Figure 19: Avoided emissions with subtraction of the emissions from combustion of RDF

Problems with the limitation for ten years could be that the realistic hypothetical emissions are too low with a view to a realistic scenario. This limitation must be made, because the maximum project time for CDM-projects is ten year (or seven years with the possibility of an extension). Also this is necessary, because maybe other treatment methods in the future, like gas collection for a landfill were not considered during the baseline emission calculation. This would and could be also influence the credited emissions now, because the scenario does not included changes in the future. It is only analyzed the current situation. For that a setting of a time boarder is necessary essential.

The methane avoidance potential is increasing over time. For the first years, a slow increase is recorded, which accelerated than over time, to a stable emission, this is based on the factors for the models which were set. It is clearly seen, that, also because of the GWP of methane, the potential avoided emissions are high. In a comparison to the emissions through combustion of the RDF, seen in Figure 19. The avoidance potential has a dynamic expansion, because of the methane generation, whereas on the other side the emissions from the combustion succumb a static expansion. From that is could be said, that through the combustion of RDF, the environmental benefit of avoiding of greenhouse-gases has a dynamic growing. It must be said, that in this thesis only the emissions from combustion and the avoidance potential are calculated, no other emissions were taken into account, especially from the production of RDF and energy consumption. The avoidance potential would be during the first time lower than expected, because of higher emissions from other processes, but on the other hand the avoided emissions in the future after ten years would be much higher, because after 20-30 years a methanogenic condition will stop and decrease.

Also, and this is also not taken into account in this thesis, it is expected, that methane in the atmosphere has a negative influence on the greenhouse effect with a global warming of over 30 years. Other studies like (Forster, Ramaswamy, & al., 2007) or (Shindell, Faluvegi, Koch, Schmidt, & Unger, 2009) assumed a longer effect on the atmosphere than IPCC. This is expressed through a different GWP, but this was also not object of this thesis.

Altogether it could be said, that the benefit for the environment will increase with a look to a long term future. Here is was only analyzed a time-period of ten years, which however also shows a clear benefit for the environment with a view to the global warming through the emission of greenhouse gases. It is assumes, that the benefit will be in the future higher than calculated because the different assumptions which were set.

4.4.2 ECONOMICAL BENEFIT

Substitution of coal

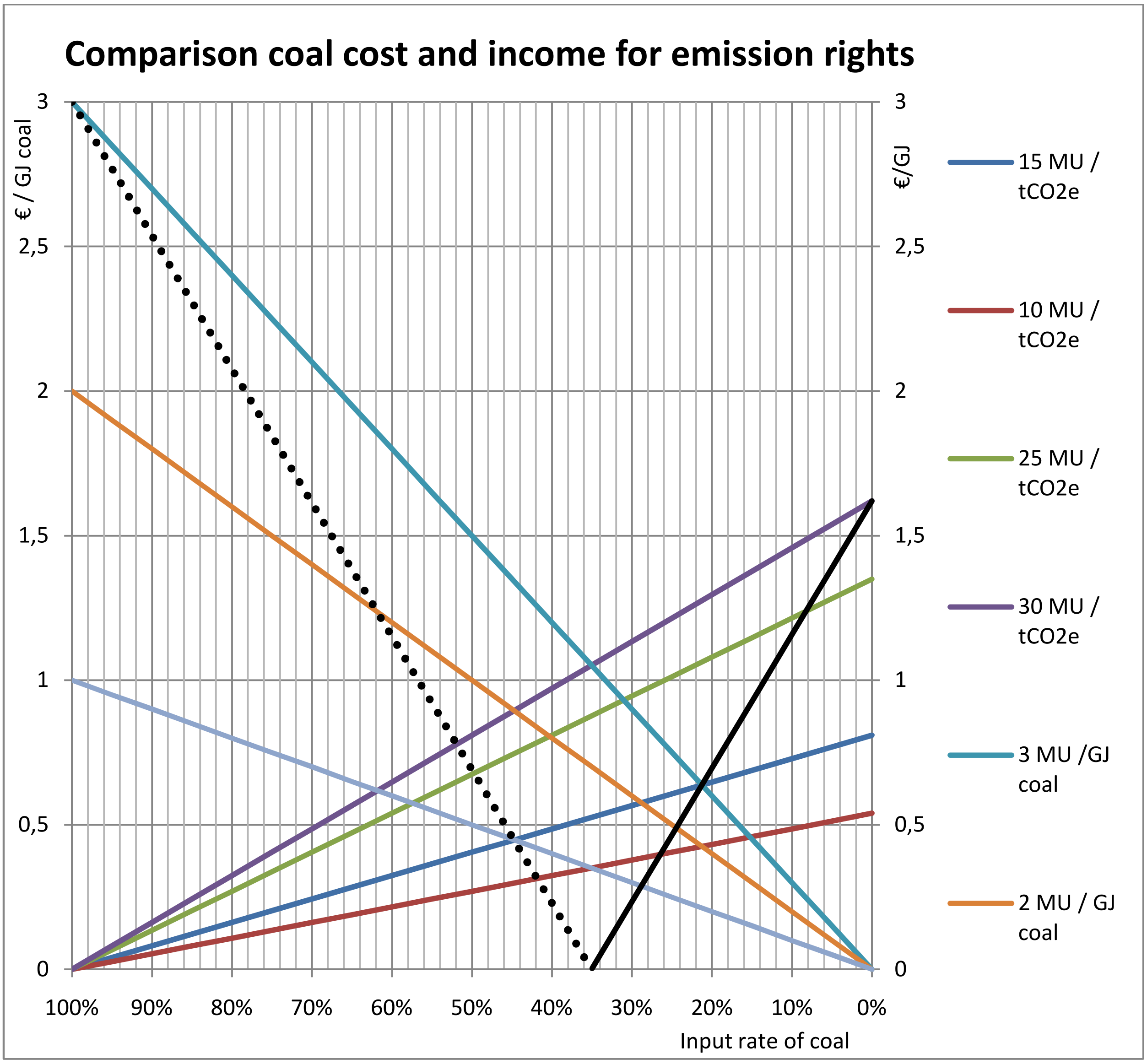

Figure 20: Comparison between coal cost and possible income from emission rights. Both in different price-ranges. The possible income from the emissions-rights is calculated for the reduction of emission factor for $RDF_{active2nd}$ >40mm with 57.5 g CO2 $\cdot MJ^{-1}$ in comparison to ignite with 111 g CO2 $\cdot MJ^{-1.}$ The Cash-loss and Cash-flow lines show the negative/positive monetary flow for different substitution grades. Horizontal axis shows the input factor for coal. (MU = monetary unit)

Figure 20 shows the comparison between the cost of coal in monetary units (MU) to energy content, GJ in comparison to the possible reduction by using $RDF_{active2nd}$ >40mm with a emission factor of 57.5 g CO_2 / MJ. The reduction is then, by using lignite with a emission factor of 111 g CO_2 / MJ, 53.5 g CO_2 / MJ. It is shows as a example, in the figure marked with a black line, the point from which a substitution with RDF brings a positive income, cash-flow. This is in the example a substitution of 65% RDF and 35 % lignite. From this point or higher, a income is established.

What it is clearly seen at this figure, that a economical benefit depends strongly in the reachable prices for emission-rights and the price for coal. There are possibilities, were a substitution-rate of 38 % brings a positive and surplus income.

From that point is could be said, that there is the possible to generate a surplus income by using RDF as a substitute for coal, together with a ecological benefit by reduction and saving of emissions.

In this comparison was not considered a price and treatment-costs for RDF, efficiency of the combustion, maximal substitution rate, different LHV, other costs etc. It should only show, simplified, a possible surplus income and with that a monetary benefit by using RDF instead of lignite. This could be reachable and possible, but detailed investigations could be necessary.

Comparison to landfill and use as RDF

The statements are also valid for the other RDF, because the results of them show the same trend. In the scenario with increasing prices for emissions rights, it is recorded a clear advantages for $\mathrm{RDF}_{\mathrm{active1st}}$ made out of the class >40mm. The increasing difference to the class 10-40 mm could be seen clearly over the time, a significant difference appear. This shows, that over the project time of ten year, a surplus benefit in comparison to RDF 10-40mm is possible. The reason for that could be found on the different content of organic matter. The organic matter is the main factor for the methane generation, so for that the reduction potential is high. As a additional factor could be seen the increasing price over time.

For the scenario with stable prices, the advantage lies also by the RDF >40mm. This is also clear, because the same reason is valid, high organic matter. What also should be considered is, that the avoidance potential has a dynamic growing over time, whereas the emission from combustion of RDF has static emissions. For that, the possible benefit also grows with the dynamic trend. For the stable price scenario could also be said, that class >40mm is clearly advantageous in a view to class 10-40mm.

For the third scenario with decreasing of prices over time shows the trend different. Also here is the class >40mm clearly advantageous, but it is recorded an decrease of the possible income from selling emission rights. During the first eight year an increase for every year is recorded and a maximum at the eight year. After that a falling prices are recorded. Two different reasons are responsible for that trend, on the fist the dynamic growing of the avoidance potential becomes a stable trend and as a second reason the price of the emission right is falling. This causes together a reduction of the potential income. Not all factors and possible emissions are taken into account for this thesis, but it could be possible, that with a lower emission reduction or higher other emission the avoidance potential could become negative, which means no income from the selling of emission rights.

For the fourth statement could be said, that a use of RDF entail a benefit in ecological view but also in economic view. The largest benefit shows the class >40 mm, because of the high content of organic matter, which cause a high potential for avoiding methane emissions, but also a high reduction factor of fossil carbon dioxide in comparison to lignite.

5. CONCLUSION

In summary it could be said that the composition of the analyzed MSW seems to be possible for a production of RDF. The MSW from Hanoi area has the typical characteristic as other Asian household waste, a high content of organic matter which contributes a high water content to the total MSW.

With that a biological stabilization is not easy possible and the process need improvements. The drying efficiency was too low, which causes a lot of problems. The lowest drying efficiency could be found at the experiment without aeration, the experiments with active aeration had better results. The high water content also have a negative effect to the storage of the RDF, where a methanogenic conditions could happen, which could be a security problem. Improvements to solve this problem could be a pre-treatment in form of size-reduction, impurity remove, big scale experiment, isolation, and changes with the aeration. Also the test-setup should be changed, for a better control of the process (temperature, etc.). Further research on these topics seems to be necessary.

With these improvements it is assumed, that an accumulation of mineral contents and heavy metals to the class <10mm is possible. Because of the low drying efficiency, the results did not reach the assumed ranges. For some heavy metals, the determined values lie over a calculated average limits from different sources. With a better drying efficiency it is assumed, that a transfer of the mineral contents, together with the heavy metals, will happen to the lower classes (<10mm).

A heating value accumulation through that is also possible, because contents with low energy content could be transferred to lower classes. A more efficiency drying would also increase the heating value of the higher classes (>40mm, 10-40mm).

Through the substitution of primary energy sources like coal could be a benefit, because of a monetary income from the selling and participate at the market for emission rights with a Clean Development project. Two basic things were analyzed, the effect of different substitution-rates on the cash-flow/-loss with a view to changing prices for coal and emission rights. Details investigations seem to be necessary, especially for concrete project, were parameters are available. Also other factors should be taken into account for a complete economic potential study. Not exhaustive: Treatment cost, maximal substitution rate, disposal cost, combustion efficiency, energy prices, etc.

Also it was analyzed the possibility of avoiding potential of the use of RDF instead of land filling MSW. Form that model, which is based mainly on the IPCC methods, a high avoiding potential seems to be reachable. For that not all emissions were taken into account. These are, not exhaustive, emissions from treatment, emission reduction from gas collection system, emission from leachate treatment, energy consumption, etc. For that a very detailed investigation, maybe based on a realistic project, together with an economical analyze, seems to be very necessary to fulfill the criteria of the IPCC and the Kyoto-protocol, to give the possibility to join the European marked for emission rights.

What is noted it, that, together with a economic benefit, a ecological benefit accompany. The emission of greenhouse gas like methane could be preventing by using the MSW as RDF.

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Annex I - Tables

Table 29: Waste composition of MSW characterization from Hanoi Hoan Kiem lake area in the year 2010 with total amount of each fraction and quote of each fraction to total amount of waste (280.68 kg)

Waste Composition	>40mm (kg)		10-40mm (kg)		<10mm	
	Amount (kg)	Quote	Amount (kg)	Quote	Amount (kg)	Quote
Metal	0.93	0.33%	0.22	0.08%	-	-
Paper	30.58	10.89%	6.86	2.44%	-	-
Glass	5.23	1.86%	0.3	0.11%	-	-
Plastics	32.39	11.54%	0.83	0.30%	-	-
Organic/Biowaste	74.92	26.69%	80.87	28.81%	-	-
Wood	0.88	0.31%	0	0.00%	-	-
Textile	2.03	0.72%	0.28	0.10%	-	-
Mineral And Soil	7.2	2.57%	1.48	0.53%	-	-
Composite	6.24	2.22%	0.28	0.10%	-	-
Nappies	6.52	2.32%	2.24	0.80%	-	-
Hazardous	1.29	0.46%	0.23	0.08%	-	-
Others	2.4	0.86%	0.56	0.20%	-	-
<10mm		-		-	15.92	5.67%
Total	170.61	60.78%	94.15	33.54%	15.92	5.67%

Table 30: Water content of the analyzed MSW waste from Hoan Kiem District, Hanoi in 2010. The values are given in percentage for the Median and the standard deviation. (n=3, if not other marked)

	Median >40mm	SD >40mm	Median 10-40mm	SD 10-40mm	Median <10mm	SD <10mm
Metal	2.25	1.24	-**	-**	-	-
Paper	75.66	4.44	73.69	0.14	-	-
Glass	-*	-*	-**	-**	-	-
Plastics	55.56	14.38	44.30	7.53	-	-
Organic/Biowaste	83.91****	7.75****	53.46	5.57	-	-
Wood	32.30***	-***	-**	-**	-	-
Textile	70.63	6.01	-**	-**	-	-
Mineral And Soil	1.35	2.62	8.19	1.95	-	-
Composite	35.87	13.03	32.50	9.40	-	-
Nappies	52.11	2.92	-**	-**	-	-
Hazardous	-*	-*	-**	-**	-	-
Others	93.31	5.55	-**	-**	-	-
Rubber	9.05	51.46	-**	-**	-	-
<10mm	-	-	-	--	62.85	1.00

*) No Sampling Possible, Because Samples Was Lost Before Analyze; **) No Sample Was Taken / Was Not Possible Because Of No Or Low Material; ***) N=1; ****) N=4

Table 31: Heating value for different waste fractions, calculated to LHV.

No.	Name of Samples	WC [%]	H(wf) [%]	Repeat 1 Ho(wf) [J/g]	Repeat 2 Ho(wf) [J/g]	Error betw. 1st & 2nd [%]	MEDIAN Ho(wf) [J/g]	MEAN value Ho(wf) [J/g]	Hu(wf) [J/g]	LHV(raw) [J/g]
>40mm class										
	metal	2.25	0.00	0	0	0.00	0	0.00	0.00	-54.9225
1	paper -18oC	75.66	5.97	15426.27	15532.6	75.19	15479.435	15479.44	14167.66	1601.12844
	glass	2.25	0.00	0	0	0.00	0	0.00	0.00	-54.9225
2	plastics	55.56	5.55	32826.31	33287.84	326.35	33057.075	33057.08	31838.86	12791.74217
3	organic/biowaste	81.87	6.21	15573.57	15222.76	248.06	15398.165	15398.17	14034.08	546.5008849
4	wood	32.30	6.54	16946.18	16779.34	117.97	16862.76	16862.76	15426.60	9655.617693
5	textile -18oC	70.63	5.89	15532.59	15218.46	222.12	15375.525	15375.53	14080.92	2411.79604
	mineral and soil	2.25	0.00	0	0	0.00	0	0.00	0.00	-54.9225
6	composite	35.87	6.20	31652.78	31136.02	365.40	31394.4	31394.40	30032.32	18383.70772
7	nappies	52.11	6.51	18499.23	18800.07	212.73	18649.65	18649.65	17220.20	6975.051753
	hazardous	0.00	0.00	0	0	0.00	0	0.00	0.00	0
8	other	93.31	6.16	21594.41	21268.01	230.80	21431.21	21431.21	20077.80	-935.4285239
9	rubber	9.05	5.58	34738.13	34753.22	10.67	34745.675	34745.68	33520.19	30265.00482

No.	Name of Samples	WC [%]	H(wf) [%]	Repeat 1 Ho(wf) [J/g]	Repeat 2 Ho(wf) [J/g]	Error betw. 1st & 2nd [%]	MEDIAN Ho(wf) [J/g]	MEAN value Ho(wf) [J/g]	Hu(wf) [J/g]	LHV(raw) [J/g]
10-40mm class										
	metal	2.25		0	0	0.00	0	0.00	0.00	-54.9225
10	paper -18oC	73.69	5.83	14487.12	14728.15	170.43	14607.635	14607.64	13326.11	1707.667874
	glass	2.25		0	0	0.00	0	0.00	0.00	-54.9225
11	plastics -18oC	44.30	5.70	27129.28	27693.93	399.27	27411.605	27411.61	26160.30	13490.88269
12	organic/biowaste	53.46	5.39	15283.58	15037.32	174.13	15160.45	15160.45	13975.28	5199.774096
	wood	32.30	3.67	16946.18	16779.34	117.97	16862.76	16862.76	16057.23	10082.56393
	textile -18oC	70.63	0.00	15532.59	15218.46	222.12	15375.525	15375.53	15375.53	2792.044655
13	mineral and soil	8.19	0.57	0	0	0.00	0	0.00	-124.45	-314.2714737
14	composite	32.50	5.57	27969.68	27492.75	337.24	27731.215	27731.22	26507.23	17099.67931
15	nappies	52.11	6.00	19738.85	19196.7	383.36	19467.775	19467.78	18149.64	7419.855102

	hazardous	2.25		0	0	0.00	0	0.00	0.00	-54.9225
	other	93.31	3.31	21594.41	21268.01	230.80	21431.21	21431.21	20704.33	-892.5771257
	rubber	9.75	0.00	34738.13	34753.22	10.67	34745.675	34745.68	34745.68	31119.97419

No.	Name of Samples	WC [%]	H(wf) [%]	Repeat 1 Ho(wf) [J/g]	Repeat 2 Ho(wf) [J/g]	Error betw. 1st & 2nd [%]	MEDIAN Ho(wf) [J/g]	MEAN value Ho(wf) [J/g]	Hu(wf) [J/g]	LHV(raw) [J/g]
<10 mm class										
16	<10mm	62.85	3.67	9775.86	11031.37	887.78	10403.615	10403.62	9598.09	2031.600384

Table 32: Ash content of different MSW fractions

No.	Name Of Samples	Repeat 1				Repeat 2				Error betw. 1st & 2nd	Repeat 3				MEDIAN	MEAN value
		Tara	Sample	After (ash+tara)	A[%]	Tara	Sample	After (ash+tara)	A[%]		Tara	Sample	After (ash+tara)	A[%]	A[%]	A[%]
>40mm Sample																
1	Paper -18oc	33.05	1.01	33.13	0.07920792	44.56	1	44.67	0.11	0.02177329	81.84	2.2	82.08	0.10909091	0.10909091	0.09943294
2	Plastics	33.64	1.02	33.78	0.1372549	37.05	1.05	37.18	0.12380952	0.00950732	38.3	2.07	38.56	0.12560386	0.12560386	0.12888943
3	Organic/Biowaste	42.44	1.05	42.59	0.14285714	59	1.09	59.08	0.0733945	0.04911751	47.88	2.09	47.98	0.04784689	0.0733945	0.08803284
4	Wood	42.19	1	42.2	0.01	42.62	1.02	42.64	0.01960784	0.00679377				#DIV/0!	0.01480392	0.01480392
5	Textile -18oc	43.59	1.1	43.69	0.09090909	35.25	1	35.33	0.08	0.00771389				#DIV/0!	0.08545455	0.08545455
6	Composite	44.58	1	44.66	0.08	35.22	1.06	35.32	0.09433962	0.01013964	38.45	2.02	38.61	0.07920792	0.08	0.08451585
7	Nappies	34.33	0.99	34.34	0.01010101	34.79	1.05	34.82	0.02857143	0.01306056	33.68	1.87	33.75	0.03743316	0.02857143	0.02536853
8	Other	35.25	1.04	35.34	0.08653846	33.05	1.01	33.13	0.07920792	0.00518348				#DIV/0!	0.08287319	0.08287319
9	Rubber	35.61	1.02	35.71	0.09803922	35.69	1.09	35.82	0.11926606	0.01500964	72.55	2.27	72.8	0.11013216	0.11013216	0.10914581
10-40mm Sample																
10	Paper -18oc	47.89	1.02	47.99	0.09803922	66.36	1.02	66.47	0.10784314	0.00693242				#DIV/0!	0.10294118	0.10294118
11	Plastics -18oc	72.57	1.05	72.72	0.14285714	65.55	1.01	65.66	0.10891089	0.02400362	42.18	2.25	42.48	0.13333333	0.13333333	0.12836712
12	Organic/Biowaste	38.3	1.1	38.48	0.16363636	53.19	1.19	53.38	0.15966387	0.00280898				#DIV/0!	0.16165011	0.16165011

13	Mineral And Soil	38.46	1.12	39.13	0.59821429	55.43	1.01	56.05	0.61386139	0.01106417	51.85	2.05	53.1	0.6097561	0.6097561	0.60727726
14	Composite	82.92	1.01	83.13	0.20792079	42.44	1.07	42.65	0.19626168	0.00824424	35.64	2.19	36.02	0.17351598	0.19626168	0.19256615
15	Nappies	44.24	1.01	44.35	0.10891089	43.58	1.04	43.68	0.09615385	0.00902059				#DIV/0!	0.10253237	0.10253237
<10mm Sample																
16	<10mm	35.22	1.11	35.65	0.38738739	43.31	1.16	43.78	0.40517241	0.01257591	44.23	2.43	45.25	0.41975309	0.40517241	0.4041043

Table 33: Chloride and Sulfur content for different MSW fractions

No.	Name of Samples	[Cl]		MEAN	[S]		MEAN
		[%]	[%]	[%TS]	[%]	[%]	[%TS]
>40mm sample							
1	paper -18oC	0.47417592	0.38979788	0.4319869	0.05975674	0.06487007	0.0623134
2	plastics	2.46047967	1.7304721	2.09547588	0.04720195	0.05672389	0.05196292
3	organic/Biowaste	0.40613172	0.36675508	0.3864434	0.09929346	0.11382258	0.10655802
4	wood	0.1335543	0.10315789	0.1183561	0.03515955	0.02787879	0.03151917
5	textile -18oC	0.13555992	0.16084179	0.14820086	0.06987557	0.07453338	0.07220448
6	composite	3.22054665	5.30109805	4.26082235	0.07942193	0.0721762	0.07579907
7	nappies	0.18742835	0.22097876	0.20420355	0.01802318	0.01833586	0.01817952
8	other	0.26591829	0.27950429	0.27271129	0.58863943	0.72297426	0.65580685
9	rubber	0.21998466	0.30075758	0.26037112	0.56297149	0.6135101	0.58824079
10-40mm sample							
10	paper -18oC	0.70225452	0.55559992	0.62892722	0.1704242	0.15818194	0.16430307
11	plastics -18oC	4.64511848	4.16157785	4.40334817	1.05939968	0.80883747	0.93411858
12	organic/Biowaste	0.73234272	0.8694165	0.80087961	0.14157983	0.45439302	0.29798643
13	mineral and soil	0.08343533	0.08796474	0.08570003	0.05317557	0.04407819	0.04862688
14	composite	4.61470478	4.48431336	4.54950907	1.14585684	0.9970568	1.07145682
15	nappies	0.60744254	0.58474889	0.59609572	0.10014593	0.10044313	0.10029453
<10mm sample							
16	<10mm	0.34640917	0.34046114	0.34343516	0.13122779	0.19858684	0.16490731

Table 34: Total carbon content of MSW fractions

Name of Samples	1st [mg/g]	2nd [mg/g]	MEDIAN TC[mg/g]	TC[%TS]
>40mm sample				
paper -18oC	397.82	405.74	401.78	0.40178
plastics	625.84	651.13	638.485	0.638485
organic/biowaste	402.92	401.69	402.305	0.402305
wood	443.78	443.82	443.8	0.4438
textile -18oC	411.14	384.3	397.72	0.39772
composite	466.34	622.03	591.95	0.59195
nappies	465.33	454.95	460.14	0.46014
other	535.56	526.37	530.965	0.530965
rubber	723.62	707.4	715.51	0.71551
10-40mm sample				
paper -18oC	376.4	380.54	378.47	0.37847
plastics -18oC	554.33	519.79	537.06	0.53706
organic/biowaste	387.62	384.31	385.965	0.385965
mineral and soil	130.76	130.26	130.51	0.13051
composite	487.59	581.59	510.985	0.510985
nappies	467.94	460.37	464.155	0.464155
<10mm sample				
<10mm	236.19	269.61	252.9	0.2529

Table 35: Biogenic / fossil carbon content for selected fractions of MSW

samples	mSRF (g)	filter (g)	empty (g)	dry (g)	mresidue (g)	crucible with ash (g)	m ash (g)	ASRF (%)	XB (%)	XNB (%)
>40mm										
paper -18°C	5	0.5413	69.0752	73.4493	3.8328	69.3615	0.28523333	9.94	19.11	70.95
plastics	5	0.56	3.42	8.5	4.52	33.8097	0.6253	12.89	9.22	77.89
organic/biowaste	5.02	0.5108	34.4325	35.2309	0.2876	34.4528	0.01923333	8.8	85.85	5.35
wood	5.02	0.5182	21.3526	22.0939	0.2231	21.3624	0.00873333	1.48	94.25	4.27
textile -18°C	4.99	0.8042	19.8123	23.9412	3.3247	20.0379	0.22453333	8.55	29.32	62.13
composite	5	0.8376	21.293	24.9932	2.8626	21.4177	0.12363333	8.45	36.77	54.78
nappies	4.98	0.68	34.4741	35.7706	0.6165	34.5843	0.10913333	2.54	87.27	10.19
other	4.97	0.5495	23.8032	24.9815	0.6288	24.0128	0.20853333	8.29	83.25	8.46
rubber	5.01	0.5181	18.6614	22.2495	3.5881	18.9445	0.28203333	10.91	23.10	65.99
10-40mm										
paper -18°C	5.19	0.8337	35.2848	39.7712	3.6527	38.1129	2.82703333	10.29	73.80	15.91
plastics -18°C	5.24	0.8304	32.5802	39.2828	4.8722	33.5868	1.00553333	12.84	13.37	73.79
organic/biowaste -18°C	5.03	0.5888	33.1794	34.8468	1.0786	33.5178	0.33733333	16.17	69.09	14.74
composite	5.09	0.8383	21.3764	24.269	2.0543	21.6572	0.27973333	19.26	45.88	34.86
nappies	5.79	0.8337	23.2878	27.9374	3.8159	23.7962	0.50733333	10.25	32.61	57.14
<10mm										
<10mm	5.05	0.5739	33.4482	35.5432	1.5211	34.9042	1.45493333	40.41	58.28	1.31

Table 36: Sieving out-/input from RDF experiments

	RDFactive1st	RDFactive2nd	RDFpassive
output drum / input sieving (kg)	27.31	23.81	35.45
Leachate (kg)	0.05461	-	-
output > 40mm (kg)	15.94	13.66	17.29
input sieving <40mm (kg)	10.36	8.4	16.94
output 10-40mm (kg)	9.86	-	15.51
output <10mm (kg)	0.186	1.02	0.94
sieving loss (kg)	1.324	0.73	1.71

Table 37: Determination of water content of RDF samples with Mean value, Median and SD. (n=3 for RDF active 1st and RDF passive; n=4 for RDF active 2nd)

RDF active 1st								
no	samples	empty (g)	wet(g)	dry (g)	WC	Mean value	MEDIAN	SD
1	>40mm	2.93	120.83	36.36	71.65%	61.99%	59.21%	8.60%
2		3.02	135.04	62.26	55.13%			
3		3.22	134	56.57	59.21%			
4	10-40mm	2.83	149.78	48.48	68.94%	72.32%	73.33%	3.01%
5		4.4	135.56	37.6	74.69%			
6		3.19	150.48	42.47	73.33%			
7	< 10mm	3.73	78.28	31.09	63.30%	64.43%	63.92%	1.45%
8		4.01	57.36	23.26	63.92%			
9		3.59	56.31	21.48	66.07%			
RDF active 2nd								
no	samples	empty (g)	wet(g)	dry (g)	WC	Mean value	MEDIAN	SD
1	>40mm	2.63	37.41	19.84	50.52%	59.98%	61.51%	7.05%
2		2.61	97.23	36.53	64.15%			
3		2.52	132.21	55.86	58.87%			
4		3.26	60.7	22.57	66.38%			
5	10-40mm	2.78	107.34	42.67	61.85%	64.57%	65.24%	1.85%
6		2.46	125.31	45.07	65.32%			
7		2.79	97.01	35.61	65.17%			
8		2.13	98.72	35.01	65.96%			
9	<10mm	2.83	116.63	64.74	45.60%	46.08%	45.83%	0.83%
10		2.82	81.2	44.16	47.26%			
11		2.79	147.42	80.79	46.07%			
12		3.06	101.63	56.88	45.40%			
RDF passive								

no	samples	empty (g)	wet(g)	dry (g)	WC	Mean value	MEDIAN	SD
1	>40mm	3.2	240	64.74	74.01%	74.89%	74.01%	2.67%
2		3.2	250	70.42	72.76%			
3		3.32	156.52	37.19	77.89%			
4	10-40mm	2.91	188.42	45.98	76.78%	71.47%	73.25%	6.39%
5		4.49	265.2	97.35	64.38%			
6		3.39	225	62.67	73.25%			
7	< 10mm	3.94	230.2	67.36	71.97%	73.34%	73.99%	1.18%
8		4.05	195.05	53.72	73.99%			
9		3.62	153.55	42.53	74.05%			

Table 38: LHV for RDF with water content

Name of Samples	WC [%]	H(wf) [%]	Repeat 1 Ho(wf) [J/g]	Repeat 2 Ho(wf) [J/g]	Error betw. 1st & 2nd [%]	Repeat 3 Ho(wf) [J/g]	MEDIAN Ho(wf) [J/g]	MEAN value Ho(wf) [J/g]	Hu(wf) [J/g]	Hu(roh) [J/g]
RDF passive										
>40mm	0.74011824	0.04823965	17368.13	16799.56	402.039703		17083.845	17083.845	16024.0682	2357.73436
10-40mm	0.73250305	0.03512974	11045.15	12034.98	699.915505		11540.07	11540.07	10768.2997	1092.44744
<10mm	0.73994764	0.03308642	10713.66	9585.02	798.068998		10149.34	10149.34	9422.46444	644.121879
RDF active 1st										
>40mm	0.59206301	0.05688639	20723.9	20551.47	121.926422		20637.69	20637.69	19387.9478	6463.83534
10-40mm	0.73331523	0.05283019	14846.31	14747.08	70.1662059		14796.70	14796.70	13636.0686	1846.50936
<10mm	0.63917526	0.04466019	10104.98	11681.56	1114.81041		10893.27	10893.27	9912.13019	2016.31502
RDF active 2nd										
>40mm	0.61511248	0.05628415	20230.13	19869.52	254.989776		20049.83	20049.83	18813.3184	5739.52186
10-40mm	0.65241028	0.04711779	13456.14	13207.19	176.034233		13331.67	13331.67	12296.5342	2681.61533
<10mm	0.4583341	0.01911111	7703.83	8195.87	347.924821		7949.85	7949.85	7529.998	2959.94962

Table 39: Heating value for RDF with calculation

Name of Samples	Repeat 1				Repeat 2				Error betw. 1st & 2nd	Repeat 3				MEDIAN	MEAN value
	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	(%)	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	A (%)	A (%)
RDF passive															
>40mm	35.7	1.01	35.91	20.7920792	100.22	1.06	100.41	17.9245283	2.02766469	88.05	2.07	88.48	20.7729469	20.7729469	19.8298515
10-40mm	66.45	1	66.7	25	51.85	1.00	52.14	29	0.02828427	34.33	2.01	34.91	28.8557214	28.8557214	27.6185738
<10mm	53.18	1.1	53.7	47.2727273	66.12	1.03	66.59	45.631068	0.01160828	87.31	2.25	88.29	43.5555556	45.631068	45.4864503
RDF active 1st															
>40mm	34.79	1	34.9	11	80.58	1.01	80.67	8.91089109	0.01477223	100.2	2.06	100.43	11.1650485	11	10.3586465
10-40mm	43.33	1.02	43.51	17.6470588	102.16	1.10	102.39	20.9090909	0.02306605	99.69	2.12	100.31	29.245283	20.9090909	22.6004776
<10mm	55.42	1.05	55.68	24.7619048	88.07	0.99	88.25	18.1818182	0.04652824	82.93	2.11	83.84	43.1279621	24.7619048	28.6905617
RDF active 2nd															
>40mm	65.55	1.06	65.67	11.3207547	87.33	1.13	87.42	7.96460177	0.02373159	80.58	2.3	80.84	11.3043478	11.3043478	10.1965681
10-40mm	42.62	1.03	42.91	28.1553398	81.88	1.07	82.1	20.5607477	0.05370188	102.17	2.08	102.7	25.4807692	25.4807692	24.7322856
<10mm	37.06	1.05	37.71	61.9047619	99.71	1.25	100.43	57.6	0.03043926	66.13	2.26	67.56	63.2743363	61.9047619	60.9263661

Table 40: Ash content of RDF

	Repeat 1				Repeat 2				Error betw. 1st & 2nd	Repeat 3				MEDIAN	MEAN value
	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	(%)	Tara (g)	Sample (g)	After (ash+tara) (g)	A (%)	A (%)	A (%)
RDF passive															
>40mm	35.7	1.01	35.91	20.7920792	100.22	1.06	100.41	17.9245283	2.02766469	88.05	2.07	88.48	20.7729469	20.7729469	19.8298515
10-40mm	66.45	1	66.7	25	51.85	1	52.14	29	2.82842712	34.33	2.01	34.91	28.8557214	28.8557214	27.6185738
<10mm	53.18	1.1	53.7	47.2727273	66.12	1.03	66.59	45.631068	1.16082843	87.31	2.25	88.29	43.5555556	45.631068	45.4864503
RDF active 1st															
>40mm	34.79	1	34.9	11	80.58	1.01	80.67	8.91089109	1.47722308	100.2	2.06	100.43	11.1650485	11	10.3586465
10-40mm	43.33	1.02	43.51	17.6470588	102.16	1.1	102.39	20.9090909	2.30660501	99.69	2.12	100.31	29.245283	20.9090909	22.6004776
<10mm	55.42	1.05	55.68	24.7619048	88.07	0.99	88.25	18.1818182	4.65282384	82.93	2.11	83.84	43.1279621	24.7619048	28.6905617
RDF active 2nd															
>40mm	65.55	1.06	65.67	11.3207547	87.33	1.13	87.42	7.96460177	2.37315851	80.58	2.3	80.84	11.3043478	11.3043478	10.1965681
10-40mm	42.62	1.03	42.91	28.1553398	81.88	1.07	82.1	20.5607477	5.3701876	102.17	2.08	102.7	25.4807692	25.4807692	24.7322856
<10mm	37.06	1.05	37.71	61.9047619	99.71	1.25	100.43	57.6	3.04392633	66.13	2.26	67.56	63.2743363	61.9047619	60.9263661

Table 41: Chloride and Sulfur content of RDF

	[Cl]		MEAN	[S]		MEAN
	(%)	(%)	(% DS)	(%)	(%)	(% DS)
RDF passive						
<10mm	0.39192757	0.32259835	0.35726296	0.12209229	0.12095151	0.1215219
<10mm	0.35845411	0.43780534	0.39812972	0.2989372	0.38838782	0.34366251
<10mm	0.38168224	0.33427313	0.35797769	0.3023053	0.24305433	0.27267981
RDF active 1st						
>40mm	0.56062718	0.47385984	0.51724351	0.08960511	0.08095415	0.08527963
10-40mm	0.54221534	0.5753374	0.55877637	0.1160599	0.11752018	0.11679004
<10mm	0.35247209	0.4173974	0.38493475	0.1258196	0.11896411	0.12239185
RDF active 2nd						
>40mm	0.25157473	0.28932584	0.27045029	0.07151492	0.0696005	0.07055771
10-40mm	0.34920953	0.32882454	0.33901703	0.11800414	0.12345209	0.12072811
<10mm	0.15443949	0.17548204	0.16496077	0.13232773	0.14859367	0.1404607

Table 42: Total carbon content of RDF

Name of Samples	1st (mg/g)	2nd (mg/g)	MEDIAN TC (mg/g)	TC (%DS)
RDF passive				
>40mm	392.49	376.1	384.295	38.4295
10-40mm	182.97	205.8	194.385	19.4385
<10mm	264.45	237.45	250.95	25.095
RDF active 1st				
>40mm	487.8	491.98	489.89	48.989
10-40mm	351.92	367.65	359.785	35.9785
<10mm	243.56	220.55	232.055	23.2055
RDF active 2nd				
>40mm	450.54	462.22	456.38	45.638
10-40mm	348.1	368.88	358.49	35.849
<10mm	266.79	275.49	271.14	27.114

Table 43: Biogenic and fossil carbon content of RDF

samples	mSRF (g)	filter (g)	empty (g)	dry (g)	mresidue (g)	crucible with ash (g)	m ash (g)	ASRF (%)	XB (%)	XNB (%)
RDFpassive										
>40mm	5.19	0.5385	33.797	36.6635	2.328	34.7004	0.90233333	19.83	52.7005074	27.4694926
10-40 mm	5.78	0.8383	24.5215	28.941	3.5812	27.4958	2.97323333	27.62	61.8615456	10.5184544
<10 mm	4.59	0.8057	24.0639	26.8394	1.9698	25.9889	1.92393333	45.49	53.5107262	0.99927378
RDFactive1st										
>40mm	5.05	0.5314	34.4732	35.3407	0.3361	34.7369	0.26263333	10.3586465	88.186568	1.45478548
10-40 mm	5.04	0.5283	24.7315	36.7575	1.4777	25.5363	0.80373333	22.6	64.0276455	13.3723545
<10 mm	5.66	0.808	21.5918	25.9555	3.5557	25.1241	3.53123333	28.69	70.8777267	0.43227326
RDFactive2nd										
>40mm	5.32	0.5104	19.6549	23.7529	3.5876	20.1187	0.46273333	10.1965681	31.0653367	58.7380952
10-40 mm	5.3	0.8278	21.58	24.09974	1.69194	22.7422	1.16113333	24.73	65.2547799	10.0152201
<10 mm	5.21	0.5443	36.2276	40.7071	3.9352	39.2175	2.98883333	60.93	20.9055726	18.1644274
<10 mm	5.06	0.8256	34.4351	36.7342	1.4735	34.788	0.35183333	60.93	16.9026746	22.1673254

Table 44: Methane emission potential for the MSW in the case of land filling. For the calculation is assumed, that the project time is eight years and every day is produced 5000 Mg MSW for 365 days per year. The calculations are cumulative, that means, for the MSW which is produced in the first year, the emissions are calculated for eight years, for the MSW of the second year for seven years, etc. All values in tCO_2e

year	>40mm (Mg CO_2e)	10-40mm (Mg CO_2e)	<10mm (Mg CO_2e)	TOTAL (Mg CO_2e)
1	970,706.52	769,419.29	124,720.70	1,864,846.50
2	2,618,244.15	2,059,333.11	457,764.88	5,135,342.15
3	4,743,573.36	3,702,551.07	1,055,173.17	9,501,297.61
4	7,211,408.88	5,586,695.03	1,954,510.73	14,752,614.63
5	9,929,365.51	7,636,150.78	3,180,958.21	20,746,474.50
6	12,833,962.03	9,799,968.22	4,751,394.74	27,385,324.99
7	15,881,224.26	12,043,748.97	6,677,134.73	34,602,107.95
8	19,040,372.94	14,344,207.04	8,965,762.44	42,350,342.42
TOTAL	73,228,857.65	55,942,073.50	27,167,419.61	156,338,350.76

Table 45: Fossil carbon emissions through combustion for the different RDF, it is expected, that 5000 Mg/day of RDF is produced for 365 days per year. The values are calculated for eight years, based on the fossil carbon content of the different classes.

(tCO_2e)	$RDF_{active1st}$	$RDF_{active2nd}$	$RDF_{passive}$
>40mm	12160.7491	398199.623	6823.95974
10-40 mm	62903.6342	25198.0355	1906.78449
<10 mm	31.3241584	13801.4323	9.40236303
TOTAL	75095.7075	437199.091	8740.14659

Table 46: N_2O and CH_4 emissions for the different RDF, it is expected, that 5000 Mg/day of RDF is produced for 365 days per year. The values are calculated for eight years, based on the fossil carbon content of the different classes.

(tCO_2e)	$RDF_{active1st}$	$RDF_{active2nd}$	$RDF_{passive}$
>40mm	23055.44	22245.36	19260.81
10-40 mm	14261.40	13679.43	17277.91
<10 mm	269.03	1661.07	1047.15
TOTAL	37585864.05	37585864.05	37585864.05

Table 47: Monetary values for economic comparison, calculated for stable (normal) increasing and decreasing prices

Normal												
	RDF$_{active1st}$				RDF$_{active2nd}$				RDF$_{passive}$			
year	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL
1	12,629.12 €	9,345.43 €	1,679.67 €	-483,247.53 €	7,428.53 €	9,862.31 €	1,474.99 €	-488,135.92 €	12,752.39 €	10,128.17 €	1,669.47 €	-482,351.73 €
2	34,870.88 €	26,759.27 €	4,492.04 €	-440,779.57 €	29,670.29 €	27,276.15 €	4,287.35 €	-445,667.96 €	34,994.15 €	27,542.00 €	4,481.83 €	-439,883.77 €
3	63,562.82 €	48,942.71 €	8,060.96 €	-386,335.26 €	58,362.23 €	49,459.59 €	7,856.27 €	-391,223.66 €	63,686.10 €	49,725.45 €	8,050.75 €	-385,439.46 €
4	96,878.60 €	74,378.65 €	12,137.00 €	-323,507.50 €	91,678.01 €	74,895.54 €	11,932.31 €	-328,395.89 €	97,001.88 €	75,161.39 €	12,126.79 €	-322,611.70 €
5	133,571.02 €	102,046.31 €	16,552.99 €	-254,731.45 €	128,370.43 €	102,563.19 €	16,348.30 €	-259,619.84 €	133,694.29 €	102,829.04 €	16,542.78 €	-253,835.65 €
6	172,783.07 €	131,257.84 €	21,196.84 €	-181,664.01 €	167,582.48 €	131,774.73 €	20,992.15 €	-186,552.40 €	172,906.34 €	132,040.58 €	21,186.63 €	-180,768.21 €
7	213,921.11 €	161,548.88 €	25,993.44 €	-105,438.33 €	208,720.52 €	162,065.77 €	25,788.75 €	-110,326.72 €	214,044.38 €	162,331.62 €	25,983.23 €	-104,542.53 €
8	256,569.62 €	192,605.07 €	30,892.42 €	-26,834.65 €	251,369.03 €	193,121.95 €	30,687.73 €	-31,723.05 €	256,692.89 €	193,387.80 €	30,882.21 €	-25,938.85 €
9	287,329.39 €	213,825.65 €	34,176.31 €	28,429.59 €	282,128.80 €	214,342.53 €	33,971.62 €	23,541.19 €	287,452.66 €	214,608.39 €	34,166.10 €	29,325.39 €
10	309,955.39 €	228,425.29 €	36,377.56 €	67,856.49 €	304,754.80 €	228,942.18 €	36,172.87 €	62,968.09 €	310,078.66 €	229,208.03 €	36,367.35 €	68,752.29 €
Increase												
	RDF$_{active1st}$				RDF$_{active2nd}$				RDF$_{passive}$			
year	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL
1	12,629.12 €	9,345.43 €	1,679.67 €	-483,247.53 €	7,428.53 €	9,862.31 €	1,474.99 €	-488,135.92 €	12,752.39 €	10,128.17 €	1,669.47 €	-482,351.73 €
2	37,453.91 €	28,741.44 €	4,824.79 €	-473,429.91 €	31,868.09 €	29,296.61 €	4,604.93 €	-478,680.40 €	37,586.31 €	29,582.15 €	4,813.82 €	-472,467.75 €
3	72,979.54 €	56,193.48 €	9,255.17 €	-443,570.12 €	67,008.49 €	56,786.94 €	9,020.16 €	-449,182.72 €	73,121.07 €	57,092.18 €	9,243.45 €	-442,541.61 €
4	118,407.18 €	90,907.24 €	14,834.11 €	-395,398.05 €	112,050.90 €	91,538.99 €	14,583.94 €	-401,372.76 €	118,557.85 €	91,863.92 €	14,821.64 €	-394,303.19 €
5	173,147.61 €	132,282.25 €	21,457.57 €	-330,207.43 €	166,406.11 €	132,952.28 €	21,192.24 €	-336,544.24 €	173,307.41 €	133,296.91 €	21,444.34 €	-329,046.21 €
6	236,776.80 €	179,871.86 €	29,047.52 €	-248,946.97 €	229,650.07 €	180,580.18 €	28,767.02 €	-255,645.88 €	236,945.73 €	180,944.50 €	29,033.53 €	-247,719.39 €
7	308,997.16 €	233,348.39 €	37,546.07 €	-152,299.81 €	301,485.20 €	234,094.99 €	37,250.41 €	-159,360.82 €	309,175.22 €	234,479.00 €	37,531.33 €	-151,005.87 €
8	389,605.71 €	292,474.36 €	46,910.71 €	-40,748.92 €	381,708.52 €	293,259.26 €	46,599.89 €	-48,172.04 €	389,792.91 €	293,662.96 €	46,895.21 €	-39,388.63 €
9	457,598.65 €	340,537.15 €	54,428.93 €	45,276.75 €	449,316.23 €	341,360.33 €	54,102.95 €	37,491.53 €	457,794.98 €	341,783.73 €	54,412.67 €	46,703.40 €
10	516,592.31 €	380,708.82 €	60,629.27 €	113,094.15 €	507,924.67 €	381,570.29 €	60,288.12 €	104,946.82 €	516,797.77 €	382,013.38 €	60,612.26 €	114,587.15 €

	Decrease											
	$RDF_{active1st}$				$RDF_{active2nd}$				$RDF_{passive}$			
year	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL	>40mm	10-40mm	<10mm	TOTAL
1	12,629.12 €	9,345.43 €	1,679.67 €	-483,247.53 €	7,428.53 €	9,862.31 €	1,474.99 €	-488,135.92 €	12,752.39 €	10,128.17 €	1,669.47 €	-482,351.73 €
2	32,287.85 €	24,777.10 €	4,159.30 €	-408,129.23 €	27,472.49 €	25,255.70 €	3,969.77 €	-412,655.52 €	32,401.99 €	25,501.86 €	4,149.85 €	-407,299.78 €
3	54,146.11 €	41,691.94 €	6,866.74 €	-329,100.41 €	49,715.98 €	42,132.25 €	6,692.38 €	-333,264.60 €	54,251.12 €	42,358.71 €	6,858.05 €	-328,337.32 €
4	75,350.02 €	57,850.06 €	9,439.89 €	-251,616.94 €	71,305.12 €	58,252.08 €	9,280.69 €	-255,419.03 €	75,445.90 €	58,458.86 €	9,431.95 €	-250,920.21 €
5	93,994.42 €	71,810.36 €	11,648.40 €	-179,255.46 €	90,334.75 €	72,174.10 €	11,504.36 €	-182,695.44 €	94,081.17 €	72,361.18 €	11,641.21 €	-178,625.08 €
6	108,789.34 €	82,643.83 €	13,346.16 €	-114,381.04 €	105,514.89 €	82,969.27 €	13,217.28 €	-117,458.92 €	108,866.96 €	83,136.66 €	13,339.73 €	-113,817.02 €
7	118,845.06 €	89,749.38 €	14,440.80 €	-58,576.85 €	115,955.84 €	90,036.54 €	14,327.08 €	-61,292.62 €	118,913.55 €	90,184.23 €	14,435.13 €	-58,079.18 €
8	123,533.52 €	92,735.77 €	14,874.13 €	-12,920.39 €	121,029.53 €	92,984.64 €	14,775.57 €	-15,274.06 €	123,592.87 €	93,112.65 €	14,869.21 €	-12,489.08 €
9	117,060.12 €	87,114.15 €	13,923.68 €	11,582.43 €	114,941.36 €	87,324.74 €	13,840.29 €	9,590.86 €	117,110.34 €	87,433.05 €	13,919.52 €	11,947.38 €
10	103,318.46 €	76,141.76 €	12,125.85 €	22,618.83 €	101,584.93 €	76,314.06 €	12,057.62 €	20,989.36 €	103,359.55 €	76,402.68 €	12,122.45 €	22,917.43 €

Table 48: Price trend for economic comparison

Year	Normal	Increase	Decrease
1	13.50 €	13.50 €	13.50 €
2	13.50 €	14.50 €	12.50 €
3	13.50 €	15.50 €	11.50 €
4	13.50 €	16.50 €	10.50 €
5	13.50 €	17.50 €	9.50 €
6	13.50 €	18.50 €	8.50 €
7	13.50 €	19.50 €	7.50 €
8	13.50 €	20.50 €	6.50 €
9	13.50 €	21.50 €	5.50 €
10	13.50 €	22.50 €	4.50 €

Table 49: Calculation data for economic comparison between RDF and lignite

Lignite quota	emission-reduction factor	20 MU / tCO2e	15 MU / tCO2e	10 MU / tCO2e	25 MU / tCO2e	30 MU / tCO2e	3 MU /GJ coal	2 MU / GJ coal	1 MU /GJ coal
1	0	0	0	0	0	0	3	2	1
0.95	2.7	0.054	0.0405	0.027	0.0675	0.081	2.85	1.9	0.95
0.9	5.4	0.108	0.081	0.054	0.135	0.162	2.7	1.8	0.9
0.85	8.1	0.162	0.1215	0.081	0.2025	0.243	2.55	1.7	0.85
0.8	10.8	0.216	0.162	0.108	0.27	0.324	2.4	1.6	0.8
0.75	13.5	0.27	0.2025	0.135	0.3375	0.405	2.25	1.5	0.75
0.7	16.2	0.324	0.243	0.162	0.405	0.486	2.1	1.4	0.7
0.65	18.9	0.378	0.2835	0.189	0.4725	0.567	1.95	1.3	0.65
0.6	21.6	0.432	0.324	0.216	0.54	0.648	1.8	1.2	0.6
0.55	24.3	0.486	0.3645	0.243	0.6075	0.729	1.65	1.1	0.55
0.5	27	0.54	0.405	0.27	0.675	0.81	1.5	1	0.5
0.45	29.7	0.594	0.4455	0.297	0.7425	0.891	1.35	0.9	0.45
0.4	32.4	0.648	0.486	0.324	0.81	0.972	1.2	0.8	0.4
0.35	35.1	0.702	0.5265	0.351	0.8775	1.053	1.05	0.7	0.35
0.3	37.8	0.756	0.567	0.378	0.945	1.134	0.9	0.6	0.3
0.25	40.5	0.81	0.6075	0.405	1.0125	1.215	0.75	0.5	0.25
0.2	43.2	0.864	0.648	0.432	1.08	1.296	0.6	0.4	0.2
0.15	45.9	0.918	0.6885	0.459	1.1475	1.377	0.45	0.3	0.15
0.1	48.6	0.972	0.729	0.486	1.215	1.458	0.3	0.2	0.1
0.05	51.3	1.026	0.7695	0.513	1.2825	1.539	0.15	0.1	0.05
0	54	1.08	0.81	0.54	1.35	1.62	0	0	0

Affidavit – Eidesstattliche Erklärung

Affidavit – Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt,
dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe angefertigt habe.
Sämtliche benutzten Informationsquellen sowie das Gedankengut Dritter wurden im Text als solche kenntlich gemacht und im Literaturverzeichnis aufgeführt.
Die Arbeit wurde bisher nicht veröffentlicht und keiner Prüfungsbehörde vorgelegt.

Herewith I declare under oath,
that I have prepared the present thesis autonomous and without external help.
All used information-sources, as well as the body of thought were marked in the Text as such and were listed in the list of references.
The thesis was until now not published and present any Board of examiners

Dresden, den
Dresden, the

Sven Schulenburg