AKADEMIN FÖR TEKNIK OCH MILJÖ
Avdelningen för bygg-, energi- och miljöteknik

Material Flow Analysis of Phosphorous and Organic Matter in Domestic Wastewater and Food Waste in Sông Công Town, Vietnam

Olli Sammalisto & Zanna Sefane

2015

Examensarbete, Grundnivå (kandidatexamen), 15 hp
Miljöteknik
Miljöteknik - vatten, återvinning, Co-op
Handledare: Zhao Wang
Examinator: Ola Norrman Eriksson

Abstract

Vietnam’s fast economic growth has to a large extent been achieved on the expense of a rapid deterioration of the natural environment, including eutrophication of local water sources. Proper planning is needed to move towards a sustainable wastewater management and one recognized tool for such planning is material flow analysis (MFA).

This thesis uses MFA to define the current flows of phosphorus (P) and organic matter, measured as COD, in domestic wastewater and food waste in Sông Công town, Thai Nguyen province, Vietnam. The aim is further to compare two different improved wastewater management scenarios with a business-as-usual scenario.

The methods used to find data for the MFA are literature review, interviews and a survey questionnaire. The literature review presents challenges facing the wastewater sector of Vietnam and treatment techniques for wastewater and septage.

The wastewater sector is affected by technical difficulties such as lack of capacity and organizational challenges as a result of adjacent and overlapping authorities. Contradictions and gaps in legislation, poor governance, and problems with financing are all issues that need to be addressed.

Although the number of wastewater treatment plants in Vietnam is increasing, not more than 10 % of the wastewater is being treated. Various techniques are tried out in Vietnam, among others constructed treatment wetlands and activated sludge techniques, such as Sequencing Batch Reactors and Anaerobic/Anoxic/Oxic processes. These and other techniques are explained and compared in the literature review.

From the gathered data three future scenarios for Sông Công’s wastewater and food waste treatment were created along with one of the current situation. The future business-as-usual scenario (BAU-2030) shows the development in Sông Công if no changes are implemented before year 2030, while the centralized scenario (CTP-2030) redirects flows of wastewater to a conventional chemical/biological treatment plant. The third scenario, semi-centralized (STP-2030), implements one treatment plant with enhanced biological phosphate removal (EBPR) followed by a constructed treatment wetland, and a bigger EBPR plant followed by disinfection. Both of the improved scenarios also use food waste and sludge to produce biogas and digestate that can be used as compost in agriculture.

The results of the MFA indicate that if nothing is done to change the current management, a 24 % increase of pollutants to the Công River is imminent in just 15 years. On the other hand, if one of the improved scenarios is implemented, 92 % (CTP-2030) or 90 % (STP-2030) of the P will be available for reuse in agriculture, reducing the need for artificial fertilizer. Further biogas is produced, which can substitute petroleum based gas for domestic purposes or be used to generate electricity.

Sammanfattning

Vietnam har åstadkommit en snabb ekonomisk utveckling under de senaste åren, till stor del på bekostnad av den naturliga miljön. Städer och industrier har vuxit fram utan hänsyn till rening av avloppsvatten. Ett tecken på detta är övergödning av lokala vattendrag.

Denna kandidatuppsats använder MFA, ett erkänt verktyg för planering av VA-system, för att kartlägga och visualisera dagens flöden av fosfor (P) och organiskt material (COD) i avlopp och matavfall i Sông Công town i Thai Nguyen provinsen, Vietnam. Syftet är även att jämföra två förbättrade scenarier med ett så kallat business-as-usual scenario.

För att hitta data till MFA-beräkningarna utfördes en litteraturstudie, intervjuer och en enkätundersökning. Litteraturstudien behandlar utmaningar i Vietnams VA-sektor och reningstekniker för avlopp och anaerob behandling.

VA-sektorn i Vietnam står inför en rad utmaningar för att nå långsiktig hållbarhet, däribland kapacitetsbrist och organisatoriska problem som beror på närliggande och överlappande ansvarsområden. Motsägelsefull och ofullständig lagstiftning, dåligt upprätthållna lagar och finansiering är andra problem som måste åtgärdas.

Även om antalet reningsverk i Vietnam ökar så renas endast 10 % av avloppsvattnet idag. Olika reningstekniker provas runt om i landet, däribland våtmarker och aktivslambehandlingstekniker, som Sequencing Batch Reactors och Anaerobic/Anoxic/Oxic processer. Dessa och ett flertal andra tekniker förklaras och jämförs i litteraturstudiekapitlet.

Baserat på de data som samlades in skapades tre framtida scenarier och ett scenario för nuläget. Business-as-usual scenariot (BAU-2030) visar hur flödena kommer se ut år 2030 om ingenting förändras från dagens läge. I det centraliserade scenariot (CTP-2030) inrättas ett centraliserat reningsverk med traditionell kemisk/biologisk rening och samtliga avloppsflöden omdirigeras dit. Det decentraliserade scenariot (STP-2030) använder två reningsverk. Ett med förbättrad fosforavskiljning (EBPR) som efterföljs av en våtmark och ett reningsverk med EBPR där desinfektion används som slutbehandling istället för våtmark. Båda de förbättrade framtidsscenarierna använder matavfall och avloppsslam för att producera biogas.

Resultaten visar att om inga åtgärder genomförs kommer COD- och fosforflödena till floden Công öka med 24 % under de närmaste 15 åren. Om något av de förbättrade scenarierna införs kan 92 % (CTP-2030) eller 90 % (STP-2030) återföras till jordbruk och därmed antas ersätta konstgödsel. Eftersom de förbättrade scenarierna även innefattar biogasproduktion kan petroleumbaserad gasol ersättas i hushållen eller användas för att generera elektricitet.

Preface

Our bachelor thesis in environmental engineering at the University of Gävle has been funded by the Swedish International Development Cooperation Agency's (SIDA) scholarship for Minor Field Studies (MFS). The thesis is part of a partnership project between the municipality of Linköping, Sweden, and the Thai Nguyen province, Vietnam. The overall aim of the partnership is to achieve a democratic and transparent planning process, involving stakeholders at different levels in the field of wastewater and organic waste management. This includes giving stakeholders new methods and tools for a participatory planning process. During a visit to Thai Nguyen in 2014 by the Linköping project group, Sông Công town was established as one pilot research area.

We came in contact with the project through Ass. Prof. Hans-Bertil Wittgren and would like to thank him for giving us the opportunity to perform our research in Vietnam. We would also like to thank Mr. Sören Nilsson Påledal from Tekniska Verken AB, Linköping, who accompanied us to Thai Nguyen to introduce us to relevant contacts at Thai Nguyen University of Agriculture and Forestry (TUAF) and the Provincial People's Committee of Thai Nguyen.

This research could not have been performed without the help of teachers, staff and students at TUAF. Most of all thanks to Ms. Phạm Mỹ Anh who has been our companion during our visits to Sông Công town and helped us to conduct the survey. We would also like to thank Ms. Hà Hồng and Mr. Cuong Duong Manh for assisting us in Sông Công. Last but not least, thanks to Ms. Duong at the International Training Center of TUAF and Ms. Minh Thuy Vu at the Department of International Relations at the Provincial People's Committee for translating documents and initiating contact with the authorities in Sông Công town.

A majority of the thesis is a synthesis of our combined work, although some parts have been divided to fulfill the requirements of the different degrees. To achieve an engineering degree Ms. Zanna has been responsible for the MFA calculations and the excel model while Mr. Olli, achieving a bachelor's degree, has performed the modeling in STAN.

List of Abbreviations

A/O	Anaerobic/Oxic
A^2O	Anaerobic/Anoxic/Oxic
AS	Activated sludge
BAU	Business as usual
COD	Chemical oxygen demand
CTP	Centralized treatment plant
CW	Constructed wetland
STP	Semi-centralized treatment plant
EBPR	Enhanced biological phosphorus removal
ECPS	Environmental Cooperation and Public Work of Sông Công (Author's abbreviation)
FDI	Foreign direct investment
FTW	Floating treatment wetland
FWS	Free water subsurface
HLR	Hydraulic loading rate
HRT	Hydraulic retention time
HSSF	Horizontal subsurface flow
MFA	Material flow analysis
N	Nitrogen
NGO	Non-governmental organization
P	Phosphorus
PAO	Phosphorus accumulating organisms
SBR	Sequencing batch reactor
SSF	Subsurface flow
TEUC	Thai Nguyen Environment and Urban Works Joint Stock Company (author's abbreviation)
UCT	University of Cape Town
VFA	Volatile fatty acids
VSSF	Vertical subsurface flow
WWTP	Wastewater treatment plant

Table of Contents

1. Introduction

Worldwide problems including climate change, eutrophicated water sources and increasing amounts of waste are all direct long-term effects of man's pursuit of increased prosperity. Today many developing countries, The Socialist Republic of Vietnam being one of them, face a decision. A choice between a path leading to long term growth in a sustainable fashion, or a path focusing on rapid economic growth at the expense of a deteriorating natural environment.

Vietnam is in many ways an example of how fast a country can develop economically. After a history of war and poverty, Vietnam can boast of having left the designation of a low-income country in only a few decades. As of 2009 the World Bank recognized Vietnam as a lower-middle economy (World Bank, 2014). Much of this development can be attributed to the economic reform of 1986 called Đổi Mới. The term literally translates into renovation and the process brought the country from a centrally planned agricultural economy towards a more industrialized market economy (World Bank, 2014).

One negative effect of the past decades' focus on economic growth is visible in the polluted water sources. Vietnam faces severe problems with eutrophication because of poor or non-existent wastewater treatment from both households and industries. As late as in 2004, "none of Vietnam's cities collected or treated municipal wastewater" (World Bank, 2011, p. 223). In 2009 six cities had wastewater treatment plants and by 2013 the number had increased to eight (WEPA, 2013). Despite these figures only 10 % of the wastewater is actually being treated (World Bank, 2013). The pollution degrades water reserves available for human consumption, agriculture and aquaculture, amplifying the shortage of freshwater in and around the region (Dan et al., 2011; WEPA, n.d.). Thus, in order to continue the journey towards becoming a high-income country, Vietnam must ensure functioning and sustainable wastewater treatment systems, which can only be completed through proper planning.

A recognized method for decision-making in wastewater treatment planning is material flow analysis (MFA) (Montangero & Belevi, 2007; Montangero et al., 2007; Montangero & Belevi, 2008; Nga et al., 2011; Zimmermann, 2014). This thesis uses the method to define the current flows of two important pollutants, phosphorous and organic matter, in domestic wastewater in the Vietnamese town Sông Công. The town is located about 70 km north of Vietnam's capital city Hanoi (Figure 1), in the flatlands of northern Vietnam, and was inhabited by 52 056 persons at the beginning of 2015. The purpose of the thesis is to compare different systems for wastewater treatment and their effect on substance flows, as a basis for implementation of a sustainable wastewater management in Sông Công.

Figure 1. Map of Vietnam with Hanoi plotted out as a star and Thai Nguyen province marked by the highlighted area in the north (Wikipedia, 2011, edited by authors)

1.1 Aim and Objectives

The aim of this study is to identify and compare different treatment systems for wastewater, with potential to be implemented in Sông Công town in the Thai Nguyen province of Vietnam. The comparison will be based on how efficiently the different technical solutions separate phosphorus (P) and organic matter, measured as chemical oxygen demand (COD), from the wastewater.

The following objectives will be met:

- Define the current domestic wastewater system in Sông Công town.
- Define the flows of domestic food waste to show the possibilities for future biogas production.
- Create a flowchart of the current P and COD flows in wastewater and food waste using MFA.
- Identify different solutions for wastewater treatment, focusing on their effectiveness in reducing P and COD.
- Conduct and present a MFA of P and COD flows of future scenarios and compare the results with a business-as-usual (BAU) scenario.

1.2 Scope

This thesis focuses on analyzing the flows of P and COD in wastewater and food waste from the households of the six urban wards of Sông Công town. Only a basic comparison based on other aspects, including economic, energy and climate, is conducted.

1.3 Target Group

The target group is Vietnamese stakeholders, university students and staff, and Vietnamese government officials on different levels. The reader is assumed to have basic knowledge of wastewater treatment processes.

1.4 Disposition

This thesis contains the following chapters:

- Chapter 2, Method, describes the used research methods. They include literature reviews, interviews, a survey questionnaire, MFA and STAN modeling.
- Chapter 3, Background of the Wastewater Treatment Sector, presents background for the MFA, including challenges in the Vietnamese wastewater sector and a literature review comparing wastewater treatment solutions. The chapter also gives a brief description of biogas production for treatment of sludge and food waste.
- Chapter 4, Survey Results and Scenario Development, gives information on the current wastewater and food waste management as found out through the survey results. Based on this information the future scenarios were created.
- Chapter 5, Material Flow Analysis of Sông Công, presents the results with flowcharts for each of the substances (P and COD) and scenarios. A comparison is made at the end of the chapter with bar charts as well as numerical figures.
- Chapter 6, Analysis of the MFA Results, discusses the results and the factors affecting the results.
- Chapter 7, Conclusions and Future Studies, concludes the research results and gives suggestions for further studies on the subject.

2. Method

In this thesis Material Flow Analysis (MFA) was used to calculate the flows of P and COD in Sông Công's domestic wastewater. The main steps of a MFA according to both Montangero (2007) and Brunner & Rechberger (2003) are to define the system in space and time, define the processes, quantify the flows of material, make a scheme of the flows and interpret the result. These steps were followed to conduct the MFA of the wastewater system in Sông Công.

After defining the system boundaries and the time frame for the current and future scenarios, the system processes were specified. Interviews were conducted with local authorities in Sông Công, however most of the requested data could not be retrieved due to lacking monitoring of the town's wastewater system. Consequently a decision was made to conduct a survey questionnaire in Sông Công to chart the on-site wastewater treatment solutions. The results from the survey could be combined with literature reviews and other field studies, including interviews and observations, as well as assumptions, to quantify the material flows. Subsequently the model was adapted based on the collected data and flowcharts of the P and COD flows were created. The research strategies used are explained more in detail below.

2.1 Literature Review

A literature review was conducted in order to reach a sufficient proficiency of the Vietnamese wastewater treatment in general and of, for Vietnam, relevant wastewater treatment techniques. The main sources for the literature review were scientific papers. Articles on research based in Vietnam and other Southeast Asian countries were prioritized to assure relevance to the thesis's geographical boundary. Cited and peer reviewed articles were preferred, and current release dates were given priority. Relevant sources were also found through tracking the references of reviewed literature. Further, reports from governments or non-governmental organizations (NGO), such as the United Nations (UN) and the World Bank were used, since many governments have studied Vietnam and its progress as a part of analyzing the need for foreign direct investment (FDI). In cases when sufficient data could not be found through journal articles or books, internet sources were applied.

The literature review was both quantitative and qualitative. The qualitative aspects included understanding the current Vietnamese sanitation management and different aspects of treatment techniques, such as advantages and limitations. The quantitative facets consisted of data on treatment efficiency of P and COD in WWTP and on statistics as a complement to the field studies. Relevant literature included statistical governmental websites, scientific articles and previous similar studies, in particular a MFA study based in Hanoi by Zimmermann (2014) from which all of the import data on food, detergent and water for quantification of the P flows into the households were gathered (Appendix A).

2.2 Interviews

After performing a preliminary literature review, interviews were conducted to gather information about the defined system, its processes and flows of for example wastewater, sludge, food waste and excreta. A list of necessary data was compiled (Appendix B) based on data needs from the Linköping/Thai Nguyen project, mentioned in the Preface. The type of data that was requested was i.a. ratio of inhabitants connected to septic tanks, ratio of inhabitants with WC or dry toilet, and volumes of collected sludge. The list was translated into Vietnamese by an officer at the Foreign Affair Department in Thai Nguyen, and subsequently presented to the local authorities in Sông Công. During the meeting, students and a professor at TUAF accompanied as translators. At a second visit to the office a limited amount of data, including maps of the town and some statistics, was gathered.

In a later stage public and private companies were interviewed to get information on the collected volumes of food waste and septage (for composed questions, see Appendix C). Two visits were made to the public Thai Nguyen Environment and Urban Works Joint Stock Company (TEUC). The private company, Environmental Cooperation and Public Work of Sông Công (ECPS), was contacted through phone by a student at TUAF. A site-visit was also made to Bách Quang wastewater treatment plant to observe the treatment process.

2.3 Survey Questionnaire

Because most of the required data, particularly regarding on-site sanitation solutions and the drainage network in Sông Công, was not available, a decision was made to conduct a paper-based questionnaire. The decision was made based on several scientific papers, by Montangero (2007), Montangero et al. (2007), Nga et al. (2011) and Binder et al. (1997), who confirm that the method can be used with good results when combining literature data, field data and survey results if the data availability is low.

The questionnaire was aimed at complementing the data gathered from the interviews with the local authorities. The main focus of the questionnaire was on the prevalence and management of on-site sanitary solutions and on how the residents discharge food waste as well as septage. Before the actual questionnaire was conducted a trial was performed on ten households, after which the questions were revised together with a professor at TUAF, who resides in Sông Công. The inquiry sheet can be found in Appendix D.

2.3.1 Sampling Method

The sampling technique used for the survey was cluster sampling. According to Biggam (2011) cluster sampling involves dividing a target population into clusters or groups, from which a random sample can be collected. Cluster sampling is a time-saving method used when it is not conceivable to cover the entire population, as was the case for this thesis. Additionally, it is beneficial when clear clusters can be identified. In Sông Công the urban wards - as shown in Figure 4, Chapter 4 - were chosen as clusters.

The confidence level was set to 95 % and the number of households that had to be interviewed was based on the assumption that three people share one household. The total number of people interviewed in each cluster was decided based on the share of people living in each ward, to provide a result which could be representative for the whole urban population's sanitation system. The interviews were conducted by Vietnamese students from TUAF.

2.3.2 Compilation of the Survey Results

The survey results were compiled in Microsoft Excel. The different response options were filled in on the lines of column A. The columns B-K were divided after the number of people residing in one household, from two to ten. Subsequently the number one was added to the corresponding column each time a respondent chose the alternative. Thereafter the answer frequency for each question was multiplied with the number of people in the household, which could be identified through the column. This way a sum of the total number of people provided with the same sanitary solution was calculated.

After receiving the data per capita the figures could be applied to the Excel MFA model. As all the data was compiled a mean confidence interval (or margin of error) could be calculated for the survey, based on the confidence interval per question.

2.4 Scenario Development

The future scenarios were decided upon the information collected from local authorities about the future plans for Sông Công. This information was combined with the survey results, which showed the current technical solutions used in Sông Công, and a literature review.

Three different scenarios were created. One business-as-usual (BAU-2030), which shows the P and COD flows if no changes are implemented, and two improved scenarios. The improved scenarios include one centralized alternative and one semi-centralized option. The time frame for the three scenarios was set to 2030 to be able to illustrate the effects of the scenarios compared to the current situation.

2.5 MFA

The data from the literature review, survey and field study make out the foundation of the MFA of P and COD flows in Sông Công. The processes and sub-processes used in this thesis are constructed in a similar way as Zimmermann's (2014), who in turn used the structure created by Montangero (2007).

2.5.1 MFA Terminology

To understand the construction and quantifications of the MFA model it is important to recognize the terminology. This report uses the definitions from the Practical Handbook of Material Flow Analysis by Brunner & Rechberger (2003), which are declared in Table 1.

Table 1 Terminology used in MFA (Brunner & Rechberger, 2003)

TERM	DEFINITION
MATERIAL	Generic term for substances and/or goods flowing through the system.
SUBSTANCE	A chemical element (atom) or compound (molecule).
GOOD	A material with a positive or a negative market value, for example food and wastewater.
PROCESS	The transformation, transport or storage of material. A process can be natural or man-made.
STOCK	The storage of material in a process. It is illustrated as a little box within the process box.
FLOW	An inflow (input) is entering a process and an outflow (output) is exiting a process. Import and export are the flows in and out from the system. The flow is defined as "mass per time" and can for example be measured in g $year^{-1}$.
FLUX	The flux is defined as "mass per time and cross section" and can be measured in kg sec^{-1} m^{-2} or g cap^{-1} $year^{-1}$.
TRANSFER COEFFICIENT	The division of a substance in a process. The percentage of a process's input that is directed to each output.
PARAMETER	The data used for describing the process, i.e. flows, concentration, area and mass.
SYSTEM BOUNDARY	The geographic or organizational border of the defined system.

2.5.2 Mass Flow and Stock Change Quantification

The mass flows and stock change rates were calculated in the Microsoft Excel model. To recognize the different parameters in the model the following notations, based on Zimmerman, were used:

y_name and y_X_name

where; y indicates the parameter class
$name$ describes the type of parameter in short
X indicates which substance the parameter is specific to, either COD or P

By multiplying the parameters the mass flow between processes were calculated. For example:

$$y\_name * y\_X\_name$$

The flow from one process to the other is recognized by the characters:

$$Xi - ii$$

indicating that the substance flows from process i to process ii.

The calculation of the stock change rate of a substance in a process is explained by the following equation:

$$\frac{dM(Xi)}{dt} = \sum_{inputs} - \sum_{outputs}$$

where; i is the process
X is the substance

The following is an example to understand the principle of the MFA calculations. The first step is the import of material to the household. The import of goods consists of food, water and detergent as seen in Appendix A. For each good the total import of P is calculated in g cap^{-1} $year^{-1}$. For example, one person's yearly mass consumption of P through rice (m_P_rice) is calculated by multiplying the mass of rice consumed annually by one person (m_rice) by the P content in rice (c_P_rice)

$$\frac{kg_{rice}}{cap * year} * \frac{g_P}{kg_{rice}} = \frac{g_P}{cap * year}$$

In the next step all of the imported P flows are summed up to receive the total import.

The outflows from the household are divided into blackwater, greywater, excreta and food waste. The stock change rate is hence calculated by subtracting the total P outflow by the total P import. All of the stock change rates and P flows are connected and calculated in a similar way as explained above.

For COD the stock change rate was not calculated since much of the substance is digested to energy and CO_2 in the treatment processes. Interesting in the context is solely the content of COD in the waste flows (Ass. Prof. at Linköping University, personal communication, 13 May, 2015).

2.5.3 MFA in STAN

The results from the MFA calculations are visualized using STAN, with which the flows of P and COD are presented as arrows that connect the processes. The arrows are proportional to the amount of the substance that flows from one process to the other, which makes it easy to compare the size of the flows.

The results from the export of P and COD are presented in diagrams for each scenario and a table showing the total export to each end-destination, for example the river or agricultural land.

3. Background of the Wastewater Treatment Sector

The background intends to provide an overview of significant deficiencies that affect the Vietnamese wastewater sector, to better understand existing challenges in the planning and implementation process. The chapter also reviews various wastewater treatment techniques, with potential to be implemented in the urban wards of Sông Công town. Note that *the urban wards of Sông Công town* will be referred to as *Sông Công* in the following text.

3.1 Challenges in the Vietnamese Wastewater Sector

It can be challenging to decide which wastewater treatment system to implement in a specific area. Whereas decentralized solutions are used with a higher frequency in developing countries, centralized solutions are more common in developed countries (Libralato et al., 2011). This does not imply that all developing countries should introduce centralized systems, it is important to analyze the social, economic and environmental aspects of the local area. Decentralised systems have advantages such as cheaper operating and construction costs and a shorter drainage network (Maurer et al., 2006). Libralato et al. mention easier recycling of water and nutrients and the reduced risk of the water being contaminated by industrial wastewater as additional benefits.

Today the on-site solution, septic tank, is the most common method for treating wastewater in Vietnam. Although up to 80 % of the Vietnamese urban households are connected to septic tanks (Nguyen el al. 2013), only 10 % of the wastewater and 4 % of the septage is treated (World Bank, 2013). These issues are affected by technical difficulties as well as several other factors, such as organizational, cultural, educational and financial.

The technical challenges include lacking capacity. A majority of the sewerage systems are combined rather than separated. However, most combined systems are only designed to discharge rainwater, which causes issues with overflowing systems (World Bank, 2013). Many of the septic tanks are also undersized and emptied too rarely **(**Schramm, 2011). The technical challenges are further aggravated in many low-income areas which are too densely populated for desludging trucks to access, instead manual desludging is performed. Consequently the septage from these areas tends to be dumped in close vicinity to peoples' living quarters, in drains, canals or dikes (AECOM & Sandec, 2010).

Organizational challenges arise because of confusions about responsibilities and division of labor, as a result of adjacent and overlapping authorities between several agencies on different levels (Karius, 2011; Zimmermann, 2014). Misunderstandings also arise in the legal system, in which gaps and contradictions exist between laws and regulations at various levels (Nguyen, 2013). These issues contribute to poor infrastructure planning, lack of law enforcement and inefficiency in approaching social and environmental issues. Bassan et al. (2014) highlights the absence of national standards regulating a safe sludge management as an issue that needs to be addressed. In addition it is essential to raise the public awareness of environmental issues, making sure the residents understand the importance of a well-managed wastewater system and by following regulations.

The financing is another challenge that needs to be addressed if Vietnam is to achieve a self-sustaining wastewater treatment infrastructure. Today public services are often provided by utility companies that deal in a wide array of businesses, such as water supply, waste collection, construction and property development. Reportedly the tariffs for water supply and wastewater treatment are rarely sufficient for operation and maintenance (AECOM & Sandec, 2010; Schramm, 2011, World Bank, 2014), much less for improvements. This lack of capital forces the companies to subsidize parts of their operations that cannot carry their own costs with income from more profitable ones. Some companies have started to privatize, but in order for it to be a sustainable business for any investor the tariffs have to be increased. A problem with raising the tariffs is the unfamiliarity of paying for public services, which is a remnant of the past times planned economy (AECOM & Sandec, 2010; Zimmerman, 2014).

3.2 Wastewater Treatment Solutions in Vietnam

The Vietnamese authorities' desire to improve the overall wastewater situation has during the past years led to an increasing number of wastewater treatment plants. Various techniques are tried out in different areas of the country. Both constructed wetlands (CW) and activated sludge (AS) techniques, such as Sequencing Batch Reactors (SBR) and Anaerobic/Anoxic/Oxic (A^2O) exist (WEPA, 2013; Bassan et al., 2014). Since these techniques already occur in Vietnam, the thesis will give a basic overview of their function. A comparison will be made, mainly focusing on the efficiency in separating P and COD from the wastewater, in order to suggest how the wastewater treatment system in Sông Công could be planned.

3.2.1 Conventional Wastewater Treatment Plants

A widespread method in industrialized countries for reducing P from municipal wastewater is through conventional mechanical/biological/chemical treatment methods. During the chemical treatment process a metal salt, usually iron or aluminum, is added to precipitate and coagulate dissolved COD and P, whereon the flocs are separated from the water through sedimentation. Removed from the process is a chemical sludge (Carlsson & Hallin, 2003). Carlsson & Hallin states that depending on the type of substance used for precipitation and in which stage the chemical is added – either before, after or both before and after the biological treatment – the removal efficiency varies. Figures of the P and COD removal in conventional WWTP and plants using activated biological sludge techniques are presented in Table 2 and Table 3 below.

3.2.2 Activated Sludge Techniques

The suspended growth process, activated sludge (AS), is the dominating technique for secondary biological treatment of municipal wastewater (Mittal, 2011). In the process the water flows into an aerated tank where aerobic microorganisms digest nutrients and organic matter. Thereafter the biological flocs sediment while an effluent of treated water flows out from the process. Activated sludge is subsequently recycled to the aeration tank to keep the process alive. Waste sludge is removed from the process.

AS processes are typically chosen when an efficient removal of organic matter and particles is desired. The removal of P is less effective, it is mainly removed in the mechanical treatment step or through uptake by microorganisms (Carlsson & Hallin, 2003). Moreover, biological P treatment in an AS plant is a sensitive process (South, 2014; Oneke, 2006). Tilley et al. (2014) emphasize the importance of an accurate design based on the volume and properties of the wastewater to ensure full treatment capacity.

3.2.2.1 Enhanced Biological Phosphorus Removal

For a more efficient removal of P, Enhanced Biological Phosphorus Removal (EBPR) methods have been developed from the AS technique. The EBPR processes most frequently mentioned in literature are Anaerobic/Oxic (A/O), which focuses on P removal only, and the Anaerobic/Anoxic/Oxic (A^2O) and University of Cape Town (UCT) processes, which efficiently remove both P and N (Figure 2). The principle for the techniques is the same, letting activated sludge circulate through anaerobic and aerobic steps. To drive the process the bacteria Phosphorus Accumulating Organisms (PAO) are mixed with the conventional microorganisms. The PAO are specialized in storing and metabolizing P whereas the conventional bacteria can “convert easily biodegradable material” into volatile fatty acids (VFA) (Haandel & Lubbe, 2007, p. 220).

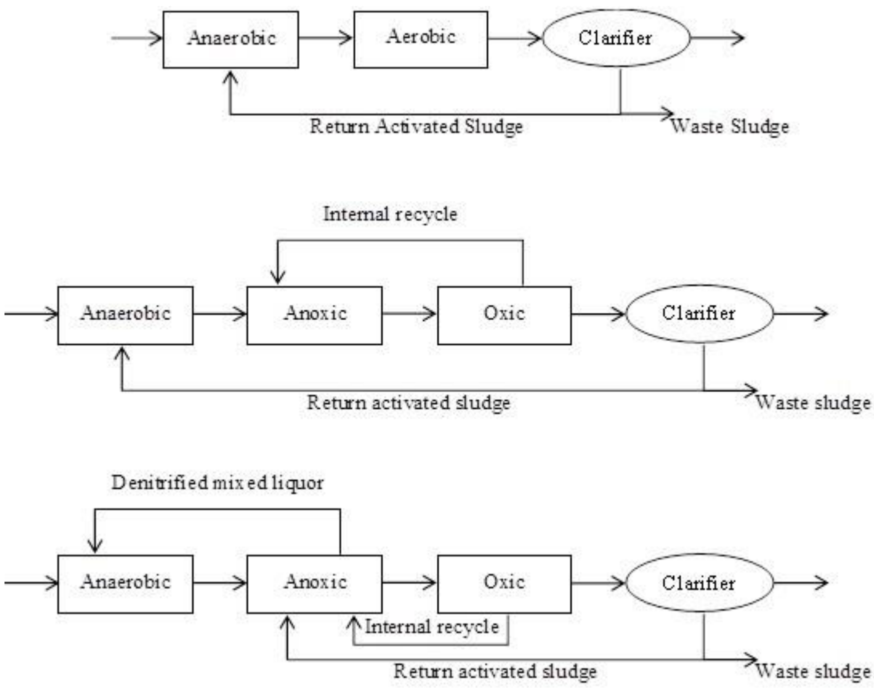


Figure 2. The steps of the different EBPR treatment processes, showing Anaerobic/Oxic (A/O) at the top, Anaerobic/Anoxic/Oxic (A2O) in the middle and University of Cape Town (UCT) at the bottom

A significant difference between the A^2O and UCT is to which stage the activated sludge is recycled. Both processes are constructed with anaerobic-anoxic-oxic processes in a series of steps. The A^2O recycle the sludge from the oxic zone to the anaerobic stage, while the activated sludge in the UCT is recycled to the anoxic zone, as illustrated in Figure 2. Subsequently mixed liquor is returned from the anoxic zone to the anaerobic zone. Because the nitrate level in UCT is kept low in the anoxic zone, this reduces the nitrogen content in the anaerobic zone, which in turn enhances the P removal efficiency. Gu et al. (2007) conclude that the UCT perform better in both P and N removal efficiency.

The P removal efficiency from the EBPR processes is however difficult to generalize since the processes are sensitive and can be disturbed by many different factors, such as low pH or, as indicated above, high nitrate content in the anaerobic zone. Additionally it is important that the amount of Volatile Fatty Acids (VFA) in the process is abundant. Särner et al. (2004) and Yu et al. (2008) explain that one technique by which VFA can be increased is through hydrolysis of primary or excess sludge.

3.2.2.2 Sequencing Batch Reactor

As mentioned, another common wastewater treatment technique in Vietnam is the SBR. It is a simple AS method where, instead of letting the water flow continuously from one step to the other, all the treatment steps occur in the same tank. The SBR operation can be varied with aerobic, anaerobic and anoxic stages depending on the wanted removal efficiency (Kapdan & Ozturk, 2005). An advantage of SBR compared to other AS methods is the relatively low capital cost and space requirement.

3.2.3 Compilation of P and COD Removal Efficiency in WWTP

Table 2 and Table 3 conclude the described WWTP's P and COD removal efficiency according to various sources. The conventional WWTP with chemical/biological treatment performs best in both P and COD removal, on an average above 90 %. The COD removal for the AS techniques is relatively high, between 76 % and 90 %. The P removal for the conventional AS is however low and ranges between 25 % and 45 %. The wide range can be explained by the sensitiveness in the P removal process, which as mentioned is affected by several factors, indicating that the local conditions are important. The figures of the EBPR include both the A^2O and the UCT processes, which are both relatively effective. The high P removal in the SBR shows the best case scenario, combining the anaerobic/anoxic/oxic processes in the reactor. An SBR with only aeration would not be as effective.

Table 2. Removal rates of P in WWTP based on different literature sources, ranging from 25 % to 95 %

Source	Conventional WWTP (%)	Conventional activated sludge (%)	Enhanced biological phosphate removal (%)	Sequencing batch reactor (%)
SMED (2012)	95	-	-	-
Naturvårdsverket (2003)	90	-	-	-
Carlsson & Hallin (2003)	-	30	-	-
Kivaisi (2001)	-	30-45	-	-
von Sperling (2007)	-	25-30	-	-
Wang et al. (2009b)	-	-	-	<90
Pambrun et al. (2004)	-	-	-	<90
Wang et al. (2013)	-	-	80	-
Zhang et al. (2010)	-	-	80	-
Wang et al. (2009a)	-	-	-	71
Rodriguez-Garcia (2011)	82-96	39	87	-

Table 3. Removal rates of COD in WWTP based on different literature sources, ranging from 76 % to 97%

Source	Conventional WWTP (%)	Conventional activated sludge (%)	Enhanced biological phosphate removal (%)	Sequencing batch reactor (%)
Wang et al. (2009a)	-	-	-	80
Kulikowska et al. (2006)	-	-	-	76-83
Silva et al. (2014)	-	80-85	85-90	-
Rodriguez-Garcia (2011)	93-97	83	92	-

3.2.4 Constructed Treatment Wetlands

Constructed wetlands (CW) can be found around the world, in many different climates and with a variety of plant species. Most studies and performance data of water treatment in CW are from Europe and other temperate climates according to Trang et al. (2010) and Zhang et al. (2014). In temperate climates the microbial activity is lower than it is expected to be in tropical areas. Thus the treatment performance is also expected to be higher in warmer climates. In tropical countries like Vietnam, the removal rates for COD and P in wetlands can reach levels which are acceptable for wastewater treatment, as opposed to colder climates (Trang et al., 2010; Dan et al., 2011).

How well nutrients, pollutants and pathogens are removed from wastewater depend on many parameters: climate, hydraulic retention time (HRT), hydraulic load rate (HLR) and which plants that are used (Zhang et al., 2014; Nguyen et al., 2010; Kivaisi, 2001; Vymazal, 2007; Jóźwiakowski, 2009). Hydrologic conditions like HRT and HLR have been highlighted by Zhang et al. (2014), Dan et al. (2011) and Trang et al. (2010) as probably the most important.

HRT is a measurement of how long the contaminants in the water are in contact with the active surface (plant rhizosphere and substrate) while the HLR is expressed in a ratio of flow into the wetland in m^3 day^{-1}. The rhizosphere is the area closest to the vegetation’s roots containing high concentrations of microorganisms, thus being important for the purification of water in wetlands (McNear, 2013).

On a general level wetlands can be divided into Free Water Surface (FWS) wetlands, Floating Treatment Wetlands (FTW) and Subsurface Flow (SSF). Subsurface flows can further be divided according to the direction of water flow, horizontal (HSSF) or vertical (VSSF). The different types have varying advantages, therefore it is often beneficial to combine them into hybrids or multiple stage wetlands in order to achieve an increased efficiency.

3.2.4.1 Free Water Surface (FWS) Wetlands

FWS wetlands resemble natural marshes with a depth of around 0.4 m. The floor of the basin is covered with a substrate (rock, gravel or sand) from which the plants grow. The plants grow up through the water surface although not covering the surface as in a FTW. FWS often consist of some kind of reeds. The FWS design gives aerobic properties along the water surface while being anaerobic in the substrate and among the plant roots.

3.2.4.2 Floating Treatment Wetlands (FTW)

FTWs similarly to FWS wetlands are open water sources with vegetation. The difference is found in the bottom of the basin as the FTW do not have a substrate supporting the plant. Instead the plants grow from a floating mat of substrate on the water surface and have roots hanging free towards the bottom. This makes FTWs particularly suited for uneven water levels, such as treatment of stormwater drainage.

3.2.4.3 Subsurface Flows (SSF)

SSFs are the wetland design for which most data has been found. As mentioned SSF can be divided into horizontal and vertical flows. The basic design consists of a permeable substrate layer up to 0.6 m in thickness in which the plants grow. The water filters through the substrate either horizontally or vertically depending on the design. This gives large contact areas between the water, substrate and plant rhizospheres. SSF wetlands create aerobic areas around the plant roots as they transport oxygen from above the water surface while anaerobic and anoxic areas occur further away from the roots.

3.2.4.4 Hybrids

As mentioned the reduction of pollutants varies greatly depending on the designs, plants, HRT, HLR and which pollutant is examined. Hybrid systems combine the above described designs in multiple stages to get the best out of each design. This allows for multiple plants species to be used, hopefully giving a higher removal of pollutants.

3.2.5 Compilation of P and COD Removal Efficiency in Constructed Treatment Wetlands

Table 4 and Table 5 show the removal efficiency of P and COD for the different CW designs. The presented figures are mean values from the respective literature, like Zhang et al. (2014) who reviewed up to 16 studies to conclude the mean removal rates of P and COD. Further the figures vary as a result of differences in the wetlands configurations within the different designs, for example differences in HRT and choice of plant species affect the results of both P and COD.

Table 4. Removal rates of P in wetlands based on different literature sources, ranging from 41% to 84%

Source	Vertical subsurface flow (%)	Horizontal subsurface flow (%)	Free water surface (%)	Floating treatment wetland (%)	Hybrid (%)
Nguyen et al. (2010)	48	-	-	-	-
Zhang et al. (2014)	60	66	49	50	55
Vymazal (2007)	60	41	49	42	-
Jóźwiakowski (2009)	51	52	-	-	84
Trang et al. (2010)	-	75	-	-	-
Dan et al. (2011)	78	58	-	-	-

Table 5. Removal rates of COD in wetlands based on different literature sources, ranging from 45% to 93%

Source	Vertical subsurface flow (%)	Horizontal subsurface flow (%)	Free water surface (%)	Floating treatment wetland (%)	Hybrid (%)
Nguyen et al. (2010)	77	-	-	-	-
Zhang et al. (2014)	64	66	45	55	86
Vymazal (2007)	-	-	-	-	-
Jóźwiakowski (2009)	82	76	-	-	93
Trang et al. (2010)	-	71	-	-	-
Dan et al. (2011)	60	48	-	-	-

3.2.6 Further Comparison of the Wastewater Treatment Techniques

Although wastewater treatment in a conventional WWTP is the most efficient method for removing P and COD from the wastewater biological treatment methods, such as the AS and CW, have their advantages:

- The cost and transport of chemicals are removed
- The environmental impact is lower
- The processes yield less sludge (Oneke, 2006) which is also lighter and of better quality

Table 6 presents a further comparison between the biological treatment techniques. However no economic comparison has been included, thus it is worth mentioning that in general the AS techniques are more expensive than the CW, both regarding capital and operating costs (Tilley et al., 2014). Also note that the table's information on the activated sludge techniques includes both conventional AS and the EBPR processes.

Table 6. Comparison between the biological wastewater treatment techniques (Tilley et al., 2014)

	Activated sludge technique (AS, EBPR)	**Hybrid constructed wetland**	**Free water surface (FWS)**	**Horizontal subsurface flow (Horizontal SSF)**	**Vertical subsurface flow (Vertical SSF)**	**Floating treatment wetland (FTW)**
P removal	25-87 %	55-84 %	49 %	41-75 %	48-78 %	42-55 %
COD removal	80-92 %	86-93 %	45 %	48-76 %	60-82 %	55 %
Pathogen removal	Low pathogen removal. Effluent and sludge require further treatment.	The effluent can be used for i.e. irrigation or discharged to recipient.	Moderate pathogen removal.	High reduction of pathogens. Domestic wastewater may require disinfection.	High reduction of pathogens. Domestic wastewater may require disinfection.	No information found on pathogen removal.
Land requirement	Little compared to natural systems.	Requires a large land area.	Requires a large land area.	Requires a large land area.	Less than FWS or Horizontal SSF.	Requires a large land area.
Energy consumption	High energy consumption.	Electricity generally only for pumps.	Electricity generally only for pumps.	Electricity generally only for pumps.	Requires constant electricity.	Electricity generally only for pumps.
Applicability	Usually implemented in densely populated areas for domestic wastewater treatment.	Appropriate for small communities.	Appropriate for small parts of urban areas or for peri-urban and rural communities.	Appropriate for small parts of urban areas, down to single households.	Appropriate for small parts of urban areas or for peri-urban and rural communities.	No information.
Implementation stage	Can be implemented after primary or secondary treatment.	Can be used after primary treatment, i.e. septic tanks.	Can be used after primary treatment. Typically used for further treatment of effluent after secondary treatment.	Generally used for secondary or tertiary treatment of greywater or blackwater.	Generally used for secondary or tertiary treatment. Pre-treatment is required to prevent clogging.	Appropriate for highly fluctuating water levels, such as storm water discharges or retention tanks.
Climate	Appropriate in most climates.	Not very tolerant to cold climates.	Not very tolerant to cold climates.	Not very tolerant to cold climates.	Not very tolerant to cold climates.	Not very tolerant to cold climates.

3.3 Sludge and Food Waste Treatment

The sludge produced from the WWTP has to be treated to prevent health and pollution risks and to reduce its volume. There are several treatment options such as stabilization, dewatering and drying to name a few. Stabilization can be divided into aerobic, i.e. composting, and anaerobic processes, i.e. biogas production. The advantage of anaerobic digestion is that both energy and nutrients from the sludge are utilized, which makes the process interesting to examine in this thesis. Both food waste and sludge can be treated through anaerobic digestion.

3.3.1 Biogas Production

The anaerobic digestion process produces energy-rich methane along with a digestate rich in nutrients that can be used in agriculture in the same way as compost. The produced methane, hereafter called biogas, can be used as fuel for domestic cooking, converted into electricity or upgraded to vehicle fuel.

The biogas production can roughly be divided into three stages where long carbon chains are transformed to short ones. First the hydrolysis uses enzymes to break down proteins and carbohydrates to sugars, amino acids and VFA. Secondly the fermentation creates alcohols, acetic acid, hydrogen and carbon dioxide etc. These are then transformed into mainly methane, carbon dioxide and water.

One important factor for biogas production is the organic matter content of the substrate inserted into the process. One way to measure this is through oxidizing a sample using chemicals in a COD test (Naturvårdsverket, 2012).

The removal of COD during anaerobic digestion varies depending on the contents of the substrate. In general a reduction of 30-50 % can be found in literature on the subject. Wood (2008) analyzed different pretreatment methods and their effect on the COD removal in waste activated sludge from a pulp mill. His findings indicate that the removal of COD ranges from about 35 % up to 53 % depending on the type of pretreatment. De la Rubia et al. (2002) has also found differences between configurations of anaerobic treatment. When digesting sludge in mesophilic conditions (35 C˚) the removal is about 53 %, and 35 % while using thermophilic conditions (55 C˚).

4. Survey Results and Scenario Development

The results from the survey questionnaire, observations and interviews conducted in Sông Công resulted in the identification of the processes involved in the urban wards wastewater and food waste flows. Based on this data, combined with Zimmermann’s (2014) and Montangero’s (2007) studies, the processes used in the MFA modeling for Sông Công were created. The chapter explains the processes and describes Sông Công’s current wastewater and food waste management. Last a presentation of possible development scenarios of the system for the year 2030 is described.

4.1 The Survey Results

The survey covers 167 households, resided by 844 persons. With the confidence level of 95 %, calculations set the average margin of error to 2.13 % for the whole survey. A table of the full results is presented in Appendix E and the quantification of the margin of error can be followed in Appendix F.

4.2 MFA Processes

The processes used in the scenario development and MFA modeling are presented in Table 7. Figure 3 displays an example of how the STAN model is composed including all of the identified processes.

Table 7. List and description of the MFA processes involved in the treatment of Sông Công’s wastewater and food waste

1. Inhabitants (Sông Công)
The process Inhabitants includes import flows of food, detergent and water, as used by Zimmermann. The partitioning of outflows from the process is primarily based on the survey results, and complemented with assumptions based on Zimmermann's calculations and statistics where required.
2. On-site sanitation
On-site sanitation is the primary collection and/or treatment process of domestic wastewater in Vietnam. In Sông Công the identified on-site solutions include septic tanks and dry toilets.
a. On-site, septic tank
A septic tank consists of a chamber in which the wastewater is collected. The solid particles in the wastewater sediment to the bottom to form a layer of sludge, where the microorganisms digest the organic matter. The septage has to be emptied at regular intervals for the treatment to be efficient (AECOM & Sandec, 2010), every second to fifth year according to Tilley et al. (2015). The effluent water can be directed to a number of places such as public drains, combined sewers or directly to local water sources.
b. On-site, dry toilet
Dry toilet (or composting toilet) is the name used for a wide range of sanitary solutions that require little or no water. A common feature is that they gather the excrements in a chamber where it is allowed to decompose, producing a final product that can be used as fertilizer (Depledge, 1997; Anand & Apul, 2014).
3. Solid waste collection
The solid waste collection process involves collecting and transporting of sludge from septic tanks and food waste.
a. Solid waste collection, food waste
The process is managed by the public company Thai Nguyen Environment and Urban Works Joint Stock Company (TEUC).

b. Solid waste collection, sludge
The process is managed by the private company Environmental Cooperation and Public Work of Sông Công (ECPS).
4. Composting
The process consists of composting of dry toilet effluent and food waste on household level.
5. Livestock
The process receives food waste and produces manure which today is used as fertilizer in agriculture.
6. Wastewater treatment plants
a. Bách Quang WWTP
Based on observations during a site visit, the plant in Bách Quang ward is assumed to treat the wastewater using the conventional AS technique combined with a hybrid CW. The treated water is released to irrigation canals.
b. Centralized WWTP
The Centralized WWTP uses mechanical/biological/chemical treatment and is implemented in the 2030 scenario.
c. EBPR, WWTP
One of the semi-centralized treatment plants implemented in the 2030 scenario, which uses EBPR combined with disinfection for higher pathogen removal.
d. EBPR+CW, WWTP
One of the semi-centralized treatment plant implemented in the 2030 scenario which combines EBPR with a hybrid CW.
7. Anaerobic sludge treatment
The private company ECPS collect the septage from septic tanks and treat it in an anaerobic process to be used as fertilizer for tea plantations. No clarity has been given on what the anaerobic treatment process involves, or if biogas might be produced.
8. Biogas plant
Biogas production is part of the 2030 scenarios where food waste, manure and sludge are utilized for biogas production.
9. Landfill
The process consists of transportation of sludge and food waste to Da Mai landfill in Tan Cuong Village.
10. Pond
The process is an export destination for greywater. Ponds are common in rural areas where they are used for breeding fish.
11. River
The Công river is an export destination for effluent, sludge, greywater and blackwater.
12. Soil
Soil is an export destination for compost leachate and greywater.
13. Agriculture
Agriculture is an export destination for digestate, manure and compost. Observed crops in the Thai Nguyen province are for instance rice, corn and tea.

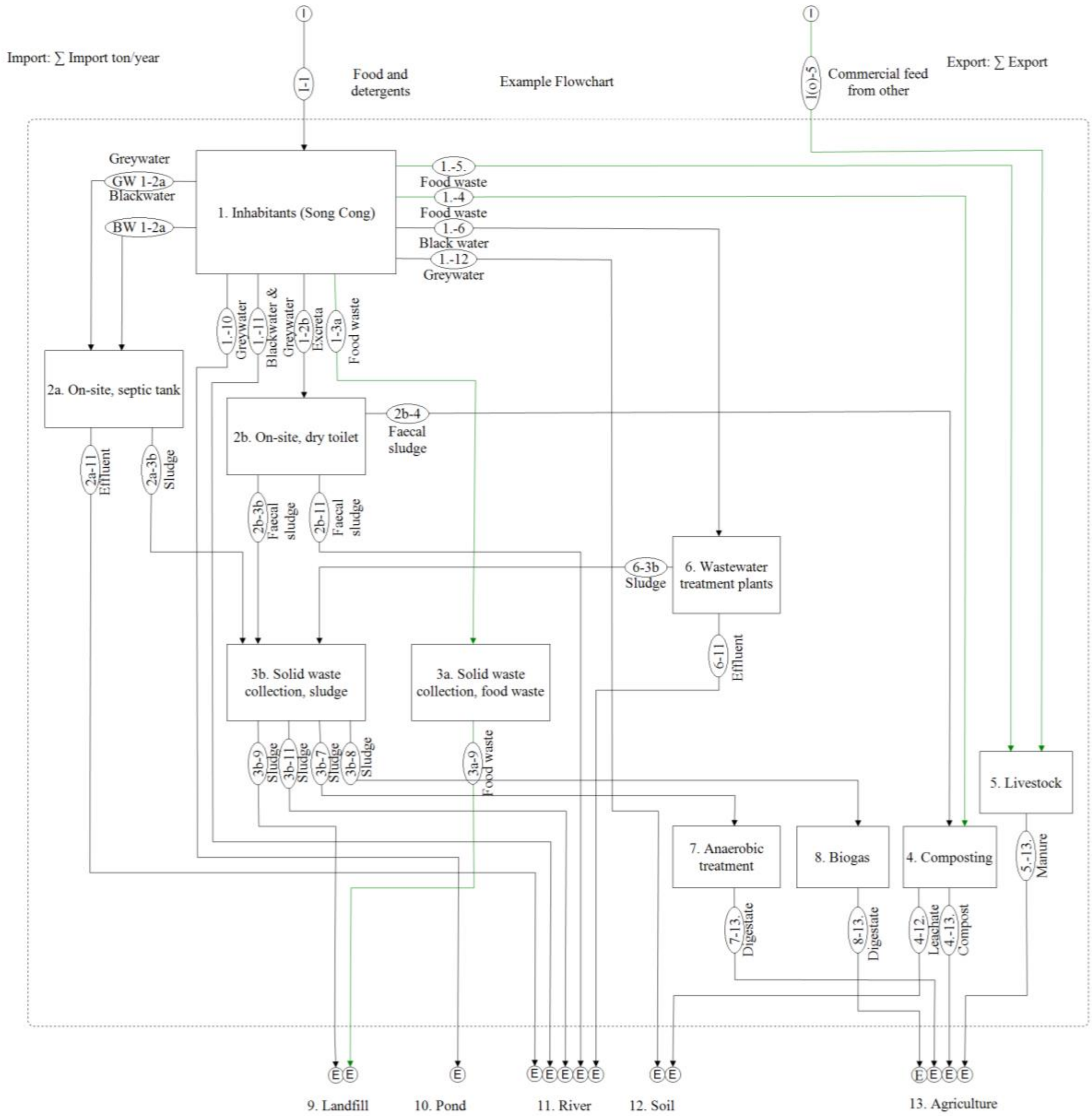


Figure 3. STAN flowchart showing the processes involved in the treatment of Sông Công's wastewater and food waste. Note that process 6. Wastewater treatment plants, has been aggregated into one process in the example figure

4.3 Background Data on Sông Công Town

Sông Công town consists of 10 wards out of which six are urban and four are rural. As stated earlier this thesis focuses on the six urban wards, which are presented in Figure 4. The total area of the urban wards is 26,76 km^2 and the population is 33 404 people. Based on data from the Sông Công Statistical Office (2015) the population growth is 1.045 % per year meaning that the town is quickly moving towards city-status according to Vietnamese criteria (Vietnamese Officials, personal communication, December 12, 2014).

Figure 4. The six urban wards of Sông Công town, with the Công River running in the east

Today the wards are a mix of urban and rural, with agriculture such as paddy fields in close proximity of the households. In the future this scenery will most likely have changed to a more structured urban environment where urban and rural areas are separated from each other.

4.4 Current Wastewater Management in Sông Công

Like most towns in Vietnam, Sông Công lacks proper wastewater treatment. Only a part of Bách Quang ward is connected to a wastewater treatment plant that receives sewage from approximately 100 households. The construction was finished in 2013 and is a pilot project which, if successful, has the capacity to treat wastewater from more households (Staff at Bách Quang treatment plant, personal communication, 5 May, 2015). Until then the domestic wastewater from the remaining households in Bách Quang and the other five wards is released untreated to the Công River. The water is transported through combined sewers or canals similar to the one seen in Figure 5. No detailed map of the town's sewer network exists according to local authorities (Sông Công Officials, personal communication, 20 April, 2015).

Figure 5. Irrigation canal in Sông Công (Author's own picture)

4.5 Future Wastewater Management in Sông Công

Since parts of the urban Sông Công are already developed, it limits the locations available for a new wastewater treatment plant. The local authorities have started to plan for the town's wastewater treatment and identified three main locations as suitable for the construction of wastewater treatment plants or wetlands. In this report these have been given the numbers 1, 2 and 3, as seen in Figure 6.

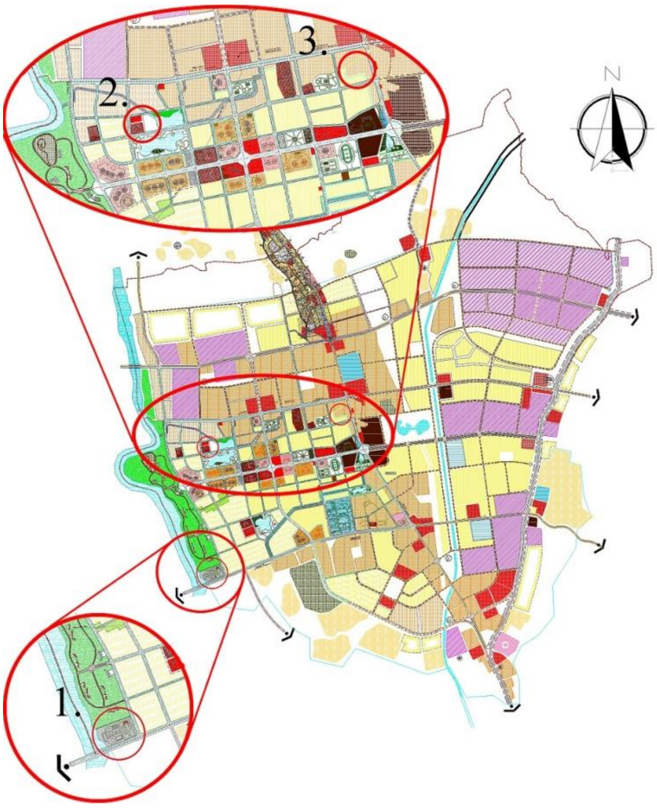


Figure 6. Detail planned map of future Sông Công. Three locations have been identified by local authorities as suitable for construction of wastewater treatment plants, location 1, 2 and 3.

Location 1 in the southwest corner is a river outlet in a low point. Located in the outskirts of the Thắng Lợi ward, this area is mainly occupied by homesteads with a dirt road connecting it to the town. The authorities have identified this location as suitable for a large centralized wastewater treatment plant.

The other two areas are in the north. One, location 2, is close to the Công River where the small river receives the wastewater. Location 3 is located to the east where the main sewer connection passes an open area (Sông Công Officials, personal communication, 13 April, 2015). These areas are today occupied by paddy fields but could in a near future be the locations for smaller WWTP combined with wetlands, similar to the Bách Quang treatment plant.

The authorities aim to treat the wastewater from the whole town. The desire is also to construct separated drains for the wastewater and stormwater (Sông Công Officials, personal communication, 13 April, 2015). Another step in the development is to construct a biogas plant to which the collected food waste and sludge can be sent.

4.6 Scenario Descriptions

To compare possible future Wastewater treatment solutions three scenarios were created. The baseline scenario (BLS-2015) is based on current (2015) information and conditions, and serves as the starting point for the other scenarios. The business as usual scenario (BAU-2030) describes the situation of the year 2030 if no changes are made to current practices. Moreover two scenarios showing how the flows of P and COD change when implementing and improving wastewater treatment solutions were created and compared to the BAU-2030 scenario. The three future scenarios are based on an annual growth rate of 1,045 %, calculated as a mean value of the population growth between 2010 and 2014 (Sông Công Statistical Office, 2015). Accordingly the population is assumed to have increased from 33 404 year 2015 to 41 455 by 2030.

4.6.1 Baseline Scenario (BLS-2015)

The data in the BLS-2015 is based on the survey results, interviews and assumptions.

4.6.1.1 Bách Quang Treatment Plant

As mentioned there is a wastewater treatment plant in the Bách Quang ward. The plant treats the wastewater from 100 households, which is estimated to equal 1.5 % of the population within the research's system boundary. The rest of the wastewater is released untreated to the Công River through a combination of open drains and sewer pipes.

4.6.1.2 Septic Tanks

According to the survey results a majority (70 %) of the households are connected to septic tanks. The figure correlates well with the amount of households with a WC (71 %). The septic tanks are emptied by the Environmental Cooperation and Public Work of Sông Công (ECPS) when full. According to the Chairman and the Director of the Thai Nguyen Environment and Urban Works Joint Stock Company (TEUC) the company empties 60 m^3 of septage each month from households around the whole town, including the rural areas (personal communication, 6 May, 2015). Based on the survey results, only about 60 % of the households have emptied their septic tanks. The septage is today used as liquid compost for tea plantations in the vicinity of the company. The standard size of a Sông Công household septic tank is about 5 m^3 according to the survey.

4.6.1.3 Dry Toilets

The second most common option for on-site sanitation is the dry toilet. 29 % of the households use some kind of dry toilet, predominantly in the Thang Loi (39 %) and Phố Cò (37 %) wards. Most of the households compost the faecal sludge from the dry toilets. Sending it to landfill is also common practice.

4.6.1.4 Food Waste

When asked about where the households dispose of their food waste, the most frequent answer was to use it as livestock feed, followed by landfill and compost. The household waste is left on the street, and then collected by workers in trolleys, as seen in Figure 7. The Thai Nguyen Environment and Urban Works Joint Stock Company (TEUC) are responsible for collecting waste in Sông Công town. According to the Chairman and the Director of the company (personal communication, 6 May, 2015), 30-35 tons of waste is collected daily, of which approximately 5-10 % is estimated to consist of food waste.

Figure 7. Solid waste collection (Author's own picture)

4.6.2 Business as Usual (BAU-2030)

In the BAU-2030 scenario all conditions are the same as in the BLS-2015 scenario, with the exception of an increased population and subsequently higher flows of P and COD. The population growth is estimated to be 1.045 %, giving a population of 41 455 in 2030.

4.6.3 Centralized Treatment Plant (CTP-2030)

The CTP-2030 scenario assumes an improvement of the wastewater treatment as a centralized treatment plant is implemented in location 1 (Figure 6 above). The plant uses biological and chemical methods to treat the wastewater and as it receives a majority of the wastewater, the discharge of untreated water to the river is minimized. Also, the Bách Quang treatment plant is assumed to be functioning and connected to more households. No data was collected on the treatment plant's capacity hence the number of connected households in 2030 had to be estimated.

The wastewater from existing households is transported through combined sewers to the treatment plant. For the new houses the sewers are assumed to be separate for wastewater and stormwater.

The sludge produced at the WWTP is transported to a biogas plant run by the ECPS. A bigger share of food waste is collected, whereas the households' composting of food waste is assumed to stop. The collected food waste is transported to the biogas plant where it is co-digested with manure and sludge from dry toilets, septic tanks and the WWTP. After digestion the end product is dispersed to local tea plantations and other agriculture in the same way as the compost in the BLS-2015 is today. The uncollected share of the food waste and a separate import of commercial feed is directed to livestock feed, which is a good alternative for utilization of the energy.

The population and consumption patterns are the same as in the BAU-2030 scenario in order to be able to compare the effects of the change.

4.6.4 Semi-centralized Treatment Plant (STP-2030)

To favor the environment the STP-2030 scenario is constructed to include only biological processes. The conditions are the same as in the CTP-2030 except that the centralized WWTP is replaced by two smaller plants. The bigger of the two is built at location 1 with EBPR treatment followed by disinfection. The other one is constructed in location 2 with EBPR combined with a hybrid CW. These two locations were chosen out of the three possible as they are natural outlets close to the river.

For a numerical overview of all the changes between the three future scenarios, see Appendix G.

5. Material Flow Analysis of Sông Công

The results from the MFA of Sông Công, calculated from the figures listed in Appendix H, are presented in flowcharts for each of the studied substance and scenario. Diagrams are utilized to compare the results of the export flows. It is important to note that a complete mass balance for COD was not performed as the digestion of organic matter in several of the processes, including the WWTP and the Biogas plant break down organic matter, which reduces the mass of COD in the outflow. This is represented by a 40 % loss of COD in the Biogas plant in the CTP-2030 and STP-2030 scenarios.

5.1 Baseline Scenario (BLS-2015)

The flowcharts in Figure 8 and Figure 9 show the current flows of P and COD in Sông Công.

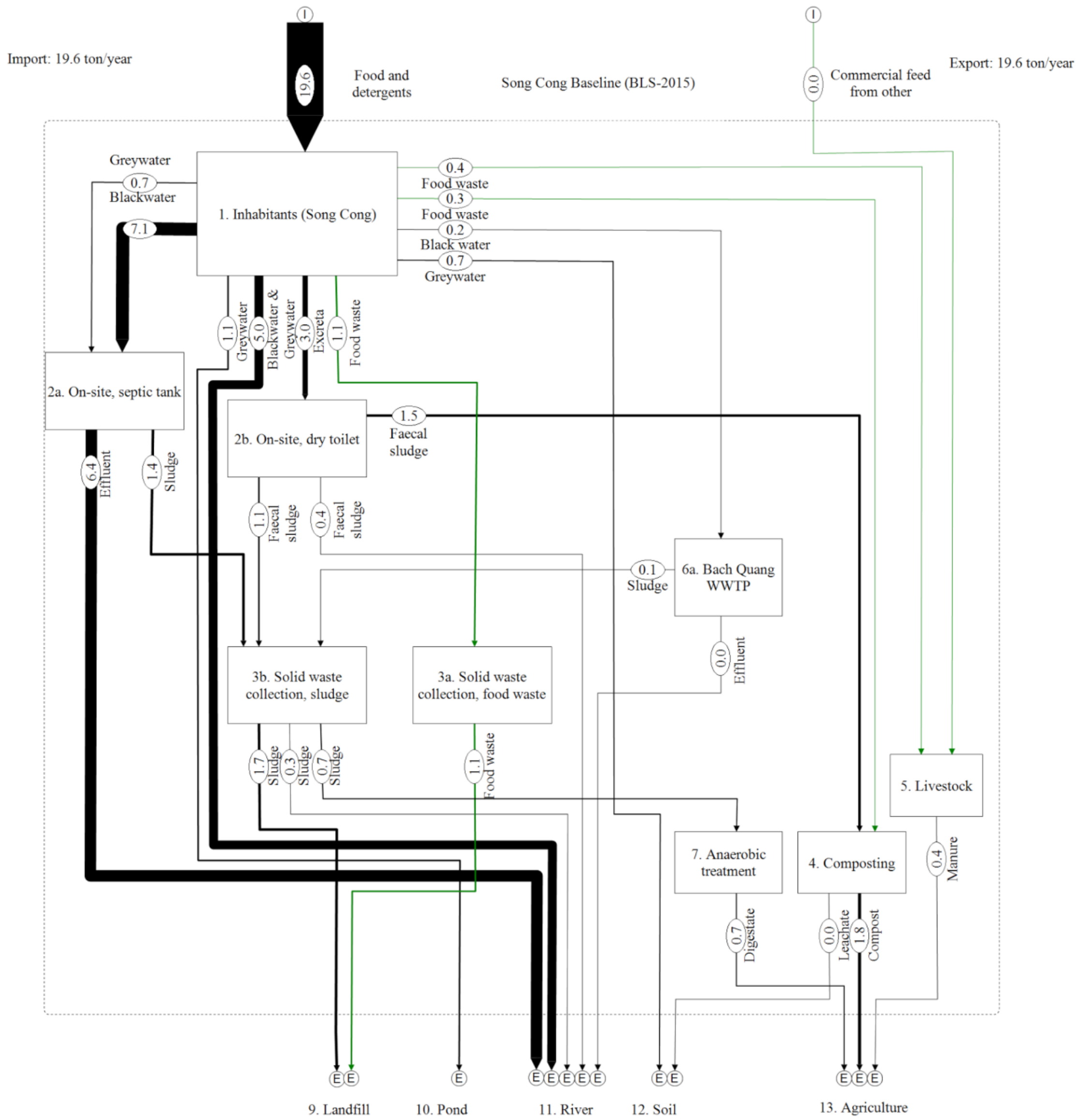


Figure 8. Flowchart of P in the BLS-2015

The total P flow (Figure 8) was calculated to 19.6 ton/year. As can be seen the two major flows, effluent from Septic tanks and blackwater and greywater from Inhabitants, ends up in the river Công.

In the context the food waste account for a small share of the P flow, with a total flow of 1.8 ton/year. The largest share goes as waste to the Landfill. Livestock and Compost receive the remainder of the food waste. Surprisingly more than half of the faecal sludge from Dry toilets is used as compost, a good way of recovering the nutrients.

The COD outflow from Inhabitants was calculated to 759.8 ton/year for the BLS-2015 scenario (Figure 9). Here blackwater and greywater from Inhabitants directly to the River dominates the flow, whereas equal volumes of effluent and sludge from Septic tanks are released straight to the River and collected by the ECPS. The largest flows of COD are from Septic tanks through Sludge collection to Anaerobic treatment.

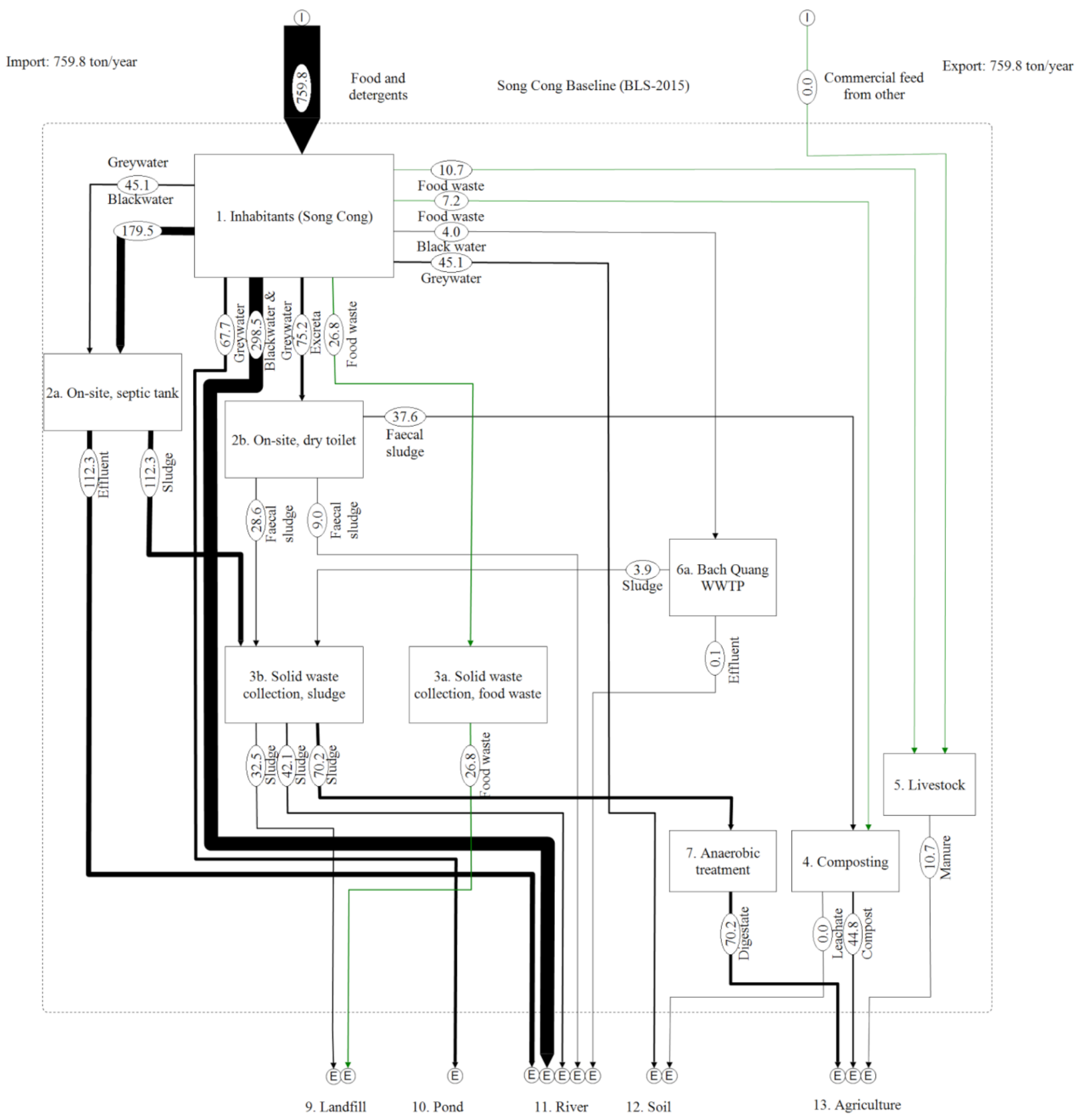


Figure 9. Flowchart of COD in the BLS-2015

As can be seen the P flows to Composting from Dry toilet is bigger than the flow from Sludge collection to Anaerobic treatment, and the other way around for COD. The difference depends on the transfer coefficients (TC) to sludge in Septic tanks. The TC for COD from Septic tank to sludge is 0.5. Hence the figure is larger than that for P (0.18), which means that a larger volume of P from the Septic tank is allocated to the effluent instead of to the Anaerobic treatment.

5.2 Business as Usual (BAU-2030)

The BAU-2030 scenario shows the development of the P and COD flows if no changes are implemented before 2030 (Figure 10 and Figure 11). The ratios are the same as in BSL-2015, the only differences are the increased total flows, reaching 24.4 ton/year for P and 942 .9 ton/year for COD.

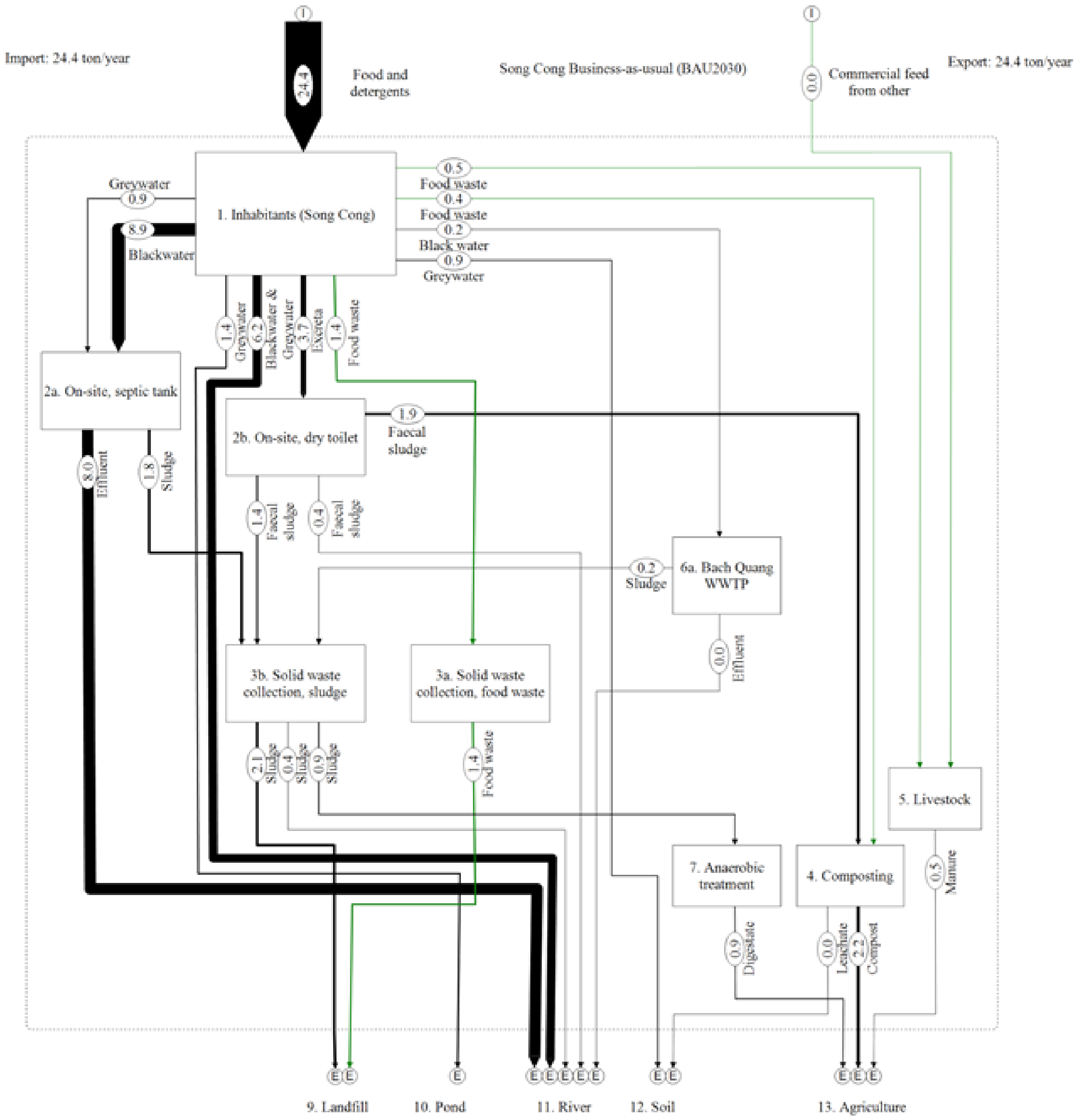


Figure 10. Flowchart of P in the BAU-2030 scenario

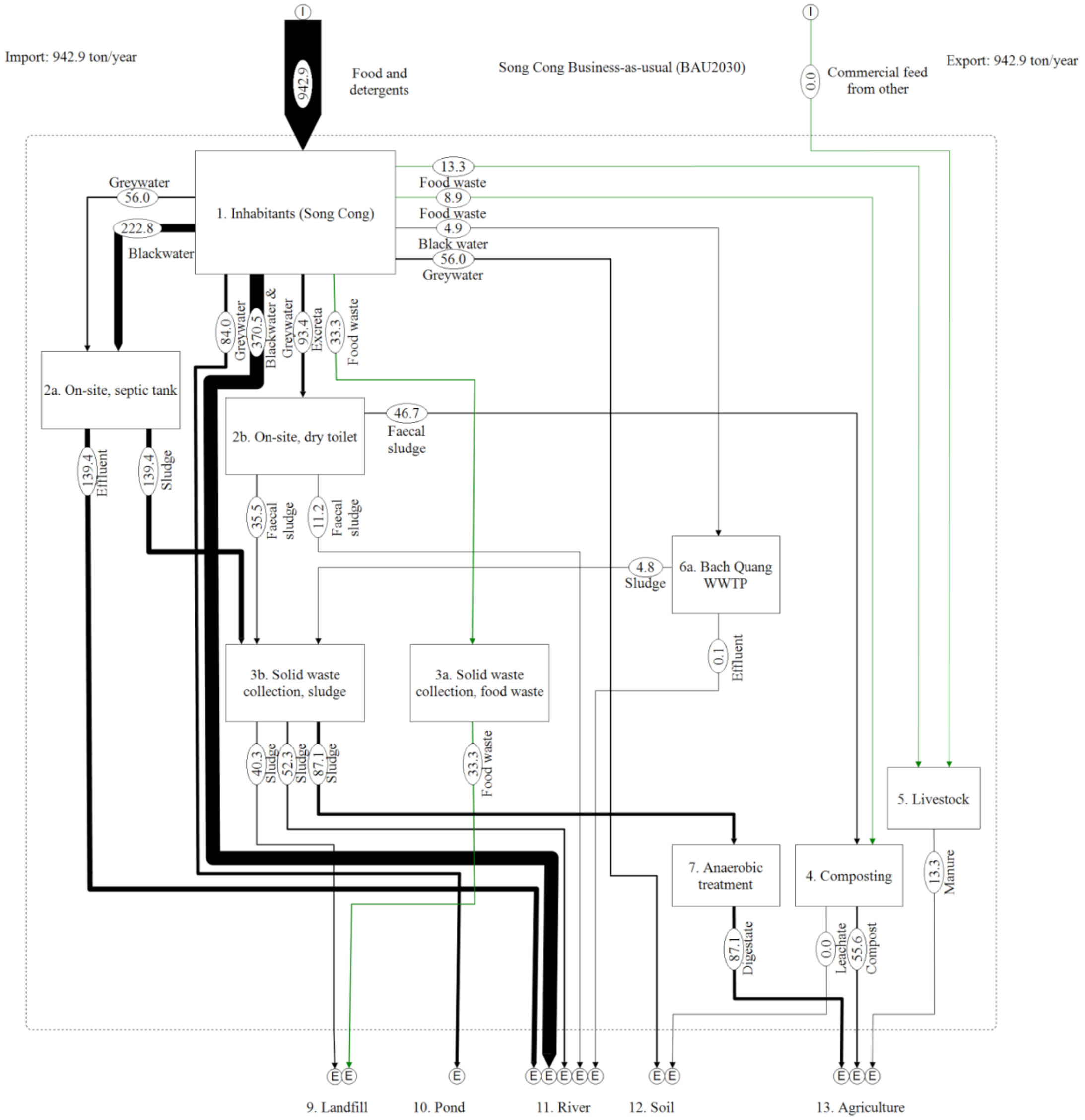


Figure 11. Flowchart of COD in the BAU-2030 scenario

5.3 Centralized Treatment Plant (CTP-2030)

The CTP-20130 scenario shows the results from implementing a Centralized biological and chemical treatment plant and redirecting all of the sludge and a majority of the food waste to Biogas production instead of to Composting and Anaerobic treatment. The P and COD flows can be studied in Figure 12 and Figure 13.

The major flows of P (Figure 12) are blackwater to Septic tank from where it is directed to the centralized WWTP as septic tank effluent, and greywater to the same WWTP. From there the accumulated flows are mainly directed to Solid waste collection as sludge. Further the collected sludge is sent to a Biogas plant that sends the digestate to Agriculture.

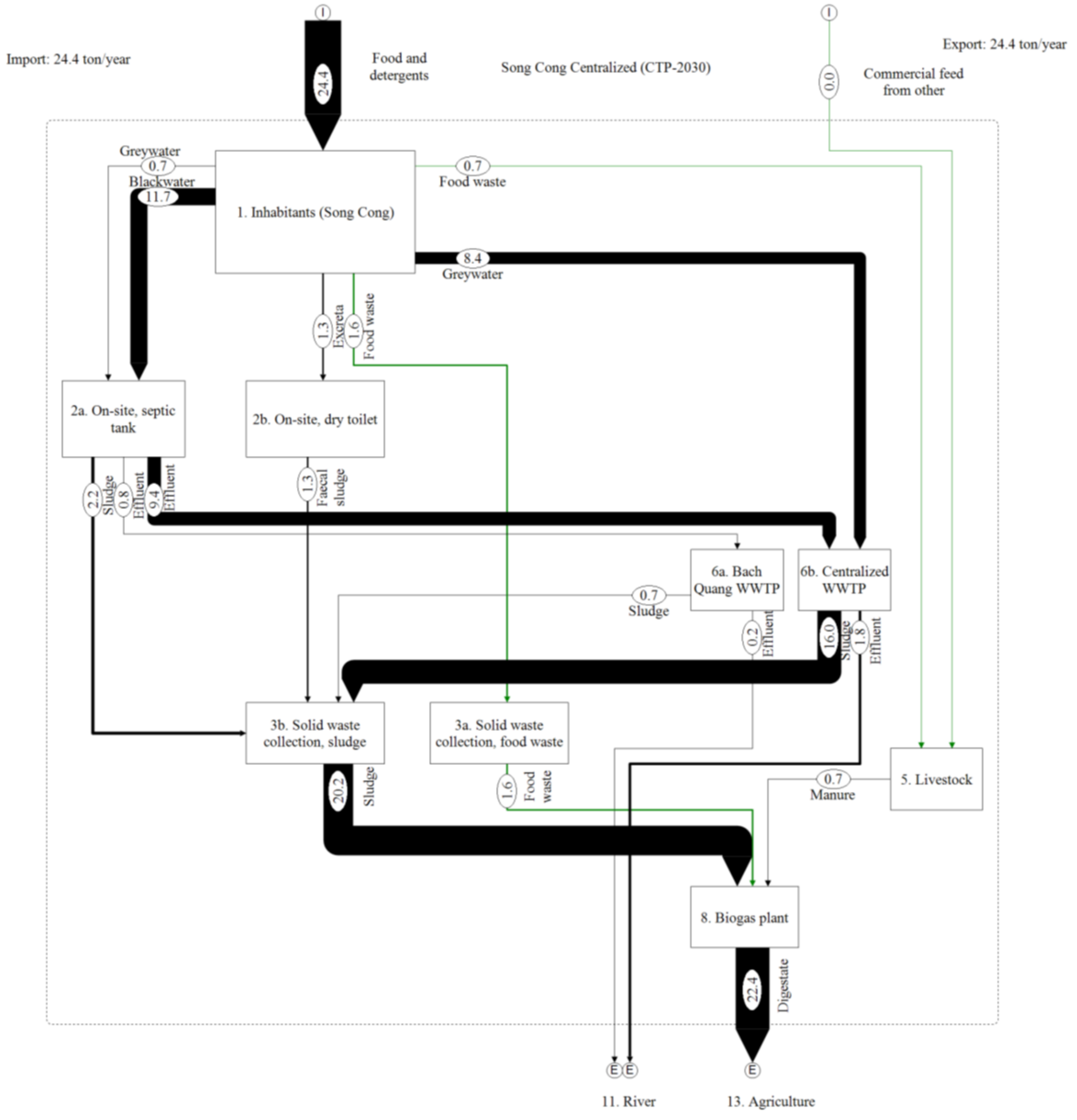


Figure 12. Flowchart of P in the CTP-2030 scenario

The COD flows (Figure 13) are similar to the P flows, although a bigger part of COD is collected directly from the Septic tank to Solid waste collection in the form of septage. The outflow of COD from the Biogas plant is only about 60 % of the inflow due to digestion of organic matter.

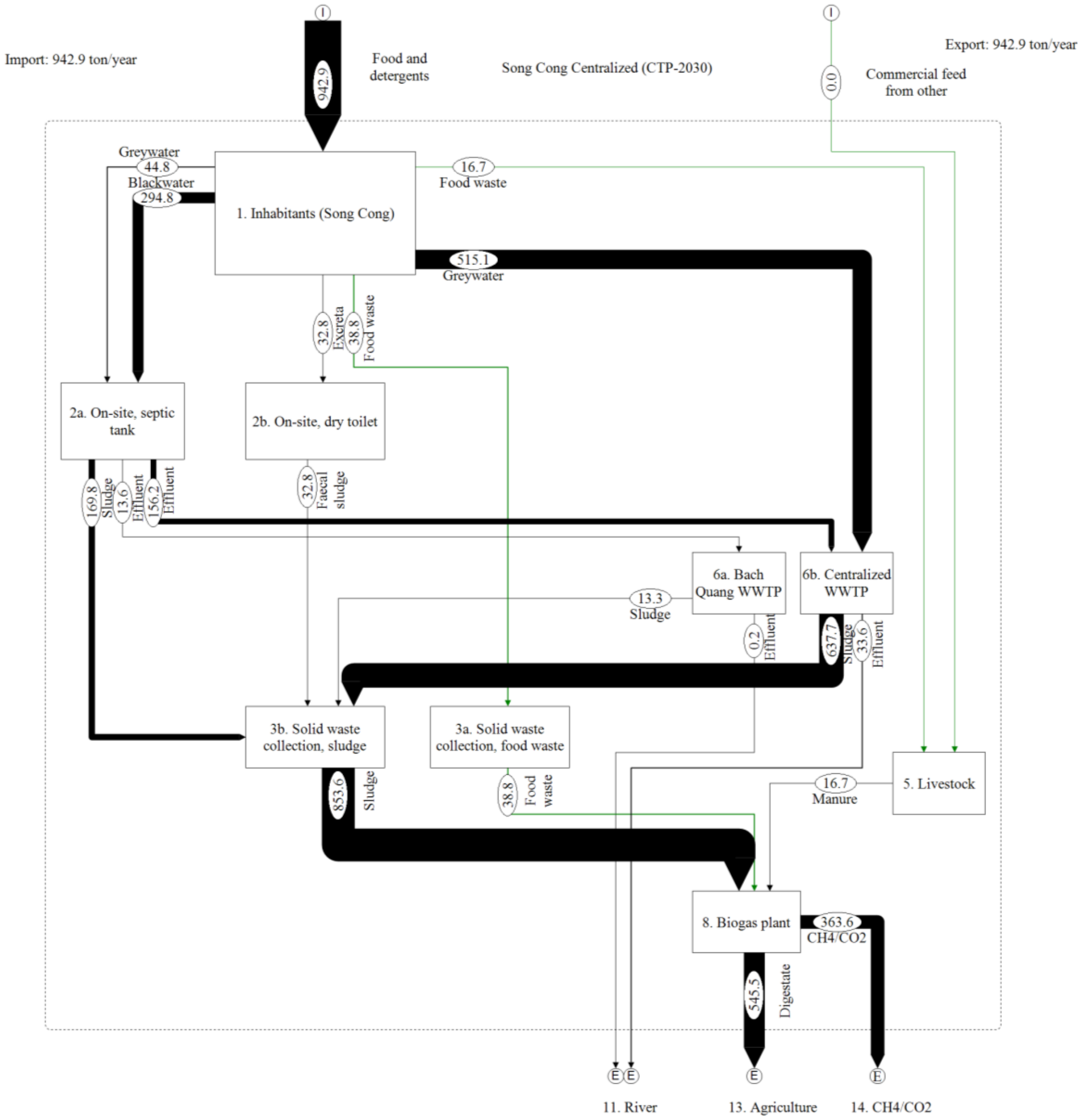


Figure 13. Flowchart of COD in the CTP-2030 scenario

5.4 Semi-centralized Treatment Plant (STP-2030)

The STP-2030 scenario shows the results of implementing two treatment plants, one smaller with EBPR followed by a hybrid CW and one bigger with EBPR and disinfection. Otherwise the conditions are the same as in the CTP-2030 scenario. The P and COD flows are presented in Figure 14 and Figure 15.

One major difference from the CTP-2030 scenario is that the flows of P (Figure 14) are divided more evenly between the WWTPs. The large flows are still blackwater to Septic tank, greywater to WWTP and septic tank effluent to WWTP. The flows of sludge from WWTP through Solid waste collection and Biogas production to Agriculture are also the same.

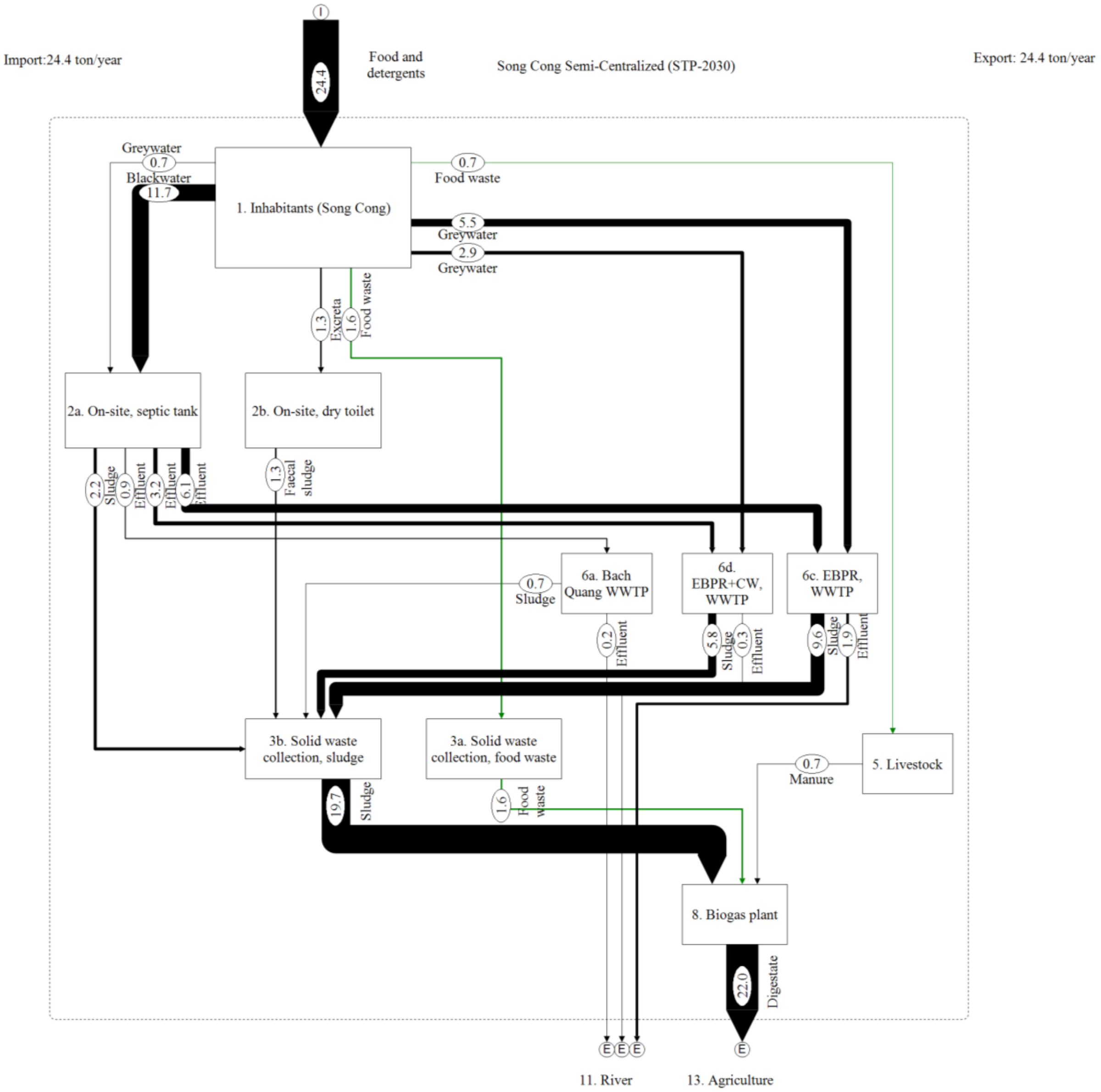


Figure 14. Flowchart of P in the STP-2030 scenario

The relationships between the flows of COD (Figure 15) are similar to those of P. However the outflow of COD from the Biogas plant is only about 60 % of the inflow due to digestion of organic matter.

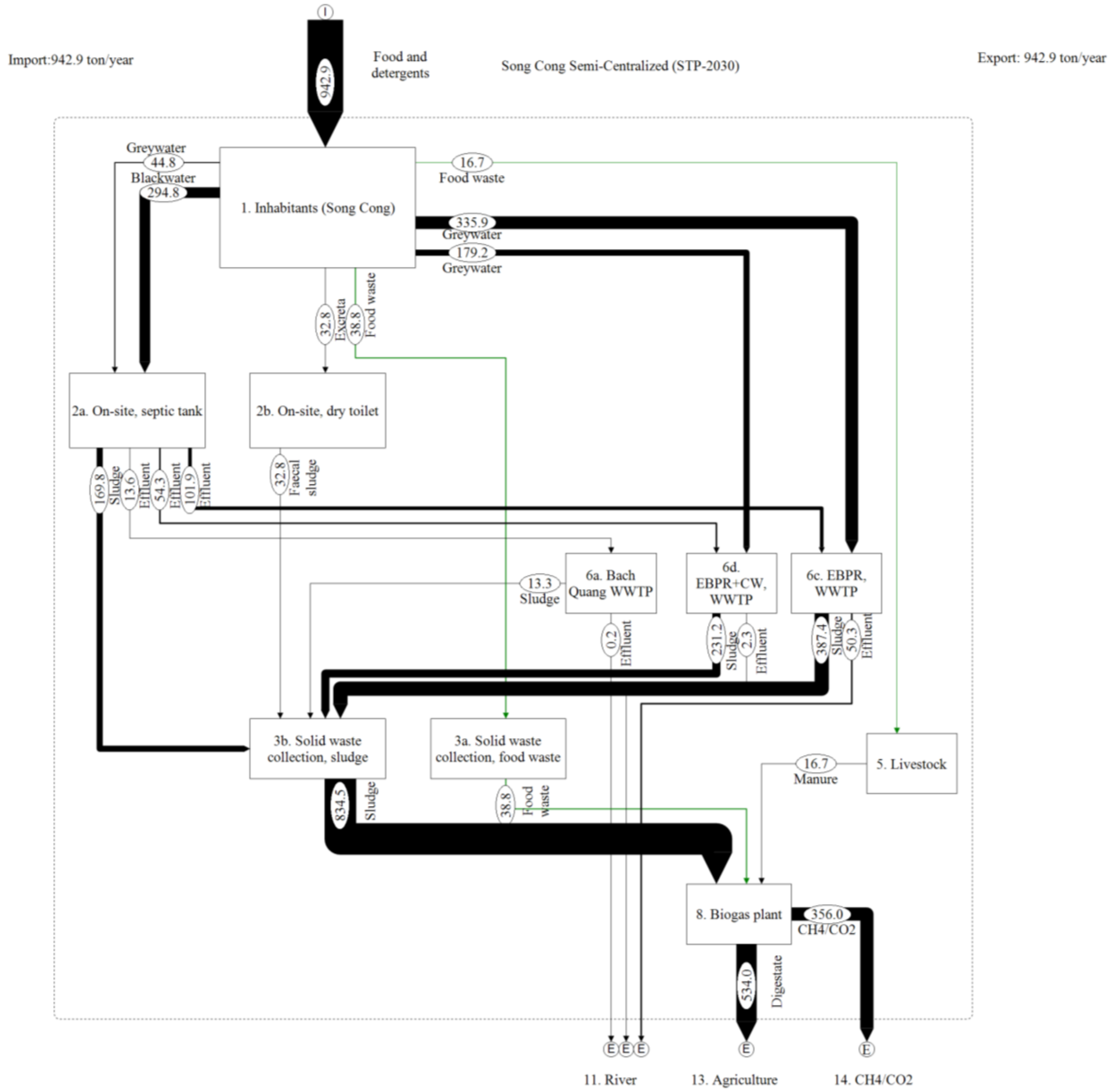
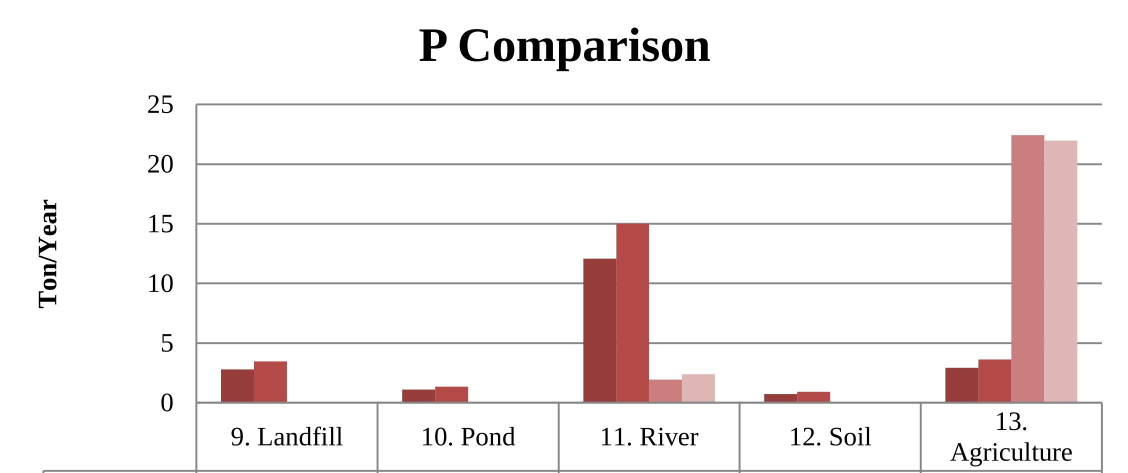


Figure 15. Flowchart of COD in the STP-2030 scenario

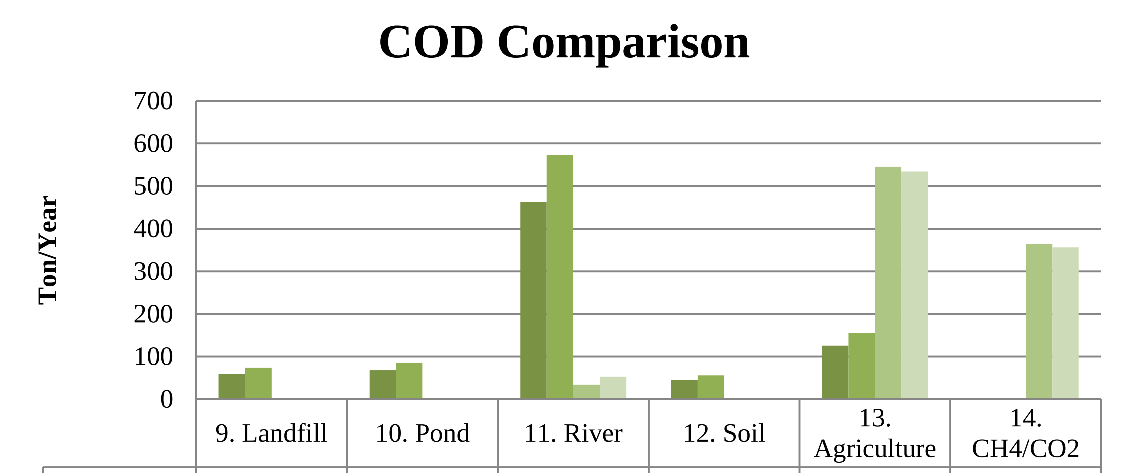
5.5 Compilation of the MFA results

The results are summarized in Figure 16 for P and Figure 17 for COD. The figures show the total mass flows to each export destination, both in numbers and bar charts. It is noticeable that the exports to Landfill, Pond and Soil have been reduced to zero in CTP-2030 and STP-2030 as these are deemed to be unsustainable. One further difference is the export of COD to CH_4/CO_2 which is caused by the breakdown of COD in the Biogas plant accounting for approximately 40 %.



	9. Landfill	10. Pond	11. River	12. Soil	13. Agriculture
BLS-2015	2,8	1,1	12,1	0,7	2,9
BAU-2030	3,5	1,4	15,0	0,9	3,6
CTP-2030	0,0	0,0	1,9	0,0	22,4
STP-2030	0,0	0,0	2,4	0,0	22,0

Figure 16. Summary of the results for P flows to each export destination for all scenarios. The BLS-2015 scenario is included to show the difference from the future improved and unimproved scenarios



	9. Landfill	10. Pond	11. River	12. Soil	13. Agriculture	14. CH4/CO2
BLS-2015	59,3	67,7	462,0	45,1	125,7	0
BAU-2030	73,6	84,0	573,4	56,0	156,0	0
CTP-2030	0,0	0,0	33,8	0,0	545,5	363,6
STP-2030	0,0	0,0	52,9	0,0	534,0	356

Figure 17. Summary of the results for COD flows to each export destination for all scenarios. The BLS-2015 scenario is included to show the difference from the future improved and unimproved scenarios

6. Analysis of the MFA Results

The MFA of current (BLS-2015) and future wastewater and food waste management (BAU-2030, CTP-2030 and STP-2030) was performed using data collected through a survey questionnaire, observations, interviews and literature. The results indicate that the current wastewater management in Sông Công is inadequate. Even though 70 % of the households are connected to septic tanks, their management is far from satisfying. A big portion of COD (61 %) and P (62 %) ends up in the Công River, particularly through effluent from septic tanks and from blackwater and greywater discharged directly from the inhabitants. It is hence apparent that whichever treatment method that is preferred, the implementation will result in a significant improvement. Without any action the amounts of COD and P reaching the Công River will increase by 24 % in only 15 years as a result of the growing population. An even larger increase could be assumed as people increase their standard of living, because they tend to both eat and discard of more food.

6.1 Scenario discussion

The improved scenario with the least volume of P and COD discharged to the river and soil is the CTP-2030. This is due to the more efficient treatment provided by the combined chemical and biological process. The result is also based on the assumption that the pipe network is intact all the way from the households to the plant, which might not always be the case. According to local government officials the sewerage network is not mapped out. If this is correct, a mapping of the network should be performed in order to maintain the existing network before building a new one. However, as the town is undergoing rapid change, with entire wards about to be remodeled, a simultaneous reconstruction of the network might be possible in some wards.

The SCT-2030 scenario has the advantage of shorter network systems, which decrease the load on the pipes. The semi-centralized system is also more flexible and hence more suitable for a quickly developing area since both plants do not need to be constructed simultaneously. As the plants are smaller the construction time is shorter than for a large centralized plant, meaning that a semi-centralized plant can be operational sooner. A further advantage is the elimination of chemicals in the treatment process. Not using chemicals reduce the environmental impact and the operational costs. Moreover, the treatment efficiency of P and COD keep almost the same standard as if chemicals are included in the process, which makes the biological treatment methods interesting options to consider.

One disadvantage of the SCT-2030 is the potentially larger land area needed to sustain a functioning constructed treatment wetland. However the CW can be used as recreational areas for both people and animals.

With this said the proposed techniques are only suggestions, other options should also be considered. For example, the semi-centralized system could include other solutions apart from the ones suggested in this study. Depending on the volume of the flows (which have to be examined in a separate study) the suggested EBPR plant in the northern Sông Công (location 2 in Figure 6) could be replaced by a conventional AS or SBR plant. Both of these techniques are cheaper and simpler, which can be an advantage for Sông Công where higher costs are an issue.

Another idea is to develop a pilot area in one of the wards, which uses more sustainable methods such as recycling of greywater to flush the toilets or for irrigation. By incorporating this practice in the society freshwater reserves would be saved. It is also a way of cutting the costs as the volume of water going to the plant is reduced, lowering the capacity requirements both for the pipes and the plant itself. However, due to resource limitations these ideas were not further examined in this thesis.

The options to reduce the P flows from the source, in other words the inhabitants, could also be investigated. As seen in Appendix A the current food import to the household is primarily based on rice. Rice also represents the biggest share of P import to the household. The second largest import source is the P-rich detergent followed by meat consumption. A change of people's food habits might be difficult. However, by solely eliminating the P in detergent would have a significant effect on reducing the total flow of P.

The current practice of using sludge, food waste and manure as compost is one step in the direction towards reusing nutrients. Still a great amount of P, about 85 % of the entire flow, is being wasted. Only the remaining 15 % is used in agriculture. In the improved scenarios 92 % (CTP-2030) and 90 % (STP-2030) of the P ends up on agricultural land after anaerobic digestion.

By using the P in agriculture it could heavily reduce the need for synthetic fertilizers. Another benefit of anaerobic digestion is the production of biogas from the organic matter. Estimations are that about 40 % of the incoming COD is converted to CH_4 and CO_2. The produced biogas can be distributed to inhabitants, reducing the need of petroleum based fossil gas for cooking, or converted into electricity. The actual environmental benefits of reducing the amount of synthetic fertilizer and replacing fossil based fuel or energy with biogas has not been examined in this thesis. The consequences could be examined through conducting a lifecycle analysis (LCA), a method with which the environmental impacts of products from cradle to grave can be studied and compared.

6.2 Implementation Challenges

Although the scenarios show great improvement, better techniques might not be enough to turn the situation around. A behavioral change is probably needed. It is essential that the inhabitants are aware of the consequences of their actions and know that if nothing is changed the already apparent environmental degradation is bound to continue. Inhabitants have to be informed about the advantages of better management of wastewater in general and septic tanks in particular, that the improvements impact their lives directly in terms of less health issues and more pleasant surroundings. Hence, it is also vital that the decision making process is transparent.

According to the survey only 60 % of the households have ever emptied their septic tank, inferring that 40 % of the town's septic tanks are full and therefore release untreated wastewater to the local water sources. Even if enhanced technical solutions are implemented, the poor management on a household level is an issue that needs to be resolved. One solution is imposing policies of sludge collection and the separate collection of food waste.

The legal system requires further improvements, so that the authorities actually condemn the polluters and make them pay for the damage they cause. The current lack of enforcement can also be linked to people’s consciousness. If the inhabitants are aware and care for the environment, it will raise the pressure on the authorities to convict the polluters.

6.3 Sources of Error

The MFA results are largely dependent on the quality of the gathered data. It is important to bear in mind that a MFA is a simplified model of a very complex reality.

In this thesis the consumption pattern was not studied specifically for the population in Sông Công, the data was based on the Hanoi figures. Hence if an accurate measure of the actual consumption was performed it could have a negative or positive impact on the flows of both P and organic matter. Moreover the data collected from the various companies was not specific for the area within the system border, i.e. the urban wards. The figures were rather for the whole Sông Công town, which was considered when executing the calculations.

To eliminate the uncertainties caused by translation difficulties, it would have been desirable to collect measured data in order to get more accurate results. However the intent to collect existing, accurate data from the local government failed due to the authorities’ limited knowledge of the current situation and their reluctance to make estimations. Thus the results are based largely on the survey, which to some extent have been affected by misunderstandings. A number of questions were answered in a manner that impedes their interpretation. Interviews and sampling give rise to the risk of biased results. All these sources of error were adjusted by combining the survey results and interviews with data collected by Zimmermann (2014) and other literature. Based on all these combined sources the assumptions are expected to be credible.

Some criticism should be mentioned concerning the survey method. It is unclear if the sample distribution is representative for all of the urban wards, as some of the peripheral households might have been excluded due to low accessibility. It can be assumed that these households have less access to improved sanitation than the more centrally located urban households. This implies that they have less efficient wastewater treatment, meaning that a higher proportion of wastewater is released untreated than what is revealed in the BLS-2015 scenario.

With these uncertainties in mind, the results of the MFA can be used to clearly visualize the outcome of decisions that are made concerning the wastewater management of Sông Công town. The MFA model can be utilized to examine different possible scenarios and can be refined after better analysis of local circumstances. Although the overall picture lacks somewhat in accuracy, the distribution of flows in specific processes can be used as a guide for further studies. The benefit of this MFA is that even those that are not familiar with the technical details of wastewater treatment can understand the advantages and disadvantages of making certain choices concerning the future wastewater management.

7. Conclusions and Future Studies

The conclusions of this MFA of the wastewater and food waste in Sông Công are that the current wastewater treatment in the urban wards is inadequate. The majority of the P and COD from households end up polluting the Công River instead of being put to productive use. If nothing is changed, the discharge to the river will increase by 24 % in just 15 years as the population grows.

Both of the two improved scenarios (CTP-2030 and STP-2030) will reduce the amount of pollution reaching the river. The nutrients are returned to agricultural land after anaerobic digestion of the sludge and food waste, where the organic matter is utilized for production of energy rich biogas (methane). The benefits of improved wastewater treatment include, but are not limited to, reduced need for synthetic fertilizer, mitigation of pollution and production of biogas that can be used for domestic purposes or converted into electricity.

This MFA thesis only laid the foundation for the planning of wastewater treatment and food waste management in Sông Công town. To further explore the possibilities the following studies are suggested:

- Detailed studies of local conditions to increase the accuracy of future MFA's in Sông Công. Such research areas include mapping and analyzing of the drainage areas, mapping of sewerage networks and water sampling to determine the composition of the wastewater.
- Mapping and MFA of industries, schools, restaurants and other large facilities which produce wastewater and food waste in Sông Công as this thesis only focuses on domestic wastewater.
- An analysis of the removal efficiency of substances like nitrogen and heavy metals in order to determine if the treatment technique is adequate.
- Investigate the potential for biogas production by studying the production of sludge and food waste throughout the Thai Nguyen province, as well as opportunities to transport the material to a biogas plant.
- Perform a cost-benefit analysis of implementing a wastewater treatment in Sông Công.
- Use the results from this study in a life-cycle analysis (LCA) showing the benefits of biogas production and the reduced need for synthetic fertilizers.

References

AECOM & Sandec. (2010). *A Rapid Assessment of Septage Management in Asia: Policies and Practices in India, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam. Environmental Cooperation-Asia (ECO-Asia).* International Development, Inc and the Department of Water and Sanitation in Developing Countries

Anand, C.K. & Apul, D.S. (2014). Composting toilets as a sustainable alternative to urban sanitation – A review. *Waste Management, 34* (2), 329–343. doi:10.1016/j.wasman.2013.10.006

Bassan, M., Dao, N. Thuy, P., Hoai, A.V., Nguyen, V.A. & Strande, L. (2014). *Initial assessment of sludge management and context in five cities: Son La, Lang Son, Hoa Binh, Bac Ninh, and Ba Ria.* PURR – Partnership for Urban Resource Recovery. http://www.eawag.ch/forschung/sandec/publikationen/ewm/dl/purr_ass.pdf

Biggam, J. (2011). *Succeeding with your Master's Dissertation: A step-by-step handbook.* New York: Open University Press

Binder, C., Schertenleib, R., Diaz, J., Bader, H.-P. & Baccini, P. (1997). Regional Water Balance as a Tool for Water Management in Developing Countries. *International Journal of Water Resources Development, 13*(1), 5-20. doi:10.1080/07900629749890

Brunner, P.H. & Rechberger, H. (2003). Practical Handbook of Material Flow Analysis. Florida: CRC Press, ISBN: 9780203507209

Carlsson, B. & Hallin, S. (2003). *Reglerteknik och mikrobiologi i avloppsreningsverk (27:2003).* Stockholm: Svenskt Vatten AB

Dan, T.H., Quang, L.N., Nguyen, H.C., Brix H. (2011). Treatment of high-strength wastewater in tropical constructed wetlands planted with Sesbania sesban: Horizontal subsurface flow versus vertical downflow. *Ecological Engineering, 37*(2011), 711–720. doi:10.1016/j.ecoleng.2010.07.030

Depledge, D. (1997). Design examples of waterless composting toilets. South Pacific Applied Geoscience Commission, Miscellaneous report nr 249

Gu, A.Z., He, S., McMahon, K.D. & Neething, J.B. (2007). Comparison of A2O and UCT operation mode at full-scale EBPR processes – performance, kinetics and pao population. Proceedings of the Water Environment Federation, 15(2007), 953-967. doi:10.2175/193864707787977352

Haandel, van A.C. & Lubbe, van der J.G.M. (2012). *Handbook of Biological Wastewater Treatment: Design and Optimization of Activated Sludge Systems (2nd edition).* IWA Publishing. ISBN 9781780400808

Jóźwiakowski, K., (2009). Possibilities of protection of water resources with the use of constructed wetland systems: a review. *Ecohydrology & Hydrobiology, 9*(2009), 297-306, doi: 10.2478/v10104-010-0012-1

Kapdan, I.K. & Ozturk, R. (2005). Effect of operating parameters on color and COD removal performance of SBR: Sludge age and initial dyestuff concentration. *Journal of Hazardous Materials, B123*(2005), 217–222. doi:10.1016/j.jhazmat.2005.04.013

Karius, R. (2011). *Developing an integrated concept for sewage sludge treatment and disposal from municipal wastewater treatment systems in (peri-) urban areas in Vietnam (Diploma thesis)*. Technische Universität Dresden

Kivaisi, A.K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological Engineering, 16*(2001), 545–560. doi:10.1016/S0925-8574(00)00113-0

Kulikowska, D., Klimiuk, E. & Drzewicki, A. (2006). BOD5 and COD removal and sludge production in SBR working with or without anoxic phase. *Bioresource Technology, 98*(2007), 1426–1432. doi:10.1016/j.biortech.2006.05.021

Libralato, G., Ghirardini, A.V. & Avezzù, F. (2011). To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management. *Journal of Environmental Management*, *94*(2012), 61-68. doi:10.1016/j.jenvman.2011.07.010

Maurer, M., Rothenberger, D. & Larsen, T.A. (2006). Decentralised wastewater treatment technologies from a national perspective: at what cost are they competitive? *Water Science and Technology*, *5*(6), 145-154

McNear Jr., D. H. (2013) The Rhizosphere - Roots, Soil and Everything In Between. *Nature Education Knowledge, 4*(3), 1

Mittal, A. (2011). Biological Wastewater Treatment. *Water Today*, Fulltide, 32-44

Montangero. A. (2007). *Material Flow Analysis: a tool to assess material flows for environmental sanitation planning in developing countries.* EAWAG aquatic research

Montangero, A. & Belevi, H. (2007). Assessing nutrient flows in septic tanks by eliciting expert judgement: A promising method in the context of developing countries. *Water Research*, *41*(2007), 1052-1064. doi:10.1016/j.watres.2006.10.036

Montangero, A. & Belevi, H. (2008). An approach to optimise nutrient management in environmental sanitation systems despite limited data. *Journal of Environmental Management*, *88*(2008), 1538-1551. doi:10.1016/j.jenvman.2007.07.033

Montangero, A., Cau, L.N., Anh, N.V., Tuan, V.D., Nga, P.T. & Belevi, H. (2007). Optimising water and phosphorus management in the urban environmental sanitation system of Hanoi,Vietnam. *Science of the Total Environment*, *384*(2007), 55-66. doi:10.1016/j.scitotenv.2007.05.032

Naturvårdsverket. (2012). *Biogas ur gödsel, avfall och restprodukter: Goda svenska exempel.* Stockholm: Naturvårdsverket, ISBN 978-91-620-6518-8, ISSN 0282-7298

Nga, D.T., Morel, A., Nguyen-Viet, H., Pham-Duc, P., Nishida, K. & Kootattep, T. (2011). Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data. *Resource, Conservation and Recycling,* (2011). doi:10.1016/j.resconrec.2011.04.008

Nguyen, T.P.L. (2013). *The Legal Framework of Vietnam's Water Sector: Update 2013*. ZEF Working Paper Series, ISSN 1864-6638

Nguyen, V.-A., Morel, A. & Tonderski, K. (2010). Baffled Septic Tank with Anaerobic Filter (BASTAF) and Vertical Subsurface Flow Constructed Wetland for Domestic Wastewater Treatment in Vietnam. Water Practice & Technology, (2010). doi:10.2166/wpt.2010.100

Nguyen V.A., Guy H., Hoang T.L., Phan H.D., Le Thu H. & Bui T.N. (2013). *Economic assessment of sanitation interventions in Vietnam*. World Bank: Water and Sanitation Program 2012

Oneke, T.A. (2006). *Comparison of chemical and biological phosphorus removal in wastewater (Master's Thesis)*. Linköping: Department of Chemical Engineering, Linköping University

Pambrun, V., Paul, E. & Spérandio, M. (2004). Treatment of nitrogen and phosphorus in highly concentrated effluent in SBR and SBBR processes. *Water Science and Technology*, *50*(6), 269-76

Rodriguez-Garcia, G., Molinos-Senante, M., Hospido A., Hernández-Sancho F., Moreira, M.T. & Feijoo, G. (2011). Environmental and economic profile of six typologies of wastewater treatment plants. *Water Research 45*(2011) 5997-6010. doi:10.1016/j.watres.2011.08.053

de la Rubia, M.A., Perez, M., Romero, L.I. and Sales D. (2002). Anaerobic Mesophilic and Thermophilic Municipal Sludge Digestion. Chemical and Biochemical Engineering, *16*(3) 119–124.

Schramm, S. (2011). Semicentralised Water Supply and Treatment: Options for the Dynamic Urban Area of Hanoi, Vietnam. *Journal of Environmental Assessment Policy and Management*, *13:2*(2011), 285-314

Silva, C., Quadros, S., Ramalho, P., Alegre, H., Rosa, M.J. (2014). Translating removal efficiencies into operational performance indices of wastewater treatment plants. *Water research 57*(2014), 202–214. doi:10.1016/j.watres.2014.03.025

SMED. (2012). Utsläpp till vatten och slamproduktion 2008 *Kommunala reningsverk, skogsindustri samt viss övrig industri, korrigerad version 2012-06-15*. Access 2015-02-18: http://www.scb.se/statistik/MI/MI0106/2008A01/MI0106_2008A01_SM_MI22SM1001.pdf

Sông Công Statistical Office, (2015). *Diện tích, dân số, mật độ dân số năm 2014 [Area, population, population density in 2014]*

South, N. (2014). *Membranbioreaktorteknik - En framtida lösning på Lundåkraverket?* (Master's thesis). Lund tekniska högskola: Institutionen för kemiteknik; Uppsala University: Institutionen för Geovetenskaper

von Sperling, M. (2007). *Activated Sludge and Aerobic Biofilm Reactors.* London & New York: IWA Publishing, ISBN13:9781843391654

Särner, E., Jonasson, C. & Petersson, M. (2004). Hydrolys av Returslam för Förbättrad Biologisk Fosforavskiljning. *Vatten,* (60), 231–238

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P. & Zurbrügg, C. (2014). *Compendium of Sanitation Systems and Technologies - 2nd Revised Edition*. Eawag: Duebendorf

Trang, N.T.D., Konnerup, D., Schierup, H.H., Nguyen H.C., Tuan L.A. & Brix, H. (2009). Kinetics of pollutant removal from domestic wastewater in a tropical horizontal subsurface flow constructed wetland system: Effects of hydraulic loading rate. *Ecological Engineering, 36*(2010), 527–535. doi:10.1016/j.ecoleng.2009.11.022

Vymazal, J. (2007). Removal of nutrients in various types of constructed wetlands. *Science of the Total Environment*, *380*(2007), 48–65. doi:10.1016/j.scitotenv.2006.09.014

Wang, F., Lu, S., Wei, Y. & Ji, M. (2009a). Characteristics of aerobic granule and nitrogen and phosphorus removal in a SBR. *Journal of Hazardous Materials, 164*(2009), 1223–1227. doi:10.1016/j.jhazmat.2008.09.034

Wang, L.K., Pereira, N.C. & Hung, Y.-E. (2009b). *Biological Treatment Processes,* (volume 8). Springer Science & Business Media, ISBN 978-1-60327-156-1

Wang, Z., Liu, B., Liu, Y.D., Wan, F.J. (2013). Evaluation of biological removal efficiency in a UCT process treating municipal wastewater during start-up stage. *Journal of Environmental Biology, 34*(2), 459-464

WEPA. (n.d.). *State of water environmental issues: Viet Nam*. Water Environment Partnership in Asia. Access 2015-05-16: http://www.wepa-db.net/policies/state/vietnam/overview.htm

WEPA. (2013). *Urban domestic wastewater management in Vietnam - challenges and opportunities*. Water Environment Partnership in Asia: policy brief, series 5, march 2013

Wikipedia. (2011). Thái Nguyên Province: Map. Access 2015-05-24: http://en.wikipedia.org/wiki/Th%C3%A1i_Nguy%C3%AAn_Province

Wood, N. (2008). Pretreatment of pulp mill wastewater treatment residues to improve their anaerobic digestion (Master's thesis). University of Toronto: Department of Chemical Engineering and Applied Chemistry.

World Bank. (2011). *Vietnam Urbanization Review: Technical Assistance Report*. Hanoi, Vietnam; World Bank in Vietnam, Report No: 66916

World Bank. (2013). *Socialist Republic of Vietnam Performance of the Wastewater Sector in Urban Areas: A Review and Recommendations for Improvement Vietnam Urban Wastewater Review*. Washington, DC; The World Bank Group, Report No: ACS7712

World Bank. (2014). *Vietnam - Scaling-up Sanitation Project*. Washington, DC; The World Bank Group, Report No: 93124

Yu, G.H., He, P.J., Shao, L.M. & He, P.P. (2008). Toward understanding the mechanism of improving the production of volatile fatty acids from activated sludge at pH 10.0. *Water Research 42*(2008), 4637–4644. doi:10.1016/j.watres.2008.08.018

Zhang, Y., Luo, G.Y., Xu, X.Y., Cao, J. & Shu, W.Q. (2010). Effect of the influent COD and C/N ratio on phosphorus removal of UCT system. *Huanjing Kexue/Environmental Science, 31*(8), 1846-1850

Zhang, D.Q., Jinadasa, K.B.S.N., Gersberg, R.M., Liu, Y., Ng, W.J. & Tan, S.K. (2014). Application of constructed wetlands for wastewater treatment in developing countries - A review of recent developments (2000-2013). *Journal of Environmental Management, 141*(2014), 116-131. doi.org/10.1016/j.chemosphere.2013.09.045

Zimmermannn, C. (2014). *Modeling Phosphorus Flows for Semi-centralized Sanitation Solutions in Greater Hanoi 2030* (Master's Thesis). Linköping University: Department of Thematic Studies

Appendix A. Parameters for import of P to inhabitants

Symbol	Description	Unit	Value	Source
m_rice	rice consumption	*kg cap^{-1} yr^{-1}*	136,51	Zimmermann: VDD & UNICEF, 2011
c_P_rice	P content in rice	*g kg^{-1}*	1,15	Zimmermann: USDA, 2012
m_pork	pork consumption	*kg cap^{-1} yr^{-1}*	23,7	Zimmermann: The Pig Site, 2010
c_P_pork	P content in pork	*g kg^{-1}*	1,55	Zimmermann: USDA, 2012
m_poultrymeat	poultry meat consumption	*kg cap^{-1} yr^{-1}*	4,8545	Zimmermann: Tho Xuan interview, 2011-10-14
c_P_poultrymeat	P content in poultry meat	*g kg^{-1}*	1,49	Zimmermann: USDA, 2012
m_fishseafood	fish/seafood consumption	*kg cap^{-1} yr^{-1}*	25,915	Zimmermann: VDD & UNICEF, 2011
c_P_fishseafood	average P content in fish/seafood	*g kg^{-1}*	1,8	Zimmermann: FAO, 1972 in Montangero, 2007
m_otherredmeat	other red meat (pork excluded) consumption	*kg cap^{-1} yr^{-1}*	5,5	Zimmermann: Tho Xuan interview, 2011-10-14; The Pig Site, 2010
c_P_redmeat	P content in red meat (other than those specifically mentioned)	*g kg^{-1}*	1,54	Zimmermann: USDA, 2012
m_vegetables	vegetable consumption	*kg cap^{-1} yr^{-1}*	69,715	Zimmermann: VDD & UNICEF, 2011
c_P_vegetables	average P content in vegetables	*g kg^{-1}*	0,4	Zimmermann: FAO, 1972 in Montangero, 2007
m_fruits	fruit consumption	*kg cap^{-1} yr^{-1}*	21,9	Zimmermann: VDD & UNICEF, 2011
c_P_fruits	average P in content fruits	*g kg^{-1}*	0,2	Zimmermann: FAO, 1972 in Montangero, 2007
m_cereals	cereal consumption (other than rice)	*kg cap^{-1} yr^{-1}*	12,41	Zimmermann: VDD & UNICEF, 2011
c_P_cereals	average P content in cereals	*g kg^{-1}*	2,5	Zimmermann: FAO, 1972 in Montangero, 2007
m_tubers	tubers consumption	*kg cap^{-1} yr^{-1}*	1,095	Zimmermann: VDD & UNICEF, 2011
c_P_tubers	average P content in tubers	*g kg^{-1}*	0,4	Zimmermann: FAO, 1972 in Montangero, 2007
m_milk	milk consumption	*kg cap^{-1} yr^{-1}*	15	Zimmermann: "USDA Foreign Agriculture Service Vietnam" in Ringier, 2012
c_P_milk	P content in milk	*g kg^{-1}*	1	Zimmermann: FAO, 1972 in Montangero, 2007
m_eggs	egg consumption	*kg cap^{-1} yr^{-1}*	7,3	Zimmermann: Tho Xuan interview, 2011-10-14
c_P_eggs	P content in eggs	*g kg^{-1}*	2,2	Zimmermann: FAO, 1972 in Montangero, 2007
m_miscfood	miscellaneous foods consumption	*kg cap^{-1} yr^{-1}*	15,695	Zimmermann: VDD & UNICEF, 2011
c_P_miscfood	average P content in miscellaneous foods	*g kg^{-1}*	1,2	Zimmermann: FAO, 1972 in Montangero, 2007
m_detergent	detergent consumption	*kg cap^{-1} yr^{-1}*	3,4	Zimmermann: Büsser, 2006
c_P_detergent	P content in detergent	*g kg^{-1}*	43	Zimmermann: Büsser, 2006

q_groundwater	groundwater consumption	$l\ cap^{-1}\ day^{-1}$	170	Zimmermann: Hanoi Data
c_P_groundwater	P concentration in groundwater	$mg\ l^{-1}$	0,05	Zimmermann: Assumption based on Nguyen Viet Anh, 2005

Appendix B. Requested data from Sông Công town authorities

- A map of the current sewage network (pipes and canals), including drainage areas for different parts of the sewage network.
- Complementary information to the maps:
  - Size (ha) and number of inhabitants of the different drainage areas?
  - Which wards are part of the different drainage areas?
- Information about current sanitary solutions (approximate data):
  - How many inhabitants have a WC or other solutions, i.e. dry toilets?
  - How many inhabitants are connected to septic tanks?
  - Of those connected to septic tanks, how many discharge only excreta to the septic tank and how many discharge both excreta and greywater to the septic tank?
  - Are there other solutions to excreta and greywater management? If yes, approximately how many inhabitants for each solution?
- Information about current practices for emptying of sludge from septic tanks and dry toilets (approximate data):
  - Frequency: How often (on average) are septic tanks emptied?
  - Volumes: How much sludge (on average) is emptied from one septic tank at each occasion?
  - Destination: To which destination is the sludge taken, for example landfill or composting plant and where are dry toilets emptied?
- Information about current practices for management of household food waste:
  - Volumes to different destinations, such as livestock feed, landfill, composting plant?
- Information about the future plans (about year 2030) for all of the above questions, for instance maps, sanitary solutions, treatment of food waste and discharge of effluent and sludge from septic tanks.
- Additional information about the future plans:
  - Planned areas to connect to the sewage system. Are all areas going to be connected?
  - Will new houses continue to build septic tanks?
  - Alternatives for the future pipes – one pipe for both wastewater and rainwater or separate pipes for wastewater and rainwater?
  - Options for future wastewater treatment? For example an advanced wastewater treatment plant or more extensive and cheaper treatment like wetlands.
  - Which locations are suitable for wastewater treatment plants?
  - Which year is the construction of the wastewater treatment plant intended to be finished
  - How are the authorities planning for the future in Sông Công? For example a location for tourism, industries, agriculture.

Appendix C. Interview questions

Questions to the staff at Bách Quang wastewater treatment plant:

- How many households are served by the treatment plant?
- Can they estimate how many households in Sông Công that will be connected to the wastewater treatment plant in 2030?
- Which treatment steps do they have at the treatment plant? (For example: Activated sludge, Enhanced phosphorous removal, Constructed wetlands like Free water flow, Subsurface flow, Floating treatment wetland?)
- Treatment efficiency (how many percent (%) of organic matter (COD) and Phosphorous are removed from the incoming wastewater?
- Where is the sludge that is produced at the treatment plant transported?
- Where is the treated wastewater released?
- Are they planning to construct more wastewater treatment plants in Sông Công in the future?

Questions to Environmental Cooperation and Public Work of Sông Công:

- From how many households do they collect waste and possibly sludge?
- Today and in the future, 2030?
- Do they know how much food waste (fruit peals and other) are in the waste they collect or can they make a rough estimate in %?
- How do they treat the waste?
- Will they produce biogas in the future?
- When implementing the new treatment, will they stop composting of sludge or still use composting also?
- If they use both how much do they estimate to will go to composting and how much to anaerobic treatment?
- Are they the only company performing this service?

Appendix D. Sông Công survey

This survey intends to collect information about the household's current wastewater and food waste management, with the purpose to plan for an improved wastewater treatment in Sông Công town.

1. What is your address (street name and area)?____
____

2. Is the household located in the rural or urban part of Sông Công town?
   - ☐ Rural
   - ☐ Urban

3. How long have you and your family lived in your house? ________________

4. How many persons are living in your household? ________________ persons

5. Does the household have a WC, dry toilet or other kind of solution?
   - ☐ WC
   - ☐ Dry toilet
   - ☐ Other, what? ________________

6. What kind of sanitary solution is the household connected to?
   - ☐ Directly to the river/ditch
   - ☐ Pond
   - ☐ Soil
   - ☐ Septic Tank
   - ☐ Other solution, which? ________________

If you answered "dry toilet" on question 5, please answer question number 7

7. Where are dry toilets emptied?
   - ☐ Landfill
   - ☐ Compost
   - ☐ River
   - ☐ Other, what? ________________

If you answered "other" on question 5, please answer question number 8

8. Where is the wastewater discharged?
   - ☐ Landfill
   - ☐ Compost
   - ☐ River
   - ☐ Other, what? ________________

Please turn to next page…

If your household is connected to a septic tank, please answer questions 9-13

9. Does the septic tank receive black water (toilet) and grey water (dishwashing) or only black water?
   - ☐ Black water
   - ☐ Black water and grey water

10. If the greywater is not connected to a septik tank, where is it discharged?
    - ☐ Directly to the river/ditch
    - ☐ Pond
    - ☐ Soil
    - ☐ Other, where?________________

11. How big is the septic tank?________________(m^3)

12. Have you emptied your septic tank?

    12a. If yes, how often is the septic tank emptied? ________________

    12b. If no, how long ago was the septic tank built? ________________

13. What is done with the sludge after the septic tank is emptied?
    - ☐ Landfill
    - ☐ Compost
    - ☐ River
    - ☐ Other, what? ________________

Food waste management

14. Where does the household discharge the food waste?
    - ☐ Landfill
    - ☐ Compost
    - ☐ Livestock feed
    - ☐ Other, what? ________________

15. Approximately how much food waste does the household produce daily? ________________(g/day)

Appendix E. Survey results

Household size (persons):	2	3	4	5	6	7	8	9	10	Persons total	Percent
2. Is the household located in the rural or urban part of Sông Công town?											
Urban	12	78	152	210	132	119	64	36	40	843	**100 %**
Rural	0	0	0	0	0	0	0	0	0	0	**0 %**
3. How long have you and your family lived in your house?											
0-2 years	4	27	28	15	18	0	8	0	0	100	**12 %**
3-5 years	0	6	16	20	24	7	8	0	0	81	**10 %**
More than 5 year	8	45	108	175	90	112	48	36	40	662	**79 %**
5. Does the household have a WC, dry toilet or other kind of solution?											
WC	4	51	124	175	78	91	48	18	10	599	**71 %**
Dry toilet	8	27	28	35	54	28	16	18	30	244	**29 %**
Other	0	0	0	0	0	0	0	0	0	0	**0 %**
6. What kind of sanitary solution is the household connected to?											
River/ditch	10	66	128	190	114	119	48	36	40	751	**89 %**
Pond	6	30	28	50	60	28	16	9	30	257	**30 %**
Soil	4	36	60	110	54	28	16	18	30	356	**42 %**
Septic tank	4	51	120	160	78	91	48	18	10	580	**69 %**
Other	2	6	8	5	6	0	0	0	0	27	**3 %**
7. Where are dry toilets emptied?											
Landfill	2	15	12	30	42	14	16	18	30	179	**21 %**
Compost	4	27	28	35	48	14	16	18	20	210	**25 %**
River	0	3	8	10	12	14	0	0	10	57	**7 %**
Other	4	3	0	0	0	7	0	0	10	24	**3 %**
No answer	2	0	0	0	0	0	0	0	0	2	**0 %**
Not relevant	4	51	124	175	78	91	48	18	10	599	**71 %**
8. Where is the wastewater discharged?											
Landfill	0	0	0	0	0	0	0	0	0	0	**0 %**
Compost	0	0	0	0	0	0	0	0	0	0	**0 %**
River	0	0	0	0	0	0	0	0	0	0	**0 %**
Other	0	0	0	0	0	0	0	0	0	0	**0 %**
No answer	0	0	0	0	0	0	0	0	0	0	**0 %**
Not relevant	12	78	152	210	132	119	64	36	40	843	**100 %**
9. Does the septic tank receive blackwater (toilet) and greywater (dishwashing) or only blackwater?											
Blackwater	4	36	72	110	42	49	8	18	0	339	**40 %**
Black and greywater	4	45	120	155	78	91	48	18	10	569	**67 %**
No answer	0	0	4	0	0	0	0	0	0	4	**0 %**
Not relevant	8	27	28	35	54	28	16	18	30	244	**29 %**
10. If the greywater is not connected to a septik tank, where is it discharged?											
River/ditch	2	48	112	170	78	84	48	18	10	570	**68 %**
Pond	0	9	20	50	18	14	16	0	0	127	**15 %**
Soil	4	45	104	160	72	84	32	9	10	520	**62 %**
Other	0	0	0	0	0	0	0	0	0	0	**0 %**
No answer	0	0	8	0	0	0	0	0	0	8	**1 %**

Not relevant	8	27	28	35	54	28	16	18	30	244	**29 %**
11. How big is the septic tank?											
3 m^3	2	12	8	15	12	0	0	0	0	49	**6 %**
4 m^3	0	9	64	60	6	7	0	0	0	146	**17 %**
5 m^3	0	12	28	55	30	49	24	9	0	207	**25 %**
6 m^3	2	6	8	10	0	14	16	0	0	56	**7 %**
7 m^3	0	0	4	15	18	14	8	9	0	68	**8 %**
8 m^3	0	0	4	10	6	0	0	0	0	20	**2 %**
9 m^3	0	0	0	0	0	0	0	0	0	0	**0 %**
10 m^3	0	0	4	5	0	7	0	0	0	16	**2 %**
15 m^3	0	0	0	0	0	0	0	0	10	10	**1 %**
No answer	0	12	4	5	6	0	0	0	0	27	**3 %**
Not relevant	8	27	28	35	54	28	16	18	30	244	**29 %**
12. Have you emptied your septic tank?											
	a) If yes, how often is the septic tank emptied?										
Several times per year	0	0	4	0	0	0	0	0	0	4	**0 %**
Once per year	0	27	60	110	42	56	24	9	10	338	**40 %**
Every second year	0	0	4	5	0	0	0	0	0	9	**1 %**
Every third year	0	0	4	0	0	0	0	0	0	4	**0 %**
Every fourth year	0	0	0	0	0	0	0	0	0	0	**0 %**
Every fifth year or more	0	0	0	0	0	0	8	0	0	8	**1 %**
No answer	0	0	0	0	0	0	0	0	0	0	**0 %**
Not relevant	12	51	80	95	84	63	32	27	30	474	**56 %**
	b) If no, how long ago was the septic tank built										
0-2 years ago	0	15	24	20	18	14	8	0	0	99	**12 %**
3-5 years ago	0	6	4	0	0	14	8	0	0	32	**4 %**
More than 5 years ago	4	3	24	35	18	21	0	9	0	114	**14 %**
No answer	0	0	0	0	0	0	0	0	0	0	**0 %**
Not relevant	8	54	100	155	96	70	48	27	40	598	**71 %**
13. What is done with the sludge after the septic tank is emptied?											
Landfill	0	30	72	105	48	49	24	9	10	347	**41 %**
Compost	0	21	52	90	36	42	16	9	10	276	**33 %**
River	0	3	12	30	12	0	0	9	0	66	**8 %**
Other	0	0	0	0	0	0	0	0	0	0	**0 %**
No answer	4	21	48	65	24	35	24	9	0	230	**27 %**
Not relevant	8	27	28	35	54	28	16	18	30	244	**29 %**
14. Where does the household discharge the food waste											
Landfill	8	60	120	180	102	98	48	27	30	673	**80 %**
Compost	8	54	76	145	84	49	40	27	20	503	**60 %**
Livestock feed	6	69	128	185	120	84	48	18	40	698	**83 %**
Other	0	6	16	35	54	7	24	9	20	171	**20 %**
No answer	0	0	4	5	0	7	0	0	0	16	**2 %**
Not relevant	0	0	0	0	0	0	0	0	0	0	**0 %**

Appendix F. Quantification of the confidence interval

The mean confidence interval (or margin of error) for the whole questionnaire was calculated from each question, using a 95 % confidence level.

To calculate the confidence interval (*E*) the following equation was used:

$$E = Z_{\propto 2} \frac{\sqrt{p(1-p)}}{n}$$

Where; $Z_{\propto 2}$ is a constant for 95% confidence level derived from standard deviation
p equals the relative frequency of the answer expressed in a percentage, how many percent of the sample size picked each answer
n is the total sample size

Further, to calculate the confidence interval of each question, *E* is added to or subtracted from the relative frequency of the question. To better understand, an example is displayed below.

For the question Nr 5: "Does the household have a WC, dry toilet or other kind of solution", 71% of the total sample size of 843 persons answered that they have a WC.

$$E = 1{,}96 \frac{\sqrt{0{,}71(1-0{,}71)}}{843}$$

This gives: $E = 3$

and the confidence interval for *p*:

$$Ep = 0{,}71 \pm 3$$

The confidence interval is hence between 68 % and 74 %. Thus with a 95 % confidence it is possible to say that between 68 % to 74 % of the population have a WC.

Appendix G. Modified parameters in the BAU-2030, CTP-2030 and STP-2030 scenarios

Description (symbol)	BAU-2030	CTP-2030	STP-2030
ratio of uncollected food waste to livestock (r_livestock_uFW)	0,6	1	1
ratio of uncollected food waste to local composting (r_composting_uFW)	0,4	0	0
ratio of households with septic tank for blackwater (r_septictankBW)	0,68	0,9	0,9
ratio of households with direct connection to WWTP Bách Quang (r_WWTPa)	0,015	0	0
ratio of households with dry toilet for excreta (r_drytoiletE)	0,285	0,1	0,1
ratio of households with direct river connection for blackwater (r_riverBW)	0,02	0	0
ratio of septic tank effluent to WWTP Bách Quang (r_STeffluentWWTPa)	*0*	0,08	0,08
ratio of septic tank effluent to WWTP centralized (r_STeffluentWWTPb)	0	0,92	0,32
ratio of septic tank effluent to WWTP semi-centralized (r_STeffluentWWTPc)	0	0	0,6
ratio of septic tank effluent to river (r_STeffluentRiver)	1	0	0
ratio of households with septic tank for greywater (r_septictankGW)	0,1	0,08	0,08
ratio of households with pond for greywater (r_pondGW)	0,15	0	0
ratio of households with direct connections to river for greywater (r_riverGW)	0,65	0	0
ratio of households with direct connection to soil for greywater (r_soilGW)	0,1	0	0
ratio of households with direct connection to WWTPb for greywater (r_WWTPbGW)	*0*	0,92	0
ratio of households with direct connection to WWTPc for greywater (r_WWTPcGW)	*0*	0	0,32
ratio of households with direct connection to WWTPd for greywater (r_WWTPdGW)	*0*	0	0,6
ratio of dry toilet excreta to composting (r_DTexcretaCompost)	0,5	0	0
ratio of dry toilet excreta to landfill (r_DTexcretaLandfill)	0,38	0	0
ratio of dry toilet excreta to river (r_DTexcretaRiver)	0,12	0	0
ratio of dry toilet excreta to biogas (r_DTexcretaBiogas)	0	1	1

ratio of collected food waste to landfill (r_landfill_FW)	1	0	0
ratio of collected food waste to biogas (r_biogas_FW)	0	1	1
ratio of septage to landfill (r_landfill_septage)	0,3	0	0
ratio of septage to river (r_river_septage)	0,2	0	0
ratio of septage to biogas (r_biogas_septage)	0	1	1
ratio of septage to anaerobic treatment (r_anaerobic_septage)	0,5	0	0
ratio of WWTP sludge to landfill (r_WWTPsludge_landfill)	1	0	0
ratio of WWTP sludge to biogas (r_WWTPsludge_biogas)	0	1	1

Appendix H. Parameters used in the MFA

Symbol	Description	Unit	Value	Source
m_waste	collected solid waste. 20 * 1000 / n_inhabitantsU	*kg cap^{-1} d^{-1}*	0,60	Between 30-35 ton waste/day in Sông Công town according to Director and Chairman of the TEUC
r_organic_FW	ratio of collected waste that is organic	*[-]*	0,075	5-10 % organic of collected solid waste in Sông Công, according to interview with Director and Chairman of the TEUC
m_organicwaste_FW	food waste production. m_waste * r_organic_FW / 0,6	*kg cap^{-1} d^{-1}*	0,07	Assuming lower urban collection rate than in Hanoi case. Zimmermann: Waste Viet (2010) has 70 % urban collection rate for a small city. Solid waste production 0,7 kg cap^{-1} day^{-1}
c_P_domesticFW	P content in food waste	*g kg^{-1}*	2	Zimmermann: Diaz et al., 1996
m_COD_domesticFW	COD load in food waste	*g cap^{-1} d^{-1}*	69	Zimmermann: Assumption based on Jönsson et al., 2005, p. 39
c_COD_domesticFW	COD content in food waste	*g kg^{-1}*	7	m_COD_domesticFW / m_domesticwaste * r_organic_FW
m_uncollectedFW	amount of household food waste NOT collected each year	*kg cap^{-1} yr^{-1}*	53,27	m_organicwaste_FW * 365 * 0,4
m_collected FW	amount of food waste collected each year	*kg cap^{-1} yr^{-1}*	35,51	m_organicwaste_FW * 365 * 0,6
r_livestock_uFW	ratio of uncollected food waste to livestock	*[-]*	0,6	Survey result, including "Other"
r_composting_uFW	ratio of uncollected food waste to local composting	*[-]*	0,4	Sông Công survey result
r_landfill_uFW	ratio of uncollected food waste to landfill	*[-]*	0	Assumption based on Sông Công survey results and observations
m_P_excreta	P load in excreta	*g cap^{-1} d^{-1}*	0,86	Zimmermann: Nguyen Viet Anh et al., 2007, p.16
m_COD_excreta	COD load in excreta	*g cap^{-1} d^{-1}*	21,65	Zimmermann: Jönsson et al., 2005

r_septictankBW	ratio of households with septic tank for blackwater	*[-]*	0,68	Sông Công survey result
r_WWTPa	ratio of households connected to WWTP Bách Quang	*[-]*	0,015	Staff at Bach Quang treatment plant
r_WWTPb	ratio of households connected to WWTP centralized	*[-]*	0	Included in future scenario
r_WWTPc	ratio of households connected to WWTP decentralized	*[-]*	0	Included in future scenario
r_drytoiletE	ratio of households with dry toilet for excreta	*[-]*	0,285	Sông Công survey result
r_riverBW	ratio of households with direct river connection for blackwater	*[-]*	0,02	Sông Công survey result
r_STeffluentWWTPb	ratio of septic tank effluent to WWTP centralized	*[-]*	0	Included in future scenario
r_STeffluentWWTPc	ratio of septic tank effluent to WWTP decentralized		0	Included in future scenario
r_STeffluentSoil	ratio of septic tank effluent to soil	*[-]*	0	Sông Công survey result
r_STeffluentPond	ratio of septic tank effluent to pond	*[-]*	0	Sông Công survey result
r_STeffluentRiver	ratio of septic tank effluent to river	*[-]*	1	Assumption based on Son Cong survey result, Zimmermann and observations
r_P_STsludge	P transfer coefficient in faecal sludge from septic tanks	*[-]*	0,18	Zimmermann: Assumption based on Nguyen Viet Anh, 2005
r_COD_STsludge	COD transfer coefficient in faecal sludge from septic tanks	*[-]*	0,5	Zimmermann: Nguyen Viet Anh et al., 2007

m_P_greywater	P load in greywater	*g cap^{-1} d^{-1}*	0,6	Zimmermann: Büsser, 2007
m_COD_greywater	COD load in greywater	*g cap^{-1} d^{-1}*	37	Zimmermann: Büsser, 2006
r_septictankGW	ratio of households with septic tank for greywater	*[-]*	0,1	Assumption based on Son Cong survey result, Zimmermann and observations
r_pondGW	ratio of households with pond for greywater	*[-]*	0,15	Sông Công survey result
r_riverGW	ratio of households with direct connections to river for greywater	*[-]*	0,65	Sông Công survey result
r_soilGW	ratio of households with direct soil connection for greywater	*[-]*	0,1	Sông Công survey result
r_DTexcretaCompost	ratio of dry toilet excreta to composting	*[-]*	0,5	Sông Công survey result. Includes the results from the alternative 'Other'
r_DTexcretaLandfill	ratio of dry toilet excreta to landfill	*[-]*	0,38	Sông Công survey result
r_DTexcretaRiver	ratio of dry toilet excreta to river	*[-]*	0,12	Sông Công survey result
r_DTexcretaBiogas	ratio of dry toilet excreta to biogas	*[-]*	0	Included in future scenario
r_composting_FW	ratio of collected food waste to composting	*[-]*	0,00	Sông Công survey result
r_landfill_FW	ratio of collected food waste to landfill	*[-]*	1,00	Assumption based on Sông Công survey result and director and chairman at TEUC
r_biogas_FW	ratio of collected food waste to biogas	*[-]*	0,00	Sông Công survey result
r_composting_STsludge	ratio of septage to composting	*[-]*	0,00	Sông Công survey result
r_landfill_STsludge	ratio of septage to landfill	*[-]*	0,30	Sông Công survey result
r_river_STsludge	ratio of septage to river	*[-]*	0,20	Sông Công survey result
r_biogas_STsludge	ratio of septage to biogas	*[-]*	0,00	Sông Công survey result
r_anaerobic_STsludge	ratio of septage to anaerobic treatment	*[-]*	0,50	Assumption based on Sông Công survey result, observations and director and chairman at TEUC
r_WWTPsludge_landfill	ratio of WWTP	*[-]*	1	Assumption based on

	sludge to landfill			observations
r_WWTPsludge_river	ratio of WWTP sludge to river	*[-]*	0	Assumption based on observations
r_WWTPsludge_biogas	ratio of WWTP sludge to biogas	*[-]*	0	Assumption based on observations
m'_compostleachate	lechate production	*ton* ton^{-1}	0,26	Zimmermann: Montangero, 2007
c_P_compostleachate	P content in leachate	mg l^{-1}	75	Zimmermann: Montangero, 2007
r_leachaterecycle	ratio of leachate recycled in the composting process	*[-]*	0,4	Zimmermann: Montangero, 2007
r_P_AS	P transfer coefficient to sludge in Conventional Activated Sludge	*[-]*	0,35	Based on collected data from literature review, chapter 3
r_P_EBPR	P transfer coefficient to sludge in EBPR	*[-]*	0,835	Based on collected data from literature review, chapter 3
r_P_hybrid	P transfer coefficient to sludge in Hybrid CW	*[-]*	0,695	Based on collected data from literature review, chapter 3
r_P_WWTP	P transfer coefficient to sludge in conventional WWTP	*[-]*	0,9	Based on collected data from literature review, chapter 3
r_COD_AS	COD transfer coefficient to sludge in Conventional Activated Sludge	*[-]*	0,825	Based on collected data from literature review, chapter 3
r_COD_EBPR	COD transfer coefficient to sludge in EBPR	*[-]*	0,885	Based on collected data from literature review, chapter 3
r_COD_hybrid	COD transfer coefficient to sludge in Hybrid CW	*[-]*	0,895	Based on collected data from literature review, chapter 3
r_COD_WWTP	COD transfer coefficient to sludge in conventional WWTP	*[-]*	0,95	Based on collected data from literature review, chapter 3