A Study on the Sustainable Infrastructure of the Songdo City Project: From the Viewpoint of the Metabolic Flow Perspective

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Declaration

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Abstract

In the 21st century, cities play a vital role in social, economic and environmental changes. They are the largest places of human settlement and it is expected that more than 80 percent of the world's population will live in cities by 2050 (UNEP, 2012). At the same time, as the role of cities significantly increases, it also contributes to negative outcomes on the planet. In particular, the current cities' demand for materials and energy consumption accounts for almost 80 percent of the world's consumption and it leads to serious environmental problems. The main problems are climate change, biodiversity loss, desertification, and ecosystem degradation.

In response to these urban issues, sustainable cities have emerged as an alternative way of urban life. Since cities consume a massive amount of energy, an efficient resource management system has to be established for the sustainable urban future. In addition, finding ways to reconcile economic growth, social well-being and the sustainable use of resources is imperative in urban sustainability. Since people's lifestyle and their material footprint are dependent on the urban design, construction and operation of urban infrastructures, ways to make an urban infrastructural system more sustainable will contribute to the transition towards sustainable cities.

In this study, the thesis applies Material Flow Analysis (MFA) to one of the sustainable cities, Songdo, South Korea. Before delving into the analysis, it explores the overview of the New Songdo City (NSC) project and describes its sustainable urban infrastructures. Then it examines the material flow of inputs and outputs of the city in order to reveal their sustainability and suggests a guideline for the realisation of sustainable cities. Quantitative and qualitative methodologies are used to assess and compare the material and energy flow trends for this city.

The results indicate that the general material consumption in Songdo is higher than the average in South Korea. It reflects the high-income households' consumption patterns in Songdo. In addition, one could see that the sustainable networks have merely contributed to the overall consumption. The findings from this study can be used to formulate sustainable development policies and strategies in terms of increasing the efficiency of resource and energy use in urban areas. Furthermore, this research is expected to provide a platform for realisation of sustainable cities by

highlighting the important role of urban infrastructures and their material resource flow.

Opsomming

In die 21ste eeu speel stede 'n belangrike rol in die sosiale, ekonomiese en omgewingskwessies veranderinge. Stede is die grootste vorm van menslike nedersetting en daar word verwag dat meer as 80 persent van die wêreld se bevolking in stede sal woon teen 2050 (UNEP, 2012). Op dieselfde tyd, namate die rol van stede aansienlik verhoog, dra dit ook by tot negatiewe uitkomste op die planeet. Veral huidige stede se vraag na materiaal en energie reken vir byna 80 persent van die wêreld se verbruik, en dit lei tot ernstige omgewingsprobleme. Die grootste probleme is klimaatsverandering, biodiversiteit verlies, verwoestyning en die agteruitgang van ekostelsels.

In reaksie op hierdie stedelike kwessies het volhoubare stede na vore gekom as 'n alternatiewe vorm van stadsbewoning. Aangesien stede 'n massiewe hoeveelheid energie gebruik, moet 'n doeltreffende hulpbronbestuur stelsel vasgestel word. Daarbenewens, is dit noodsaaklik om maniere te vind om ekonomiese groei te integreer met sosiale welsyn en die volhoubare gebruik van hulpbronne. Aangesien mense se lewenstyl en hul impak op die omgewing afhanklik is van die stedelike infrastruktuur, sal maniere om hierdie infrastruktuurstelsel meer volhoubaar te maak bydra tot die oorgang na volhoubare stede.

In hierde studie word, stedelike materiaalvloeiontleding toegepas op een van die volhoubare stede, Songdo, Suid-Korea. Voor die analise, sal 'n oorsig van die nuwe Songdo stad projek en die stad se volhoubare infrastruktuur gegee word. Dan word die vloei van materiaal in-en uitgange van die stad ondersoek om hul volhoubaarheid te illustreer, en stel dit 'n riglyn voor vir die verwesenliking van volhoubare stede. Kwantitatiewe en kwalitatiewe metodologie word gebruik om die materiaal en energie vloei tendense vir hierdie stad te bepaal en vergelyk.

Die resultate dui daarop dat die algemene materiaal verbruik in Songdo hoër is as die gemiddelde in Korea. Dit weerspieël die hoë-inkomste huishoudings se verbruikspatrone in Songdo. Daarbenewens kan 'n mens sien dat die volhoubare netwerke slegs bygedra het tot die algehele verbruik. Die bevindinge van hierdie studie kan gebruik word om die volhoubare ontwikkeling van beleid en strategieë te formuleer in terme van die verhoging van die doeltreffendheid van die hulpbron-en energie gebruik in stedelike gebiede. Verder word verwag dat hierdie navorsing 'n

platvorm in terme van die realisering van volhoubare stede sal voorsien deur die belangrike rol van stedelike infrastruktuur, en die materiaal hulpbron vloei te beklemtoon.

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List of Acronyms and Abbreviations

BIS	Bus Information System
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DAC	Development Assistance Committee
ECI	Environmental Corporation of Incheon
FEZ	International Free Economic Zone
GCF	Green Climate Fund
GDP	Gross Domestic Product
IBD	International Business District
IFEZ	Incheon Free Economic Zone
IMC	Incheon Metropolitan City
IMF	International Monetary Fund
INTECO	Incheon Total Energy Company
IT	Information Technology
ITC	Incheon Transit Corporation
KEPCO	Korea Electric Power Corporation
KPF	Kohn Pedersen Fox
K-water	Korea Water Resource Corporation
KNOC	Korea National Oil Corporation
KOGAS	Korea Gas Corporation
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
LEED-ND	LEED for neighbourhood Development
LNG	Liquefied Natural Gas
MCT	Ministry of Construction and Transportation
MFA	Material Flow Analysis
MOE	Ministry of Environment
MOU	Memorandum of Understanding
NGO	Non-Governmental Organisation
NSC	New Songdo City
NSIC	New Songdo International City
NSSD	National Strategy for Sustainable Development
OECD	Organisation for Economic Cooperation and Development
RFID	Radio Frequency Identification
SD	Sustainable Development

SNTD	Songdo New Town Development
U-city	Ubiquitous city
UNEP	United Nations Environmental Program
UN Habitat	United Nations Human Settlement Program
UNOSD	United Nations Office for Sustainable Development
WBCSD	World Business Council for Sustainable Development
WHIMC	Waterworks Headquarters Incheon Metropolitan City

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Chapter 1 – Introduction

1.1 Background

In the 21st century, our cities face two major challenges – population increase and resource use. By 2007, it is estimated that almost 3.5 billion of the world's population lived in urban settlements (UNEP, 2012). According to the United Nations Human Settlements Program (UN Habitat, 2008), the majority of the world's population growth will take place in cities putting heavy pressure on heavy urban infrastructure in the next decades (James, 2012). At the same time, human beings have always been closely linked to the use of natural resources for their living, especially fossil fuel. Since the world economy and its infrastructures have been built based on fossil fuel energy consumption, economic development has meant that fossil fuel consumption in many areas has been massively increased over the last decades. These areas are agriculture, industrial, commercial and residential buildings, transportation, and civil infrastructures - all of which depend heavily on fossil fuel in order to function (Mezher, 2011). Beside that, "Today humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to regenerate what we use in a year" (Mezher, 2011:137). Of particular importance in this regard is that the main consumption of resources occurs in cities. Almost 80% of the world's material and energy supply is consumed in urban areas, producing 75% of global carbon emissions (UNEP, 2012).

In considering the growing urban population, it seems quite clear that a large amount of resources are going to be consumed, transformed and disposed of in cities across the world (UN Habitat, 2011). Now the demand for natural resources has reached the earth's limit and it has become a serious threat to human survival (Behrens et al., 2007). Since the urban areas and the surrounding environment are interconnected, the problems of cities cannot be seen as just urban issues but as the world's problems (Dentinho, et al., 2011). In this regard, the world's future will be dependent on the sustainability of cities because another three billion people are expected to live on the planet by 2050 and the majority of the population will live in towns and cities (Swilling, 2004).

If we want our next generation to sustain their social life as we do, developing a positive and environmental way of urban life is necessary. Given the situation of increasing urban population, the alternative ways to sustain our life is to increase energy efficiency and minimise resource use (UNEP, 2012). Following this, different forms of environmental movements have emerged in cities, such as "Sustainable city," "Carbon neutral zero-waste," "Eco-city," and "Green city" (Shwayri, 2013). In order to achieve this, decoupling should be considered as a main concept of sustainable cities. "The term 'decoupling' is typically used to describe the disassociation of economic 'goods' from environmental 'bads', and can be extended to include all changes to the negative relationship between broader societal benefits and the environment" (UN Habitat, 2011:5). In this regard, decoupling can be seen as the pursuit of economic development and environmental protection at the same time. However, as the majority of economic growth is based on the resource consumption, the question that arises is how can we decouple economic growth from resource use in the real world, specifically in urban areas.

When it comes to city-level decoupling, infrastructures provide numerous opportunities for resource efficiency that protect the ecological boundaries. It is situated between urban consumers and the resources and has major impacts on urban resource flow (Hodson et al., 2011). These infrastructures provide transportation, food, sewerage, water, and energy distribution. Moreover, the design, construction and operation of infrastructures contribute to the life-style of citizens. How urban residents purchase, consume and dispose of the resources is dependent on the urban system. Reconfiguring urban infrastructure is therefore a key driver of the decoupling of economic development from the resource use, as well as improving basic welfare and access to resources for urban citizens (UNEP, 2013).

The urban metabolism model provides a guideline to perform sustainable urban planning and establish sustainable urban policies to build sustainable urban infrastructures (Pina & Martinez, 2013). Material flow analysis (MFA) has emerged as an essential tool to measure the resource flow of an urban system. MFA includes identifying and accounting for the flows associated with inputs (energy and water) and outputs (waste, sewage and greenhouse gas). From this analysis, it is able to observe the material flow of cities and compare with other cites (Robinson, et al., 2013).

Songdo is located in South Korea and will be 'ready for use' in 2020. Songdo was originally designed as a free economic zone for international business, but the city plan changed in order to be the first 'smart city' through green technologies. Gale

International, the project developer, CEO John Haynes stated, “Songdo city will be one of the greenest, most sustainable, most ubiquitous cities in the world, with an unmatched quality of life” (Kuercker, 2013:6). Although the New Songdo City (NSC) project is still in it’s early stage of development and thus too early to determine its success, the current urban infrastructure and its resource flow can be used for indicating the status of the urban sustainability.

1.2 Research problem & objective

1.2.1 Research problem

Material inputs and outputs have to be reduced through efficient urban infrastructures to develop sustainable cities (UNEP, 2013). Hence, it seems necessary to examine the main features of urban infrastructures though the case study.

One of the main reasons why Songdo has chosen for the case study is that Songdo has claimed itself as the most greenest and wired city in the world (Gale International, 2014). The city’s main approach for sustainability is based on the green design, which promotes both economic development and environmental protection through advanced technologies. This approach has been the mostly used approach to alleviate environmental problems in the world over the last few decades. According to Khanna (2010, 128). “Songdo might well be the most prominent signal that we can—and perhaps must—alter the design of life”. In this regard, there is a high possibility that Songdo can be a role model for a sustainable future to other cities. When all the things above are taken into consideration, the following research questions arise;

1) What is the origin of the New Songdo City (NSC) project?
2) What is the approach to sustainable urban infrastructure in Songdo?
3) How sustainable is Songdo’s urban infrastructure from a metabolic flow perspective?
4) Why the material footprint has to be considered for the city planning?

1.2.2 Research objective

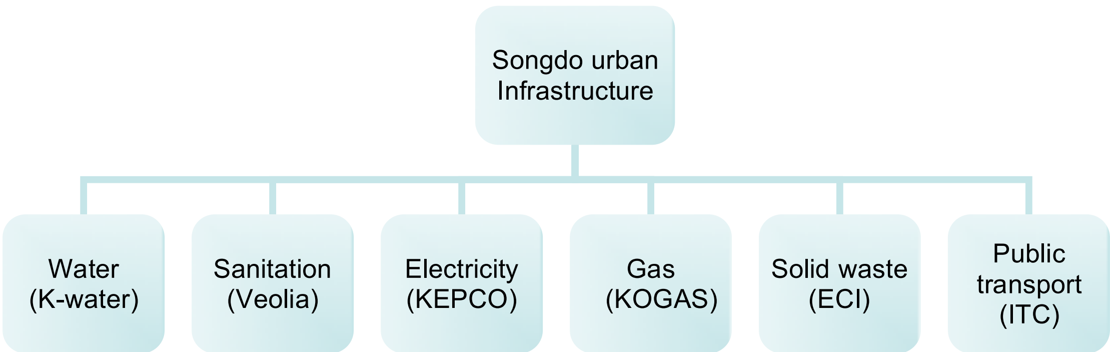
The overall objective of this research is to examine the infrastructure of Songdo through the metabolic flow perspective. As a result, it is expected to estimate the Songdo resident's material footprint and thus it is able to check the current status of sustainability and suggest improvements for sustainable cities. Specifically, the project aims to:

1) Explore the background of NSC project and sustainable development strategies.
2) Describe Songdo's urban infrastructures in terms of sustainability.
3) Apply MFA to Songdo and analyse annual resource flow for the following areas: water, sanitation, energy, solid waste and public transportation.
4) Estimate the material footprint of the average Songdo resident and suggest guidelines for the realisation of sustainable cities

1.3 Research strategy

In order to accomplish the research objective, it is essential to visit urban infrastructures in Songdo. According to Gale International and Kohn Pedersen Fox (KPF)'s sustainability report (2014), the city built four main sustainable infrastructures – water use network, waste collection and treatment system, energy network and public transportation. Figure 1.1 shows the institutions that are responsible for the urban infrastructures.

Figure 1.1 Structure of urban infrastructure system in Songdo



However, a field trip to above urban infrastructures is allowed only for group visitors, not for an individual and thus the author was unable to partake in the field trip. Additionally, these institutions denied to provide the resource consumption data to individuals without formal letter from certain authorities. In this regard, the author applied for an internship position at the Non-Governmental Organisations (NGOs) and international organisations in Songdo in order to have more access for data. Fortunately, the author got an internship offer from the United Nations Office for Sustainable Development (UNOSD), an organisation which was established to support governments in implementing international agreements on sustainable development (UNOSD, 2014). By undertaking an internship, the author was able to access the resource consumption data from the institutions and conduct the participant observation for the case study.

1.4 Research methodology

1.4.1 Literature review

A literature review is a fundamental part of research as it provides a theoretical background for the research. It also suggests an overview of studies in terms of the research problem (Mouton, 2001). According to Mouton (2001:87), a literature review is imperative for the following reasons: *to avoid duplication of previous studies; to discover the most recent and authoritative theories and debates about the research problem; to identify what literature is scientifically proven and is reliable; and to understand the most widely accepted definitions of key concepts in the field of the research.*

This thesis reviews the general academic framework of the sustainable city theory. As a background, the effects of urbanisation and the emergence of sustainable cities are looked into first. It then moves on to the identification of sustainable city theories based on existing documents, focusing particularly on city-level decoupling, urban infrastructure and urban metabolism. Since the increase of resource consumption is causing social and environmental problems in cities, the ways to minimise environmental impacts and maximise resource efficiency are the core values of the sustainable city theory. Also, effective urban infrastructure can possibly impact on the flow of resources. In this sense, city-level decoupling and urban infrastructure play a pivotal role in this thesis. It explains how city-level decoupling is a matter for urban sustainability and why urban infrastructure is important for decoupling in cities. The concept of green design is provided, as it is regarded as the main urban design trend. Lastly, in order to indicate the sustainability in Songdo, the urban metabolism model and MFA will be reviewed and applied.

1.4.2 Case study

According to Yin (2003:13), "a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context". It is most likely to be appropriate for "how" and "why" questions (Yin, 2003) and provides "complex explanations or interpretations in the form of an unfolding plot or narrative story about particular people or specific events" (Neuman, 2011: 177). In addition, a case study is useful in terms of a "holistic understanding of the situation, phenomenon, episode, site, group or community" (Kumar, 2011: 127), since it entails not only qualitative data but also quantitative data. Therefore, it can be seen as a comprehensive research method that offers a complete understanding of the case.

For research, there are six types of case study research can be identified. Case study is based on single- or multiple- case studies; second, whether single or multiple, the case study can be exploratory, explanatory, and descriptive. A single case study focused on a single case only whereas multiple-case studies presented two or more cases within the same subject. An exploratory case study is intended to formulate the questions and hypotheses of a study or to check the feasibility of the future research. An explanatory case study presents data based on the cause-effect approach by describing how events happened and are connected. A descriptive case study presents a complete description of the phenomenon within its context. It is designed to describe, explain, and interpret conditions of the specific place and time. It is also described as an in-depth study as it reflects the real life context. Participants are able to gain an insight or deep understanding of a phenomenon through the detail of the process of observation and investigation (Yin, 2003).

Given Songdo is a unique case of sustainable cities, it is worth documenting and analysing as a single case study. Furthermore, the descriptive case study is most likely to be appropriate for the research objective as it enables to provide a deep understanding of the NSC project and to examine its sustainable infrastructures from a metabolic flow perspective. In this regard, the following sources of evidence are presented - documentation, archival records, direct observations, and participant-observation for the research.

Documentation

Documentary information is relevant to most case study topics. For case studies, the most significant role of documents is to provide specific information related to the case. Therefore, it is necessary to allocate time for using local libraries and other information centres and examine any projects or organisations being studied before field visits (Yin, 2003). According to Yin (2003: 85), the following variety of sources are regarded as documentations:

- Agendas, announcements and minutes of meetings, and other written reports of events
- Administrative documents - proposals, progress reports, and other internal records
- Formal studies or evaluations of the same "site" under study
- Newspaper clippings and other articles appearing in the mass media of in community newsletters

The documentation information provides a detailed description of how the NSC project has been progressed and how Songdo's infrastructures are organised. This source of information offers a key evidence to address the research objective 1 and 2. For instance, the Incheon Metropolitan City (IMC) published the Incheon Free Economic Zone (IFEZ) report to provide the general overview of the IFEZ project, including Songdo. From the Gale and KPF's sustainability report, one could see that how the Songdo's infrastructures are designed for sustainability. Furthermore, the local resident's feedback for Songdo's infrastructures can be referred from the local newspaper. Consequently, a number of documentations from public and private sectors are beneficial to achieve the research objectives.

Archival records

Archival records can be used as supplementary sources of information in producing a case study. Survey data, such as census records or data in relation to the case study, is very imperative for quantitative analysis. Additionally, most archival records are intended to provide specific information and thus it has to be aware of the usefulness and accuracy of data in accordance with the research purpose (Yin, 2003).

In this study, archival records play a vital role in conducting MFA, which is relevant to the research objective 3. Yeonsu-gu Municipality provides the number of residents that officially registered in Songdo. Moreover, material consumption data in Seoul and Incheon are available from their municipalities' website. Besides that, the author directly collected the data of electricity consumption and solid waste generation from the Korea Electric Power Corporation (KEPCO) and the ECI.

Direct observation

In order to create the opportunity for direct observation, a field visit to the case study site is required. It is useful in providing some additional information, especially when the previous research is not yet implemented. For instance, when a new technology is introduced to the market, the direct observation is helpful to understand the actual uses of the technology or potential problems being occurred. Beside that, taking photographs at the case study site is able to guarantee the reliability of observational evidence to outside observers (Yin, 2003).

The location of the UNOSD is close to the downtown area in Songdo, therefore the author could easily access to public transport system, such as the bus, subway, bicycle lane, and car sharing system. Furthermore, the operation of pneumatic waste collection system and its adverse effects can be observed during the field visit in Songdo.

Participant observation

Participant-observation is useful especially when the case study data is not available. As "taking some other functional role in a neighborhood, such as serving as a storekeeper's assistant" (Yin, 2003:94), it provides the most distinguishing opportunity to gain access to events or groups. In the case of Songdo, since the size of the city is small and it is still under construction, the majority of data on material consumption in this city was not available on public websites. However, as the UNOSD has a tight business network with the IMC, the author was able to gain access to the internal data of resource consumption. The data of water consumption, Liquefied Natural Gas (LNG) consumption, and sewage generation were received through the IMC.

The researcher visited Songdo's infrastructures and gathered the data relating to the topic through participant observation. The UNOSD organized the sustainable development workshop and conducted the field trip to the urban infrastructures in Songdo for the workshop participants. The author could also join in the field trip as an intern. The field trip to the Songdo Compact Smart City Centre provides the overview of the NSC project and thus the author was able to access the data for the history of Songdo. From the Waterworks Headquarters of Incheon Metropolitan City (WHIMC) and the Environmental Corporation of Incheon (ECI) visit, one could observe how the water supply and sewage treatment system and the municipal waste incineration facility were operating.

1.5 Outline of the thesis

Chapter 1 includes an introduction to the topic of this research and describes how the topic is associated with the development of research problems and objectives. It also embraces an overview of the research methodology.

Chapter 2 is a literature review that serves as a theoretical background for the research. It begins with an explanation of the material consumption in cites and its following the resultant environmental problems such as resource exploitation, ecological destruction and climate change. Thereafter, the discussion moves on to the theory of a sustainable city, which has emerged as a response to these environmental problems. It then explains why the research focuses on the urban infrastructures for sustainability. It also mentions the reasons why Songdo was chosen as the case study for this research. This chapter also introduces the concept of MFA, which will be used as an indicator of the sustainability of Songdo in chapter 5.

Chapter 3 is an overview of the NSC project since 1980 in relation to the sustainable city project. The thesis will show how Songdo has evolved and progressed toward a sustainable city. The six core design principles of Songdo are presented, as well as an overview of the National Strategy for Sustainable Development (NSSD). In this chapter, the important role of the government in terms of the implementation of sustainable development policy can be observed.

Chapter 4 shows how Songdo's urban infrastructures are designed and how they are operated. It presents the information from the field trip (observation) in Songdo.

Based on the project developer's sustainability report, 4 main sustainable urban infrastructures will be reviewed - water use network, waste collection and treatment, energy network and public transportation. This chapter provides a detailed description of these infrastructural systems.

Chapter 5 applies the theoretical framework developed in Chapter 2 to the case of Songdo's infrastructures to examine its sustainability. The amount of material consumption and its outputs, such as the usage of water, electricity, gas and the generation of sewage, solid waste and greenhouse gas will be analysed from a metabolic flow perspective. Thereafter, findings and suggestions on how to improve sustainability in the city are presented based on results from the analysis.

Chapter 6 provides a summary of the thesis, its limitation, and future areas for research and concluding argument. The conclusions are drawn from the MFA of Songdo's infrastructures. The chapter closes by recommending further studies to analyse the challenges and complex urban systems with a view to improving the knowledge available for decision makers.

Chapter 2 – Literature Review

2.1 Introduction

Cities are central to the human settlement. They are the places where people live, produce and consume. The majority of economic, political and social activities are concentrated in cities and thus they can be seen as core drivers of economic growth. It has become evident that there is a correlation between economic growth and urbanisation. Since 1950, there has been an increase in the world's economic growth, which has influenced urbanisation (Girardet, 2004). No country has ever accomplished sustained economic and social development without urbanisation. This is one of the reasons why people from rural areas move to urban ones. As better infrastructures are built and access to urban products and information systems are secured in cities, rural people migrate to urban areas in search of more job opportunities, social relation and high incomes. For these reasons, urbanisation has happened over the last decades. According to the UN-Habitat report (2012), there are 7 billion people in the world today and the urban population accounts for almost 3.5 billion. Furthermore, it is expected that more than 80 percent of the world's population will live in cities by 2050.

Even though cities account for less than 3 percent of the land surface, nearly 50 percent of the world population lives and works in cities. It is estimated that urban residents contribute to almost 60 percent of the global Gross Domestic Product (GDP) (UN Habitat, 2012). In light of this situation, cities have to be more dependent on the outside resources such as food, water, energy, and materials. Dealing with the increasing urban waste and pollutants in water and air are also challenging parts of urban management (Brown, 2008).

The significant increase in the size of cities and the roles they play are contributing to the heart of the problems facing the earth. Then, what are the main problems in cities? Generally, major cities are facing problems such as growing automobile use, suburban sprawl, pollution, profligate use of natural sources, rising inequities and loss of indigenous landscapes and ecosystems (Wheeler & Beatley, 2004). These problematic urban issues result from the concentration of intense economic systems and high levels of consumption in cities. It is clear that the urban system and its consumption patterns dominate the human activity on earth and therefore cities will continue to demand more resources in order to function properly. Since most population and economic growth are expected to take place in urban areas in the upcoming decades, the exploitation of national resources could become even more serious, unless we explore different ways of managing them (Girardet, 2004).

From this background, urban sustainability has become a major focus in the 21st century. In response to these urban issues, sustainable cities have emerged as an alternative way of urban life. Hence, this literature will examine the current urban energy consumption, climate change, the concept of sustainable cities, urban infrastructures and the metabolism model in order to deepen the understanding of cities. Lastly, the literature will briefly review the NSC project and explain why Songdo is chosen for the case study.

2.2 Energy consumption in cities

Human activity has always been related to the use of energy. Everything that is produced or consumed is based on energy supply. Energy is not only required to produce electricity or to fuel the transportation that is essential to our urban life, but also for the process of energy production or disposal; for example, water needs energy for pumping or supply and waste has to be delivered to a landfill site for disposal (UN Habitat, 2012) In this sense, energy can be regarded as the life-blood of the economy. Through a country's energy production and consumption, we are able to evaluate the level of countries' economic development (Thematic Social Forum, 2012). However, our economic system has been exclusively focused on the exploiting of natural resources, not protecting or recycling of them. Over the past decades, demand for natural resources has reached the planetary boundaries and it has become a serious threat to the function of the economy due to associated environmental problems such as climate change, biodiversity loss, desertification, and ecosystem degradation (Behrens, et al., 2007).

> *Today humanity uses the equivalent of 1.5 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to regenerate what we use in a year. In 2050, we will use the equivalent of 2.5 planets if we keep using resources at the status quo; and therefore we need to do things differently and in a smarter way in order to survive in a resource-constrained world* (Mezher, 2011:137).

Over the last 100 years, the world economy and its infrastructure have been built based on the burning of fossil fuels as the main source of energy. A majority of economic activities, including agriculture, industrial, commercial and residential building, transportation, and civil infrastructure are not able to function without a proper supply of fossil fuel energy (Mezher, 2011). The issue is that the ways that people produce, distribute and utilise of fossil fuels are causing the environmental, social and economic problems in our society. For instance, the burning of fossil fuel has contributed to the increase of greenhouse-gas emission on the planet by more than 40%, thereby causing climate change issues (Thematic Social Forum, 2012).

When it comes to the city-level scale, the energy issue is more critical because the demand for environmental goods and services is increasingly higher than other areas. Cites where a large number of people are concentrated, consume more and more food, water and energy (Dentiho, et al., 2011). They use 75 percent of the natural resources on the planet and about 67 percent of greenhouse gas emissions are produced by cities at the same time. Moreover, the energy and material that are consumed in cities also have to be disposed of in various ways, such as solid, liquid and gaseous waste. With this in mind, cities are places where intense energy and material consumption as well as waste production are occurring (UN Habitat, 2012). Given the concentrated demand for resources in cities, the resource constraint has become a global issue in a number of different sectors by threatening the cities' growth. In particular, access to oil, electricity, water, food and transport are important parts of a city's competiveness, due to the global resource limitations on the availability of materials for production and construction (UNEP, 2012).

If cities do not properly manage natural resources or waste, it can easily ruin the quality of the air and water, thereby negatively impacting the natural living conditions. (UN Habitat, 2008). Natural resources are getting more scarce and expensive, as the demand for fossil fuel energy is increased. Also, high-energy consumption contributes to the global warming. Even though the fossil fuel resources are being rapidly depleted, the fossil fuel oriented urbanisation is still expanding all over the world and causing the serious environmental degradation (UN Habitat, 2012).

2.3 Cities and climate change

> *The 1990s was the hottest decade of the last century and the warming in the 20th century was warmer than anything in the last 1,000 years in the Northern Hemisphere. We will see a drier summer in arid and semi-arid areas which will make water management much more difficult in the future. Major ecosystems such as coral reefs and forests will suffer from the rising temperatures as never before* (Girardet, 2004:10).

There seems to be a growing awareness of global climate changes that are becoming a reality in the world. The Antarctic and Arctic glaciers are gradually melting. Billions of people are experiencing unexpected and irregular weather changes, such as high-temperature, droughts, storms, floods and forest fires. For instance, almost 20,000 people were killed by heat injury in Europe in 2003, which was caused by global warming (Girardet, 2004). Since 1906, the earth's surface temperature has increased from 0.74 degrees to 1.8 degrees. It is clear that human activities have mainly contributed to the global rise in temperature. The burning and consumption of fossil fuels is responsible for more than 70 percent of this temperature rise. Greenhouse gas, especially CO_2, which is most directly related to global warming, has increased to close to 42 percent since 1750 (UN Habitat, 2008).

Now climate changes seem likely to menace human survival in different regions and locations of the world. In particular, unexpected weather changes will occur at faster rates and more irregularly than before. Cities may suffer from extremely hot and cold weather, which will lead to increased energy demands for heating and cooling. Furthermore, cities are also vulnerable to environmental disasters such as cyclonic storms, flooding, water table rise, electrical storms, hurricanes, and tornadoes. Since infrastructures of city are only able to cope with a minimum range of rain, temperature and wind, the vulnerability of cities will be increased. Consequently, climate change has become one of the most stressful issues facing humanity today (UNEP, 2012).

Global climate change occurs almost simultaneously with urbanisation. It is no coincidence that climate change and urbanisation have become major international environmental issues at the same time. As most human and economic activities are taking place in urban areas, cities play a vital role in carbon emissions and climate change. Cities are getting bigger as more people move from rural area, but this creates many problems in terms of environmental pollution and the general quality of life. In particular, many cities have failed to manage the natural resources efficiently for their urbanisation and place heavy environmental burdens on the world's resources by causing climate change (UN Habitat, 2008). In a certain way, urban development is proportionally associated with some of the environmental and social challenges in cities. This includes the high-energy consumption, a high level of greenhouse gas emissions, a massive ecological footprint, high resource consumption (water, food) and large infrastructure costs, the growth of slums and lack of livelihood opportunities (UN Habitat, 2012).

As can be seen above, there are various factors that contribute to unsustainable aspects of cities. These factors include an increase of population, depletion of natural resources and environmental degradation. All these factors are interconnected and therefore should be dealt with simultaneously (Mezher, 2011).

2.4 Emergence of sustainable cities

Cities form the ground for knowledge, culture and creativity and thus an efficient urban resource management system has to be established for the sustainable future of the human being. In order to achieve this, the physical limitation of the global eco-system has to be considered first. In doing so, sustainable utilisation of natural resources is possible within the ecological limit. The history of collapsed ancient cities shows the dangers of overuse of the natural capital of the local and regional hinterland (Girardet, 2004). As mentioned, the current cities' demand for materials and energy supplies accounts for almost 80% of the world's consumption and thereby threatens not just the future of cities, but the whole of our planet.

In addition, the increasing population and personal income level in developing countries, such as China or India, has greatly contributed to the increasing global material consumption (UNEP, 2012). In this regard, the world's future will be dependent on the sustainability of cities because another three billion people are expected to live on the planet by 2050 and the majority of the total population will live in towns and cities (Swilling, 2004). In dealing with these issues, a system for balancing the levels of consumption and limited resources is necessary for cities (UNEP, 2012). In particular, in order to protect our global environment and improve the quality of life in cities, we have to commit ourselves to a sustainable way of life, which entails a sustainable pattern of production and consumption, prevention of pollution, and respect for the planetary boundaries (Girardet 2004). Hence, finding ways to reconcile economic growth, well-being and the sustainable use of resources are imperative in the urban context (Hodson, et al., 2012).

From the historical facts, one is able to see the reconciliation of environmental and social urban movements. Jeb Brugmann, Executive Secretary of the International Council for Local Environmental Initiatives, has mentioned that cities have been slowly changed toward sustainability. In the 19th century, the first environmental protection management facilities, such as drain systems, waste collection and healthy water supply were built in urban areas. In the 20th century, local municipalities constructed the environmental infrastructures, such as sewage and sludge treatments (Blassingame, 1998). In 1975, Richard Register established the nonprofit organisation, called the Urban Ecology. The main objective of this organisation is to rebuild cities in balance with nature. They endeavored to build a slow street in Berkeley, planting and harvesting fruit trees on streets, designing and building solar greenhouses, promoting public transportation and cycling, discouraging use of private vehicles and constructing a local freeway and holding conferences on environmental and social issues (Roseland, 1997). These eco-city movements can be seen as the origin of sustainable cities.

There is an increasing consensus that urban sustainability has gained great attention among the global societies. For instance, the concept of ‘sustainable cities’ and ‘sustainable human settlements’ was clearly indicated at the second UN Conference on human settlements (also known as the City Summit) held in Istanbul in June 1996. Even though there were some points of disagreement among the different groups at the summit, all government delegations agreed to support the idea of ‘sustainable human settlements’ or ‘sustainable urban development’. However, in spite of the general increase of recognition of the need for urban sustainability, there is not a clear definition of ‘sustainable cities’ thus far because the concept of ‘city’ is too broad and cannot cover all of its characteristics (Haughton and Hunter, 1994*).* The concept of sustainable cities includes such a wide range of environmental, economic, social, political, demographic, institutional and cultural goals. Most governments and international institutions, therefore, are associated in terms of the sustainable city context (Satterthwaite, 1997). In this sense, it follows that different forms of urban movement in terms of sustainability can be seen as follows – eco city, green city, sustainable urban development, community economic development, etc. It is helpful to begin by briefly reviewing some of these concepts in order to further the understanding of sustainable cities.

> *A green city is a living city by definition. It is an existing city, where the full potentials of all the intricately interconnected forces of nature are realized. In a sense, a green city is complete in its survival capacity.*
>
> *Greening the city in the context of the urban explosion of Third Word cities implies a reconstruction process that goes beyond anti-pollution measures, conservation of green areas, and reforestation of the surrounding environment of the city. As well, it goes way beyond better transportation systems, public services, and waste recycling technologies to rationalize the use of resources and energy with the urban ecosystem.*
>
> *Sustainable urban development must aim to produce a city that is 'user-friendly' and resourceful, in terms not only of its form and energy efficiency, but also its function, as a place for living.*
>
> *Sustainable urban development should have as its goal that cities (or urban systems) continue to support more productive, stable and innovative economies, yet do so with much lower levels of resource use.*
>
> (Haughton and Hunter, 1994:24~25)

As we have seen, a green city generally highlights the harmonisation between cities and natural eco-systems. Sustainable urban development, on the other hand, focuses more on the efficient use of resources. In the light of these approaches, the term "sustainable cities" can be defined or understood as below.

> *A sustainable, resource efficient city can be defined as a city that is significantly decoupled from resource exploitation and ecological impacts and is socio-economically and ecologically sustainable in the long term. By contrast, a low-carbon growth contributes to achieving sustainability but does not guarantee sustainability in itself* (UNEP, 2012:9).
>
> *A sustainable city is one that reduces it's total consumption of inputs, increases the efficiency of it's throughputs, and transforms all it's waste outputs into productive inputs (Swilling, 2004:9).*

A sustainable city enables all its citizens to meet their own needs and to enhance their well-being, without degrading the natural world or the lives of other people, now or in the future (Girardet 2004:6).

A sustainable city is one in which its people and businesses continuously endeavor to improve their natural, built and cultural environments at neighborhood and regional levels, whilst working in ways which always support the goal of global sustainable development (Haughton and Hunter, 1994:27).

Even though one can see the different definitions of sustainable cities, it is quite obvious that sustainable cities, as alternative future city models, have to address the current urban issues. In addition, from the above definitions, we are able to see that efficient resources management is a core value of sustainable cities. In particular, in order to address urban issues, natural resource use and its associated negative environmental impacts has to be separated as much as possible from the economic activity that supports a growing population (UNEP, 2011).

In order to further the understanding of efficient resource use, it is necessary to explore the term ‘decoupling’. According to the UNEP’s International Resource Panel, ‘decoupling’ has been introduced as a way to disconnect the linkages between economic growth and the depletion of natural resources and environmental degradation. While numerous economic activities have negative environmental impacts on the planet, decoupling growth from efficient resource use is necessary to encourage economic development and environmental protection (UNEP, 2013). In this sense, resource decoupling can be defined as “the rate of use of resources from economic growth rates, which is equivalent to ‘dematerialisation” (Swilling & Eve, 2012:77). It entails reducing the total amount of material, energy, water and land resources output for the same economic activity. An increase in resource productivity or efficiency is essential for resource decoupling (UNEP, 2011). Thus, the question arises of how the decoupling can be implemented at the city-level.

2.5 Urban infrastructures

“Cities are the summation and densest expressions of infrastructure. Or, more accurately, a set of infrastructures, working sometimes in harmony,

sometimes with frustrating discord, to provide us with shelter, contact, energy, water and means to meet other human needs" (Herman & Ausubel 1988:1).

The notion of infrastructure refers to "physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions" (Fulmer 2009:31). In this regard, the progress of urbanisation implies that every aspect of human activities is likely to become more reliant on the urban system to meet the human needs, such as health, security, economic opportunity, and social well-being (Graham, 2010).

When it comes to the city-level decoupling, one must understand the significant role of infrastructures in the urban ecosystem. Urban researchers and the sustainability community neglected the importance of the vast networked urban infrastructures that connect natural resources and information to our daily life (Swilling, 2011). However, networked infrastructures have played pivotal roles for the promotion of urban sustainability. These infrastructures, such as energy, water, sewage, solid waste, food and transport system mediate urban resource flows and have a major impact on everyday life and local economies (Monstabt, 2009). At this point, there are two main reasons why urban infrastructures are critical in terms of urban sustainability.

First, as the second wave of urbanisation continues, mankind will become more dependent on the operation of urban infrastructure systems.

Emerging-market cities will need better housing and infrastructure – including transportation, water, sanitation, and electricity. Meeting these needs will require an estimated cumulative expenditure of $30 trillion to $40 trillion by 2030- the equivalent of 60 to 70 percent of the total global investment in infrastructure (The Boston Consulting Group, 2010).

Second, efficient infrastructure systems have a great potential to reduce future energy resource use because design, construction and operation of urban infrastructures will directly determine how resources are produced and distributed (UNEP, 2013). In this sense, the positive impacts of effective energy use can be analysed in terms of economic, social and environmental factors. Eco-efficient infrastructures are able to contribute to economic development, as they support economic growth and deliver services to local communities. Additionally, since its outputs have a direct impact on environmental results, they are also an important part of urban ecosystems. For instance, considering the massive resources and energy consumption that are related to each other, energy savings and carbon emission reduction through the eco-efficient infrastructures are possible, as well as reducing the region's ecological footprint (Ness, 2008). However, if they are not properly managed, environmental degradation will gradually undermine the equitable resources distribution, thereby causing the rising price of resources. Therefore, the mismanagement of infrastructures not only ruins the environment ecosystem but also causes social problems, especially the poverty gap between the rich and the poor (Swilling, 2011).

With this in mind, the main concept of resource efficient infrastructure is to maximise service delivery while minimising resource use and environmental impact. In keeping with this approach of sustainable infrastructure, it is generally acknowledged that "sustainable urban infrastructure focuses on the prevention of unnecessary consumption of natural resources (especially non-renewable ones) and mitigation of harmful emissions" (Zavrl & Zeren, 2010:2951). At the UN Meeting on Sustainable Infrastructure, it is described as follows: "a sustainable infrastructure system is one that facilitates the delivery of transport, energy, water and other services to support social and economic development in an integrated, resource-efficient and socially inclusive manner" (Ness, 2008:291).

It is obvious that infrastructural systems enable resource flows through cities. Throughout urban systems, coal transforms into electricity, oil converts into petroleum and provides fuel for transportation. In this sense, infrastructures can be seen as intermediaries between urban consumers and the resources since they create numerous opportunities for decoupling oriented innovations that deliver the benefits of the city within ecological limits. They are essential for promoting resource efficiency and decoupling at the city level, as well as a "way of life" for citizens. Therefore, the increasing amount of investment in urban infrastructures provides an opportunity for economic development and sustainable consumption of natural resources (Hodson, et al., 2011).

Consequently, the "way of life" of residents and their material footprint will be dependent on the urban design, construction and operations of urban infrastructures (UNEP, 2013). Considering how to make an infrastructural system more sustainable will help the transition to more a sustainable way of life in the urban future. Therefore, it requires careful consideration in terms of making decisions about infrastructures that mediate the provision of basic urban services (UNEP, 2012).

2.6 Green design

The green design approach has been the mostly used approach to alleviate environmental problems in the world over the last few decades. In the late 1980s, there was a growing awareness of environmental issues in the public. As a result, green movements were becoming increasingly widespread throughout Europe, especially in Germany and Netherland. The green design is derived from the colour 'green', which implies environmental politics and mindfulness of nature. Consequently, it has become a symbolism of environmental preservation in an unprecedented way. It follows that green movements have emerged with different forms such as green products, green packaging, green building and green cities (Madge, 1997).

Green design promotes both economic development and environmental protection through advanced technologies. And it emphasises 'eco-efficiency' in order to reduce resource use and adverse environmental impacts. It is believed that environmental problems can be remedied within a technocratic approach (du Plessis, 2012).

> *"With the same scientific technological pattern of dominance, submission, and exploitation of nature that has overtaken the planet's capacity to regenerate, they intend to affirm and introduce high-risk technologies such as nanotechnology, synthetic biology, geo-engineering, and nuclear energy, which are intensifying these appropriation processes. These are even presented as "technological solutions" to the ecological limitations of the planet, intended to create an "artificial nature", and also as the solution to the many disasters we are facing* (Thematic Social Forum, 2012:8).

In 1991, the World Business Council for Sustainable Development (WBCSD) adopted the term 'eco-efficiency' to describe the 'business aspect' of sustainable development. 'Eco-efficiency' implies not only pursing the environmental benefits, but also encouraging business sectors to search for ways to improve the economic development. According to the European Environment Agency, it can be defined as "more welfare from less nature" (du Plessis, 2012:12), which means much effort should be made to use fewer resources in order to satisfy humans' persistent desire for economic development. In the context of green building design, the design manual offers an assessment tool that mitigates environmental impacts which is cause by massive resource consumption and waste generation. In addition, it provides ways to improve health and wellbeing for building residents (Cole, 2012a). Therefore, green design can be understood as 'doing less harm' or, reducing the negative impact of human activity on the ecological system (Cole, 2012b).

Even though the green design has became widespread, it is often criticised for not alleviate the fundamental cause of environmental problems. The approach is based on the temporary response of the current impacts, not on the underlying the root causes of adverse impacts (Korhonen, 2008). Furthermore, current green design tools focus primarily on the individual performance, with no emphasis being placed on interactive aspects of urban system. For instance, the green building environmental assessment tools are mainly focus on the individual performance of building without considering synergetic interactions with other buildings or surrounding ecological environments. Therefore, the success of green buildings is typically dependent on the green strategies and technologies to meet the certain level of individual performance (Cole, et al., 2012).

Consequently, despite the fact that green design and its associated assessment tools are still not enough to address the current complex environmental issues. They are acknowledged as the most viable design approaches with the current capitalism economic framework (Cole, 2012b).

2.7 Urban metabolism and Material Flow Analysis (MFA)

As we have already seen, urban infrastructures and sustainability are strongly related to each other. Moreover, it is crucial that infrastructures should not be seen by themselves but should be considered as complex urban mechanisms that are essential for economic growth and environmental protection (Ness, 2010). In this regard, the urban metabolism model will be used for deepen the understanding the urban system. This model is intended to show the urban resource flow and to provide an indication of the current situation for establishing the goals and indicators for sustainability (Hodson, et al., 2012). In doing so, one is able to demonstrate the practical meaning of urban sustainability through this metabolism model. Also, a comprehensive account of the material flows can be observed by applying MFA to cities (Pina & Martinez, 2013).

Urban Metabolism

Following the above issues in more detail, urban metabolism is a biological metaphor of looking at the resources inputs and outputs of settlements. To put it differently, the resources flow through cities can be seen as an urban metabolism (Hodson, et al., 2011). The term metabolism can be described as “the sum of all the biological, chemical and physical processes that occur within an organism or ecosystem to enable it to exist indefinitely” (Girardet, 2004:124). This metabolic system enables natural resources to be imported into cities and consumed and disposed of. Put briefly, food is imported into cities, consumed by the urban residents and discharged as sewage or solid waste into rivers or landfill sites. Therefore, urban metabolism can be defined as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy and elimination of waste” (Kennedy, et al., 2007:1).

Urban metabolism implies that if we want to solve the urban problems, we need to consider the city as an ecosystem. Like all ecosystems, cities are systems with inputs of energy and outputs of wastes. Since the main environmental problems and economic costs are interrelated, how to deal with these urban circulated systems will decide the urban sustainability. If we start to look at cities as whole systems and analyse the urban resource flow, it is possible to integrate management systems and technologies and thus increase the efficiency of resource use, the recycling of wastes and the conservations of energy (Newman, 1999). The unsustainable way of urban production, consumption and disposal undermines the overall ecological capability of urban systems. In order to reduce the urban ecological footprint and to enhance resource efficiency, the application of the urban metabolism model needs to be considered as the main urban agenda. In doing so, cities can assure their long-term ecological viability and their surrounding environments as well. Furthermore, outputs of urban systems also need to be recycled as possible inputs for urban resources, such as paper, metal, plastic and glass and the conversion of organic materials for sustainable cities (Girardet, 2004).

The urban metabolism model provides a guideline to analyse the current sustainability of a city, perform sustainable urban planning and establish sustainable urban policies to build sustainable urban infrastructures (Pina & Martinez, 2013). In addition to providing an appropriate plan for assessing the metabolism of cities, the model also underscores the need for using this plan as a guideline to design more sustainable cities. Unlike nature's ecosystem, a city cannot self-regulate its resource flow without proper management of the urban infrastructure. In this regard, the urban infrastructure that self-regulates the resource flow is necessary for the urban sustainability (Robinson, et al., 2013). Furthermore, the urban metabolism model focuses on the resource inputs into the city and waste outputs from the city, instead of merely tracking a vast number of environmental impacts they may have. The model can be applied to reconfigure urban infrastructure to achieve more resource efficiency and to encourage more renewable energy usage and sustainable consumption (Pina & Martinez, 2013).

Material Flow Analysis (MFA)

While urban metabolism offers a framework to collect data on resource flows, MFA offers an accounting and assessment method to quantify these flows. MFA is a methodology identifying and quantifying the resource flows associated with inputs (material and energy) and outputs (waste and products). It follows that a city requires several types of resource inputs, such as water, energy, food and air, and generates a wide variety of outputs, such as goods, services, waste heat and emission. In this model, the various resources converting processes into useful products or wastes can be observed and thus create a balance sheet of inputs and outputs for material flow (Pina & Martinez, 2014).

According to Brunner and Rechberger (2004:28), MFA generally aims at achieving the following objectives:

1. Delineate a system of material flows and stocks by well-defined, uniform terms.
2. Reduce the complexity of the system as far as possible while still guaranteeing a basis for sound decision making.
3. Assess the relevant flows and stocks in quantitative terms, thereby applying the balance principle and revealing sensitivities and uncertainties.
4. Present results about flows and stocks of a system in a reproducible, understandable, and transparent way.
5. Use the results as a basis for managing resources, the environment, and wastes.

Eventually, the objective of the application of MFA is finding opportunities for maximising the functionality of a city. MFA is also defined as "a systematic assessment of the flows and stocks of materials within a system defined in time and space" (Hodson, et al., 2012:794). In order to achieve this, all the pieces of data should be linked to one another and regarded as part of an interconnected metabolic system, instead of merely analysing data separately. For example, the amount of water supply, sewage generation and wastewater reuse can be analysed all together, since those material flows are interconnected to one other. From the linear metabolism perspective, most urban outputs are treated as waste and dumped into the landfill or released into the air. However, from the circular urban metabolism perspective, urban infrastructures are organised to reuse those wastes outputs. This leads to an increase of energy resource efficiency and to reduce the negative impact fossil fuels have on the environment. It is therefore vital to reconfigure urban infrastructures from the circular metabolism perspective (Choi, et al., 2011).

From this background, it can be seen that urban metabolism and MFA can offer different ways of developing strategies to mitigate the exploitation of resources. With Songdo as a case study, the following flows were measured: (i) inputs, such as water, electricity and gas, and (ii) outputs, including sewage, solid waste and greenhouse gas.

2.8 New Songdo City (NSC) project

Songdo was originally designed to a Free Economic Zone (FEZ) to facilitate South Korea's growth. Hence, the city was initially known for being a 'global business hub' or 'Aerotropolis'. However, in order to make an effort to build a better city environment and to lead in its competition with other FEZ cities, the city developer accepted the Green Urbanism policy and made an attempt to be a green city in 2006. This green city movement is based on their core sustainable city design approaches. These core values focus on building eco-friendly environments in terms of open and green space, transportation, water, energy use, recycling and operation. These core design goals for Songdo entail the government and the private developer's commitment to sustainability of the city. Therefore, how this green city movement has been progressed and its actual impact on the city will be examined in the following chapters.

As the NSC project is still under construction and estimate to be completed in 2020, relatively little research has been carried out. Moreover, since the size of the city is relatively small (250,000 residential population), there is a limitation to obtaining specific statistical data in terms of MFA. Therefore, the literature review of Songdo was limitedly carried out through the IMC and FEZ websites, public news and a few case studies from academic articles. Detailed information on Songdo will be reviewed in the next chapter.

2.9 Conclusion

As we have seen, this literature review has attempted to sketch out the current major social and environmental problems of cities and to provide the proper interventions for sustainable cities. Given the limitation of natural resources and the fossil fuel energy oriented economic systems, the continuation of world economic development will be dependent on the decoupling of economic growth from the escalating resource use. Following this line of thought, since urban infrastructures are key features in the urban ecosystem, it will be necessary to reconfigure the world's urban infrastructure to encourage more efficient resource flows through cities (Hodson, et al., 2012). In order to achieve this, according to the urban metabolism model, cities have to balance their inputs and outputs (Swilling, 2004). However, unprecedented accelerated urbanisation does not allow urban systems to balance cities' inputs and outputs. Proceeding from this fact, one could logically assume that core challenge of sustainable cities is to manage the urban resource flows efficiently through urban infrastructures. In line with this view, the thesis will conduct a case study by focusing on the urban infrastructures in Songdo and analysing them from a metabolic flow perspective.

Chapter 3 – Introduction of Songdo

3.1 Introduction

In the previous chapter, it is explained why the role of cities is important, especially focusing on urban infrastructures and material resource flows. In order to facilitate understanding of the literature review, it is proposed to examine the main features of sustainable cities through the case study. According to the literature review, sustainable cities have to deal with current major social and environmental issues through efficient resource management. Hence, the primary goal of this chapter is to provide an overview of one of the claimed to be sustainable cities, "Songdo" in South Korea.

In recent years, researchers have shown an increased interest in the concept of sustainable cities. So far, however, the current status of eco-city projects shows us the difficulties of implementing the sustainable city project in the real world. Most projects are still in the early stage of development or have changed their original plans due to unexpected internal and external factors - corruption, changes in political leadership and lack of financial support. Since there are no cities that could demonstrate the theoretical concept of sustainable cities, much uncertainty still remains about the possibility of the existence of sustainable cities (Shwayri, 2013).

Despite the challenges facing the realisation of sustainable cities, the sustainable city project in Songdo is nearing completion. Songdo is located in South Korea and will be 'ready for use' in 2016. It appeals to be a green city model because it implies sustainable elements, such as 'eco-efficiency'. The city was originally designated as FEZ to promote economic growth in South Korea. However, the plan changed to 'Eco-city' or 'Ubiquitous city' to get a competitive edge among the other FEZ cities, such as Hong Kong, Shanghai, and Singapore. In order to maximise the synergy effects of Songdo, different kinds of residential and commercial buildings are designed based on the master plan that was inspired by famous buildings from all over the world. In addition, a large scale of green design approach has been applied to associated buildings and public transportation, energy reduction on building design, all kinds of green space, and efficient infrastructures. The project is also pursuing the Leadership in Energy and Environmental Design (LEED) certification to build a world-class environmentally-friendly city. Gale International CEO, John Haynes, mentioned, "Songdo city will be one of the greenest, most sustainable, most ubiquitous cities in the world, with an unmatched quality of life" (Kuercker, 2013:6). According to Statistic Korea (2014), population in Songdo has constantly increased and now, in August, 2014, it is up to 79,395. For these reasons, scholars have started to pay attention to the NSC project by applying the theoretical conceptions of the sustainable city and examining the goals, business models, and sustainability (Kuercker, 2013). In line with this view, this thesis will explore chronologically how the NSC project originated and progressed toward a sustainable city.

3.2 Overview of New Songdo City (NSC) project

3.2.1 Historical development of Songdo

Before the construction of Songdo, the city was located between the Ongnyeon-dong and the Dongchung-dong in Yeonsu-gu, IMC (see Figure 3.1).

Figure 3.1 Map of Yeonsu-gu area

Source: Google map

However, the scope of Songdo was extended since the reclamation project has started on the wetland of the west coast of the Incheon. From the 1980's, a majority of land reclamations of Incheon were carried out along the coastal area. The original purpose of reclamation of this area was to build a new town for housing development. In 1988, as the construction of a new international airport was confirmed in Yongjong-do, which is only 7 miles away from Songdo, IMC has extended the area of land reclamation to the Songdo area to take advantage of its geographical position. Therefore, Songdo was designated as one of the Incheon FEZ cities in August 2003 and the construction officially began in 2004 (Incheon Association of Museums, 2009).

In order to further the understanding of the NSC project, it is necessary to know why the reclamation project was initiated in Incheon. First, there was a lack of land that could be irrigated for agriculture in the Incheon area. As the city is located on the west coast, most of lands are hilly and even reach to the coastal area. For this reason, land reclamation of tidal flats has been a solution to the problem of land shortage since the Koryo Dynasty (between the 17th – 18th century) for the purpose of securing agricultural land and food. Secondly, the Incheon coastline is complex and large tidal ranges of wetlands are widely distributed along the coastline. Lastly, in considering the geographical location, Incheon was regarded as an important city since it is closely connected to the economic and cultural centre of the country, Seoul. Therefore, the wetland reclamation has been conducted over the last centuries in the Incheon coastal area. Historically, the majority of projects were conducted on a small scale until the 1960s. Since then, the number of small reclamation projects have decreased whereas a significant size of tidal flat reclamation projects have been conducted by the government, destroying the massive wetlands in Incheon (Incheon Association of Museums, 2009).

Figure 3.2 Songdo wetland in the 1960s

Source: Incheon Free Economic Zone, 2013

The development of Songdo started in the late 1980s. President Roh Tae-woo announced the development of a housing plan to stabilise the real estate market in his first year in 1988. Nevertheless, housing prices continued to skyrocket and thus the supply of enough housing land in the metropolitan area had become a central issue. In line with this background, approval for the land reclamation of 30 million square metres offshore of Songdo was permitted to supply the extra land for housing in 1991. This is the so-called Songdo New Town Development (SNTD) project (Incheon Association of Museums, 2009).

Despite the fact that IMC announced the Songdo reclamation plan in October 1991, the actual reclamation started in 1994 due to the delay of the administrative procedures with the central government, specifically with the Ministry of Construction and Transportation (MCT). The MCT expressed their concern about the metropolitan traffic burdens as the Incheon International Airport was under construction simultaneously. They requested the local authorities for the detailed project plan, including an environmental evaluation of the Songdo wetlands and environmental pollution prevention plan in order to avoid expected environmental issues. As a result, the reclamation plan was delayed for almost 3 years. It also led to complaints from the local residents that the project was just a political campaign agenda for the President to attract more votes from the residents of Incheon and its neighbourhood (Shwayri, 2013).

Finally, the reclamation of the wetland began in 1994. Meanwhile, when the project was still in progress in 1995, the main purpose of this project was changed to build the IT industry and international business centre. The main reason was that the inflation of housing prices was finally stabilised since its first announcement in 1988. In addition, there was a growing awareness that high-tech industry was going to for a core driver for the country's economic growth for the next decades. Furthermore, the increasing trade with China and the new Incheon International Airport Project highlighted the potential of Songdo as an international city for commerce and information (Incheon Association of Museums, 2009).

However, the SNTD project experienced difficulties due to the failure of the media valley business and the financial crisis. The Daewoo Group, as a local developer, originally contracted with the South Korean government for the SNTD project. They planned to build a media centre on reclaimed wetland, which is South of the new Incheon International Airport. However, soon thereafter, the Asian economic crisis hit South Korea's economy in 1997. The country came very close to national bankruptcy and requested a bailout by the International Monetary Fund (IMF). It was right after the national financial crisis that Daewoo went bankrupt. Therefore, those plans for Songdo were postponed indefinitely, leaving the future of the city in doubt. Also, the financial crisis made the government rethinks their current economic structure and future development strategy (Kuercker, 2013).

Figure 3.3 Reclamation of wetland in Songdo (2003)

Source: Incheon Free Economic Zone, 2013

3.2.2 New Songdo City (NSC) project

Free Economic Zone

In December 2000, the South Korean Government officially declared that the country had overcome the IMF crisis. It follows that the government came up with the FEZ strategy to recover from the economic recession and rebuild the South Korean economic structure. After the IMF crisis, the South Korean economy was still suffering from external and internal factors. Even though the amount of trade in Northeast Asia has rapidly increased over the last 20 years, China and Japan were the main players responsible for this increase. Based on the manufacturing industry, China's economy grew in the late 1990's and led to the influx of international capital into their market. At the same time, South Korea was still struggling to catch up with Japan's high-technology industries, such as automobile, electronics and information technology (Lee & Oh, 2008). Moreover, other Asian countries, such as Hong Kong or Singapore, had already specialised their economic structure through the FEZ policy to attract foreign investments. In this regard, the economic situation of South Korea was described as a 'Nut-cracker' in the early 2000's. Internally, the South Korean economic growth has been reduced since the late 1990's. Average growth rate was 8 percent between the 1970s and the 1980s, but it decreased to 6.5 percent in the 1990s. Finally it reached around 3 - 4 percent in the 2000s. Main reason was that growth in the manufacture industry has stagnated due to the rise of China's economy and infrastructure of the service industry was still in the early stage of development. This is attributed to the fact that the South Korean government decided to change their economic development strategy, which is based on the service and technology oriented economic structure (IFEZ, 2007).

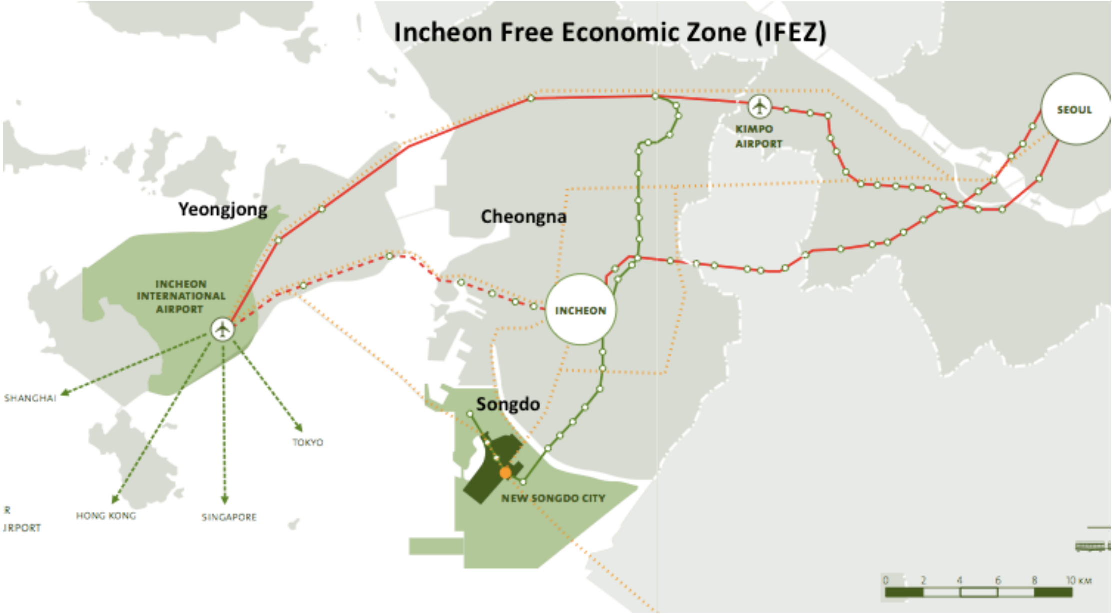
The central government has attempted to attract more foreign investments and capital for their market, because they considered foreign direct investments as essential elements in recovering the South Korean economy. To achieve this goal, the government offered many incentives to foreign businesses and investments through the FEZ, such as no tariffs, corporate and personal income tax exemption, low-priced land, flexible labour policies, an English-based social system, relaxed foreign currency regulations, and foreign schools and hospitals (Segel, 2006). According to Thomas Hubbard, the former U.S. ambassador to South Korea, "The idea was that it would be an international business district and that foreigners would find this a convenient place to set up business" (Washington Post, 2013). Not only providing the optimised environment for business, the government also strives to build appropriate infrastructural facilities and welfare services (Shwayri, 2013).

Finally, the designation and Management of the FEZ was adopted in November 2002, and officially effected on July 1, 2003. The government announced the formation of three FEZs: Kwangyang, Pusan and Incheon. IFEZ was launched as the first FEZ on August 15, 2003. Songdo was a part of IFEZ, covering 53.4 square kilometres of the total area of 209 square kilometres of the zone, including the Yeongjong and Cheongna area. The total cost of development of the IFEZ zone is estimated to US$ 9.69 billion with expected completion in 2020 (Shwayri, 2013).

Vision and strategy

In early 2001, IMC launched the NSC project with the motto of "New Songdo City, the Hub of Northeast Asia". The central government announced the FEZ to be a 'logistic base' for Northeast Asia and Songdo is considered as a fitting place for an international business district or a logistic hub (Incheon Association of Museums, 2009). As the Incheon International Airport was officially opened in 2001, the government set three main hub strategies, which are the "logistic, business and Information Technology (IT) hub of Northeast Asia".

Figure 3.4 Map of Incheon Free Economic Zone



Source: Gale International & Kohn Pedersen Fox, 2014

First, when it comes to the logistics strategy, the goal is to make the best use of Songdo's geographical advantage. Geographically, Songdo is located along the North-eastern coast on the trade zones of three of the biggest economies in the world, China, Japan, and Korea, as well as being close to Hong Kong and Singapore (Shwayri, 2013). The city is only 7 miles away from Incheon International Airport. From the Incheon International Airport, there are 61 cities with more than a million people located within 3.5 hours flight time. It is estimated that 2 billion people are potentially able to conduct business in Songdo within a day. The Incheon International Airport holds the record for the second largest freight service and was given an award for having the best service in the world since 2005. In this regard, the airport will play a pivotal role in this logistic strategy. In addition, with these advantages, the city is planning to host the 4 major logistic companies such as DHL, UPS, Fedex, and TNT by offering a tax free zone and a high tech logistic cluster (IFEZ, 2007).

Second, in order to leap forward to establish itself as the business hub of Northeast Asia, the city is going to build an international business centre for international corporations to provide local branches and financial centres. Moreover, world-class business and living environments with modern technology and high-quality human resources will be offered (IFEZ, 2007).

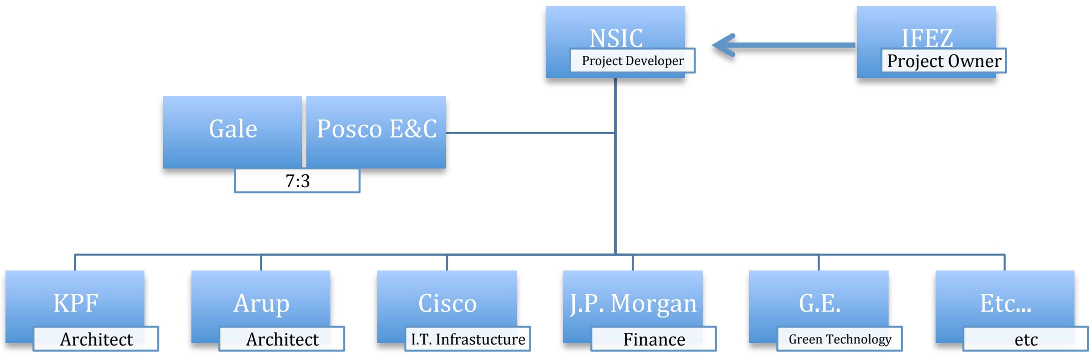
Lastly, with regard to the IT hub strategy, South Korea has diverse industrial infrastructures, from high technology industries to middle-sized component suppliers. The workforce is more skilful than Chinese workers and cheaper than Japanese workforces. In consideration of the advantages of IT infrastructure, R&D-oriented IT clusters will be developed, and will support the venture business in Songdo (IFEZ, 2007).

Stakeholders

As discussed, the central government was looking for foreign capital and investments to contribute to the economic growth in South Korea. In line with this strategy, a foreign developer was the first option in terms of assigning the main developer of the NSC project. At the same time, the successful 'One Lincoln Office Project' in Boston, which was implemented by Gale International, caught the attention of government. Thus, IMC contacted Gale International and invited Stan Gale, president, and John Hynes III, CEO of Gale International to Korea (Kuecker, 2013). After visiting Songdo and having a meeting with city officials, they saw the great potential of this project and requested three conditions from the government. First, the Incheon Bridge, which directly connects from Incheon International Airport and Songdo has to be completed. Second, since foreigners consider education to be their first priority, a high standard of international schooling must be offered to foreign residents. Lastly, a world-class hospital with English-speaking staff should be available for the sake of public health. As the government guaranteed these conditions, Gale International signed up for the NSC project as a main developer in 2001, in the same year the Incheon International Airport opened (Donga, 2014).

In March 2002, Gale and POSCO Engineering & Construction (E&C) established a joint venture company to facilitate the project and to avoid any unexpected business risk. The New Songdo International City Development, Limited Liability Company (NSIC, LCC) is the official main project developer and owned by Gale and POSCO E&C by 70.1% and 29.9% respectively (see Figure 3.5).

Figure 3.5 Stakeholders of the NSC project



Source: Gale International, 2014

Gale is in charge of the general operation of the project. Their main job is to attract more foreign investments and companies to the NSC project as well as the management of the development plan, financial support, construction, and marketing activities. POSCO E&C, South Korea's largest steelmaker and an icon of the nation's industrial past, is the construction manager of the project (Songdo, 2014). In order to make the city design plan and thereby get the official project permission from the government, Gale International selected KPF to devise the initial master plan. The first step of the NSC project was to make a Land Supply Agreement between IMC and NSIC based on the KPF's plan. Then, a survey for the feasibility of the master plan was conducted by Vigers, a market research firm in Hong Kong. In 2003, as the first financing of US$ 90 million was completed, the government approved the business plan of the NSC project (Lee & Oh, 2008).

As the government made the official approval of the master plan, the Memorandum of Understanding (MOU) with other companies was also accelerated. One of the well-known financial companies 'J.P. Morgan', was a main player to raise funds and invest in the project. They made the first investment of US$ 350 million. The design consultant company 'Arup', famous for designing the Sydney Opera House, the Hongkong Shanghai Banking Corp Building in Hong Kong, and the Bird's Nest in Beijing, participated as an architect of the project. Cisco systems joined to build the 'Ubiquitous city' based on their smart-grid technology. Generally, they are responsible for building the high-technology infrastructures in Songdo. In order to provide the high standard of education service, an advisory group from Harvard University and Milton Academy participated in the establishment of international schools. Philadelphia International Hospital and New York Presbyterian took part in designing a world-class hospital complex (Kuecker, 2013).

City Design

KPF was assigned as urban designer and an architect in 2001 and they spent 2 years designing the city. Songdo is intended for approximately 250,000 residents and 300,000 commuters and business travellers within the 30 million square metres of land. The idea for the city design is based on the 'hub cities' approach. The main purpose of 'hub cities' is to encourage people to walk or use public transportation through the efficient design of the public transport and city streets, without relying on private vehicles (Segel, 2006). In line with the 'hub city' approach, the city tends to make multiple-purpose buildings by integrating commercial, residential, educational and cultural facilities to meet the various interests of residents. This complex design includes varied networks of pedestrian-friendly streets, boulevards, neighbourhoods, shops, markets and parks (Gale International, 2014).

Out of 30 million square metres of land, 10.5 and 15 million square metres were allocated for residential and commercial spaces respectively. 2.5 million square metres were assigned for open space, including the central park. Besides, a natural gas bus system, Light Emitting Diode (LED) traffic lights, special parking zones for fuel efficient vehicles, a truck-free waste management system, a 25-kilometre-long network of bicycle lanes, and a seawater based ecological canal in the urban centre for water taxis will contribute to less carbon emission in the city. Furthermore, in order to find inspiration for the city design, KPF referred to the physical designs of key western cities from all over the world – the wide boulevards of Paris, New York City's Central Park, a canal system from Venice and the Sydney Opera House for a Convention Centre (Shwayri, 2013).

When it comes to the business purpose, Songdo is strategically divided into 11 land use zones including an international business district, a knowledge and information complex, a high tech industrial cluster, a new port logistics complex, and a residential area. Zones 1 - 4 are the major downtown area of Songdo (see Figure 3.6). Since the construction of these areas started in November 2004, it has become a major business and residential district with business centre, international trade centre, convention centre, world-class hotel, department store, shopping mall, office buildings, golf course, art house and residential buildings. In Zone 2, Techno Park, a high tech industrial cluster that was inspired by Silicon Valley in United States of America (USA) is under construction. Silicon Valley was able to become a leading high tech knowledge cluster since it created a favourable environment for research. It attracted different types of ventures and R&D institutions from all over the world so that institutions could interact and share diverse information from one another. In the same way, the Techno Park is designed to grow as a leading high-tech semiconductor cluster in South Korea. So far, a total of 40 venture companies are working in the Techno park area. In zone 4, one of the leading protein vaccine companies, Celtrion, plays a crucial role in promoting the bio industrial cluster. With the completion of the new vaccine production plant and the R&D centre, they started to expand their business area across East Asia beginning in 2005.

Figure 3.6 District zones in Songdo

Source: Gale International, 2014

In Zones 6 and 8, International real estate development company, Portman Holdings, Korea's Hyundai Engineering & Construction and Samsung C&T Corporation intend to build a landmark city with investment of US$ 17 billion. The landmark city is a multi-functional complex, including housing, working and entertainment environments. This area maintains the mutually beneficial cooperative relationship with an international business district, and therefore it is likely to promote Songdo more extensively and attract more investments from overseas. Zones 5 and 7 are designated for an educational purpose that includes Yonsei University, Korean Foreign University, and Stony Brook University so far. Land reclamation is still ongoing in Zones 9 - 11 and they are expected to function as new port logistic complexes in the near future (IFEZ, 2010).

Governance

Before 2006, the first priority of the NSC project was to make a contribution to the economic growth through the 'business hub strategy'. However, as environmental issues are increasingly recognized as a serious, worldwide public concern, the city developer changed development direction toward a 'green city'. Before we explore the emergence of an eco city in Songdo, it is beneficial to begin by reviewing the role of the government in terms of the sustainable development policy that affected the NSC project.

On the 4th of June 2005, the 16th President of the South of Korea, Ro Mu-Hyun, announced "A National Vision for Sustainable Development". The main goal is to keep encouraging South Korea's economic growth toward an advanced country while maintaining a balance between the goal of the economy, society and the environment. It is based on issues and implementation tasks from the 2002 Johannesburg world summit agreement. This national vision contributed to the formulation of the NSSD in 2006. In this view, therefore, this statement can be regarded as an initial draft of the NSSD, since it provides the basic information of sustainable development that emphasised the government's action (Chung & Hwang, 2006).

In 2006, the government officially launched the NSSD program. The Development Assistance Committee and the Organisation for Economic Cooperation and Development (OECD) defines the NSSD program as "a strategic and participatory process of analysis, debate, capacity strengthening, planning and action towards sustainable development" (Rice, 2008:2). It is an integrated approach to address the economic, social and environmental issues faced by South Korea. The creation of the NSSD was one of the first national policies, which was implemented by the South Korean government in terms of sustainable development. The main objective of the NSSD is similar to the definition of sustainable development. It is stated that "a balanced development of the economy, society and environment, common prosperity of present and future generations and the balanced development of metropolitan areas and provinces" (Rice, 2008:7).

The major strategies of NSSD can be reviewed as follows: First, in the economic sector, the program focuses on building an environmentally friendly production and consumption system and formulating the resource circulation type of economic society. It follows that the government is seeking to extend the size of eco-friendly markets, promote the sustainable development evaluation system to the whole manufacturing process, and upgrade the current chemical management system. Second, in the social sector, minority groups, such as the urban poor, will receive increased benefits and will be protected from environment-related disease. The plan entails an increase in the free education rate from 31 percent to 80 percent, fostering of the elderly long-term care insurance system and lifetime health management system, and halving population that suffered from air pollution (3,51 to 1,76 million people). Third, in the environmental sector, sustainable natural resource usage is the key concept. In this regard, the rate of natural protected zone will be extended from 9.6 to 11 percent. In addition, in order to cope actively with the Climate Change Convention, the CO_2 emission rate per GDP will be decreased to 0.77 kg/US$ (current 0.88), as well as further spreading renewable energy proportion in the energy sector (2.3 to 5.0 percent). Besides, the government established the Sustainable Development Committee to support and encourage the local municipalities to achieve the goal of the NSSD (Chung & Hwang, 2006).

Furthermore, in January 2009, on the 60th anniversary of the founding of South Korea, the new president launched his vision of green growth, by adopting it as a national strategy with short- and long-term goals. The Green Growth policy emphasises creating synergy effects between economic growth and environmental protection. The three main goals are to create new engines for economic growth, to improve the quality of life and to enhance South Korea's international standing.

Cities are regarded as platforms to make an essential contribution for the implementation of green growth policies and innovation. Ministries and local government therefore launch different urban project models, such as the greening cities project, the eco-rich city competition, the climate change adaptation model city project and the smart city project. From this background, Songdo was selected as a leading model of the eco-city project for the central government to combine economic and ecological objectives. The government is also trying to get a dominant position for competing with other FEZ cities through this eco city strategy (Shwayri, 2013). For these reasons, the IMC and the Central Government fully support the NSC project. The benefits are Incheon Bridge, basic infrastructures, discount land price (25 to 50 percent), mitigation of regulation, and advantages of permitting process (Lee & Oh, 2008).

Eco city project

> *It is the Koreans who built the foundational green infrastructure for us. They built the pneumatic waste collection system, the subway, the airport, etc., We then provided the vision for additive green features such as the cycling lanes, Central Park, building-by-building water catchment systems and a USGBC LEED-certified design and development standard* (Tom Murcott, 2012).

It is no coincidence that the turning point of the NSC's development toward an eco-city was the same year that the central government announced the NSSD program in 2006. As we have already seen, South Korea was seeking a competitive edge in the global market through the FEZ strategy. They were also looking for the strategy that could be differentiated from other FEZ cities. According to Lee Hwan-kyun, head of the Incheon FEZ, "This project is a pivotal part of the survival strategy for our economy in this globalized era." Huh Chan-guk, an economist at the Korean Economic Research Institute, also said that "NSC needed to do something to differentiate itself from other free-trade areas to make foreign investors choose it".

At the same time, as sustainability was becoming an increasingly important issue in the global society, the city developer considered the green city project as an opportunity to distinguish itself from other FEZ cities. KPF mentioned "New Songdo City builds on this effort of the state's green economy framework by implementing measurable initiatives that will help mitigate growing global and regional environmental conflicts" (Kuecker, 2013:6). Furthermore, KPF's eco-boutique- city vision embraces a diverse group of people with similar tastes and needs, not restricted to a certain nation or region. Those visions include an English-speaking environment, world-class medical and educational facilities, diverse cultural and art events, and an eco-friendly lifestyle. In this regard, NSC makes an attempt to build 'one of the greenest, most sustainable, most ubiquitous cities in the world, with an unmatched quality of life' (Kuercker, 2013:6). Consequently, the transformation of the eco-city resulted from the country's green growth policy and KPF's eco vision.

In line with this green city initiative, the city developer started to take sustainability into consideration for the city development. Gale international established a "Charrette", which is a workshop for all stakeholders to come up with better ideas for sustainable development. The members are project developers, key architects, engineers, and environmental experts (Kuecker, 2013). In particular, their main objective is to identify ways to improve environmental performance and quality of life in Songdo. They participated in most of the decision making process in terms of sustainability, including site planning, energy use, building designs, water consumption, transportation, material choices, waste treatment and the impact of development. They also contributed to the social activities that promote sustainable production and consumption, public transportation and a major sustainable development agenda to the public (Newman & Matan, 2012).

Charrette made an essential contribution to set six core design principles for sustainability in the city. These six core values are: open and green spaces; transportation; water consumption, storage and reuse; carbon emissions and energy use; material flows and recycling; and sustainable city operations (see Appendix B). The principles are intended to lead the project to more sustainable ways and also likely to provide a new standard for green city projects in the world (Songdo, 2014). In particular, open and green space and sustainable transport comprise fundamental characteristics of the master plan. Energy use and recycling are regarded as an essential value in terms of the building process and the functioning of the city. Given the importance of the resource management of the city, the developers are focusing on sustainable material use through green technology, recycling and efficient landscape design features. Operation is also an important part of the urban infrastructure management to set sustainable procurement goals and recycling guidelines (Shwayri, 2013).

In order to implement the six-core design principles, the city developer use the LEED Green Building Rating System as a tool to meet the international standard and thus demonstrate its implications for sustainability. The LEED system can be described as below.

The LEED is a voluntary third-party rating system in which credits are earned for satisfying specified green building criteria. Projects are evaluated within six environmental categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality. Certified, Silver, Gold, and Platinum levels of green building certification are awarded based on the total credits earned. LEED-ND focuses on residential, commercial, and mixed-use projects developed by a single entity (Gale International, 2014).

In 2007, the U.S. Green Building Council declared the NSC project as part of the "Green Urbanism" Pilot Project, since it acquired the LEED for Neighbourhood Development ("LEED-ND") certification. LEED-ND certification is not merely about green building, but also about enhancing and protecting the health, natural environment and quality of life of a community. Compared to other LEED-ND projects, Songdo is one of only three LEED-ND projects in Asia (two projects in China are much smaller than Songdo), and one of only five outside the USA and Canada. Moreover, an entire city is projected to get the LEED-ND certification by the end of construction in 2020. In doing so, NSC is likely to set a new standard for sustainable urban planning and smart growth, particularly in density, proximity to transport, environmental preservation, mixed housing type, and pedestrian-friendly design. Following this, there are about 13.7 million square metres of the LEED certified space, including the South Korea's first LEED certified school, a 100-acre entail park with a navigable canal fed by seawater, South Korea's first non-smoking hotel, a golf course and the first phase of Asia's first LEED-certified convention centre. In order to facilitate this green project, NSC agreed to a partnership with GE Korea to cooperate on the sustainable development strategy and marketing. NSC is expected to share GE's experiences and knowledge, especially in environmentally friendly products and development solutions (Gale International, 2014).

Besides that, there are many green innovations in Songdo. The green space occupies 40% of the city, recycling of the 'grey water' and 'black water', LED traffic light and a pneumatic waste-collection system. It also aims to encourage using the public transportation, including a rental bike network, a car-sharing system, natural gas buses and an express subway line connecting to Seoul. In the following chapter, a further description of sustainable city approaches in Songdo will be provided in detail.

3.2.3 Now and future of Songdo

The official name of Songdo changed to Songdo International Business District (IBD) in January 2014. Songdo IBD is planned for a daytime commuting population of 300,000 and residents of 250,000. The city currently has 79,395 residents, including 1,420 foreigners (August, 2014). Public transportation, such as bus, subways, water taxis and bikeways are already in service. It has been 11 years since the government announced the IFEZ project. Even though the majority of buildings are still under continuing construction, there are signs that Songdo is becoming an important location in terms of the international business hub. In October 2012, the United Nation designated Songdo as the home of the new Green Climate Fund (GCF) agency. Currently, there are 13 different international organisations located at the G-Tower with around 200 staff and 500 employees and their families will probably move to Songdo. It is assumed that IMC's effort to attract the new international organisations, such as financial funding, free rent and its proximity to Incheon International Airport were the main contributors to hosting the GCF successfully (Songdo, 2014). IFEZ is planning to attract more international organisations and will rapidly become a mecca for international organisations.

Figure 3.7 Aerial view of Songdo

Source: Incheon Free Economic Zone, 2013

At present, Songdo has 40 leading bio-related companies and research institutes in the centre of Techno Park and Bio Medical Park Complex, from the U.S., Hong Kong, Japan, the Netherlands, Singapore and Sweden. They will set up a foundation as a worldwide bio-cluster in the near future. The eco-friendly building "Convensia", which was inspired by the Sydney Opera house, was the first building in Asia certified by LEED-ND, holding a variety of exhibitions and international events. In addition, the Art Centre is being constructed by 2015, which includes a concert hall and an opera house housing 1,800 and 1,400 visitors respectively, and a multi-purpose hall. IFEZ and Gale attract around 450 corporations from around the world, including the world leading companies, such as IBM, GE, DHL and Microsoft in order to become a global business hub. It follows that IMC is planning to attract 1,200 domestic corporations and research centres in 2014.

3.3 Conclusion

Up to now, we have looked at how Songdo has evolved, developed and transformed to the current city model. Songdo was originally designed for the new town area to provide a housing development district but the plan has changed to be an international business hub to increase the economic growth in South Korea. For this reason, the South Korean government announced the FEZ strategy for three different regions including Songdo. As a competitive strategy, Songdo is planning to be a 'Green city' because environmental issues have become major concerns in the world. Based on the high standard eco-design rating system "LEED – ND", Songdo made an attempt to be a model for future cities. In particular, based on the six core design principles, Songdo is going to be an environmental standout not only in Asia, where many urban areas are in a state of environmental crisis. From this fact, therefore, the following question arises: how the Songdo's urban infrastructures are organized and operated in terms of urban metabolism? In responding to this question, this thesis will explore the major sustainable infrastructures based on Gale's sustainability report.

Chapter 4 – Approaches to sustainable urban infrastructures

4.1 Introduction

From the literature review, one is able to see that urban infrastructures play a pivotal role in sustainability and thus the city decoupling can be attainable through sustainable infrastructures. In light of this theoretical background, the question arises of how Songdo's infrastructures are designed and operated in the city. Particularly, in order to find the answer to the following research question – "What is the approach to sustainable urban infrastructures in Songdo?" – this chapter will identify Songdo's urban infrastructures in terms of urban metabolism perspective, specifically focusing on the water use network, waste treatment system, energy network and public transportation.

4.2 Sustainable urban infrastructures

4.2.1 Water use network

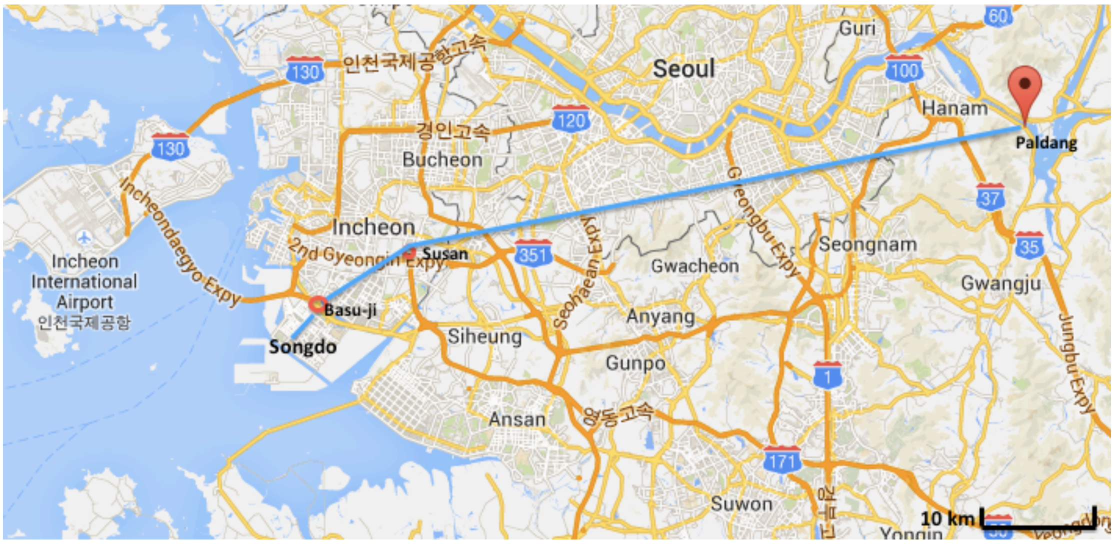
According to the UN, South Korea has been a water stressed nation in terms of per capita available water since 2005. In general, the availability of water is different due to the regional and seasonal variations of precipitation. During the summer season, the precipitation rate accounts for more than 60% of the average annual rainfall (June to September). Moreover, the rainfall rapidly flows into the rivers and the ocean due to the steep slope and shallow aquifer. These geographic characteristics lead to a constant shortage in water supply during the winter (November to February) and flood damage during the wet season. Moreover, water resources are unequally distributed throughout the region. Therefore, the South Korean government is facing multiple challenges to ensure the sufficient supply of water and to maintain good water quality with regards to increasing water demands and environmental risks from climate change (K-water, 2014).

In dealing with these issues, IMC has made an attempt to overcome the shortage of water resources. The water-related NGOs and local municipalities are implementing the recovery of local streams and a seawater desalination project (Byeon, et al., 2013). In Songdo, the city is trying to minimise freshwater usage and maximise black water or rainwater usage to mitigate this shortfall of water resources. The sewage will be treated and used in a tiered gray water network of non-potable water activities. Rainwater will be collected for non-potable use such as irrigation or cooling tower operations. This multilayered network will make an essential contribution to the water use efficiency throughout the city (Gale International, 2014).

Water supply

Geographically, Songdo faces challenging conditions in terms of access to drinking water resources. Since the city is located in the coastal area, there is no drinking water around the city. In this regard, the city has to install 40 kilometres of waterworks' pipes to the Paldang area, which is the major drinking water resource zone for 20 million residents in the metropolitan area, including Seoul and Incheon city (see Figure 4.1). The Paldang area was designated as the protection area of source water in 1975. Water in the Paldang area is reserved for drinking water rather than other Han River areas because the water quality is better than the areas downstream of Han River areas. It follows that the area surrounding Paldang is also selected as a national reserve area for water protection (Byeon, et al., 2013).

Figure 4.1 Water supply flow in Songdo



Source: Google map

The water supply plan is based on the 'Incheon Waterworks Maintenance Plan'. The Korea Water Resource Corporation (K-water) is responsible for providing general water service in South Korea. As can be seen above, water originally comes from the Paldang dam, is purified at the Susan and Basuji Water Purification plant and delivers to the households in Songdo. Currently, almost 100 percent of Songdo's population has access to water.

Sewage treatment

While the municipality is in charge of the water supply in Songdo, the sewage treatment facility is operated by the private sector. The public service market in South Korea opened only recently to private corporations, and Incheon was the first case of the Build-Transfer- Operate agreement in the wastewater sector. In order to build and operate the wastewater treatment plant in Songdo, the Incheon Municipality signed the Engineering, Procurement and Construction contract with a consortium comprising Veolia Water Korea and Samsung Engineering in December 2001. The contract covers the design, financing, construction and operation of the plant with 80 (Veolia)-20 (Samsung) partnership between two companies (Veolia Korea, 2014).

The main challenge in Songdo is to cope with the growing volume of wastewater within the limited space of the treatment facility. Therefore, the main objective of the wastewater treatment facility is: to build the capacity to manage the growing volume of wastewater; to comply with the stricter wastewater discharge standards (less than 20 mg/l of phosphorus and nitrogen), which is set by the Incheon municipality; to improve the image of the city that cares about the environment (Veolia Korea, 2014).

In consideration of this condition, compact technologies that can handle very high volumes of sewage are necessary for the facility. Specifically, the capacity of the facility has to manage 30,000 cubic metres of daily wastewater within the limited space of 22,755 m^2. In order to achieve this, Veolia Water suggests 'Biostyr™' filters. Biostyr™ is the Biological Aerated Filter system, which is created by Veolia Water. The system combines in a single structure the biodegradation of carbonaceous and nitrogenous pollution (nitrification –denitrification) and the clarification of effluent by filtration through a media bed that acts as an environment for biological activity. It is intended to meet the most stringent sewage standards for organic and/or nitrogen removal with a simple and innovative process in a compact structure, thereby presenting a low environmental footprint. In addition, the technology is particularly appropriate for increasing facility capacity where space is limited; therefore it is regarded as a suitable technology for Songdo (Veolia Korea, 2014).

The Biostyr™ filter is able to eliminate all pollution, organic, nitrogenous (N-NH4 and

N-NO3) and particulate compounds (TSS). In particular, the sewage treatment operates as described below;

Figure 4.2 Wastewater treatment facilities

Source: Veolia Korea, 2014

The first step of wastewater treatment is to remove the larger particles of floating materials from the effluent at the screen facility (1). Thereafter, the physio-chemical treatment is applied to the sewage. The Multiflo™ is a compact lamellar technology that utilises the sedimentation process. As the sewage gets through the swash plate from bottom to top, the debris is eliminated by the force of gravity. The sludge from the wastewater treatment plant is delivered to a methane reactor, which will turn the sludge into an energy source. (2) After that, the wastewater is refined by the Biostyr™ filter through a biologically active media bed at the biological filtration stage. In doing so, the biodegradable pollution such as carbon and nitrogen can be removed by the nitrification and denitrification processes (3). In addition, at the second stage of the Biostyr™ process, the remaining nitrogen from the first stage is eliminated by injecting methanol (4). The Actiflo™ is a highly compact physiochemical settling process, which eradicates the residual phosphorous and floating micro pollutants. (5). Lastly, the ultraviolet light disinfecting chamber(6), deodorization facility(7), and enrichment facilities (8),(9),(10) treat the purified sewage and discharge into the ocean or send to the wastewater reuse treatment facility. The quality of discharge sewage water is strictly maintained in accordance with the Incheon Municipality requirements – Biochemical Oxygen Demand (10 ppm), Suspended Solids (10ppm), Total Nitrogen (20 ppm), Chemical Oxygen Demand

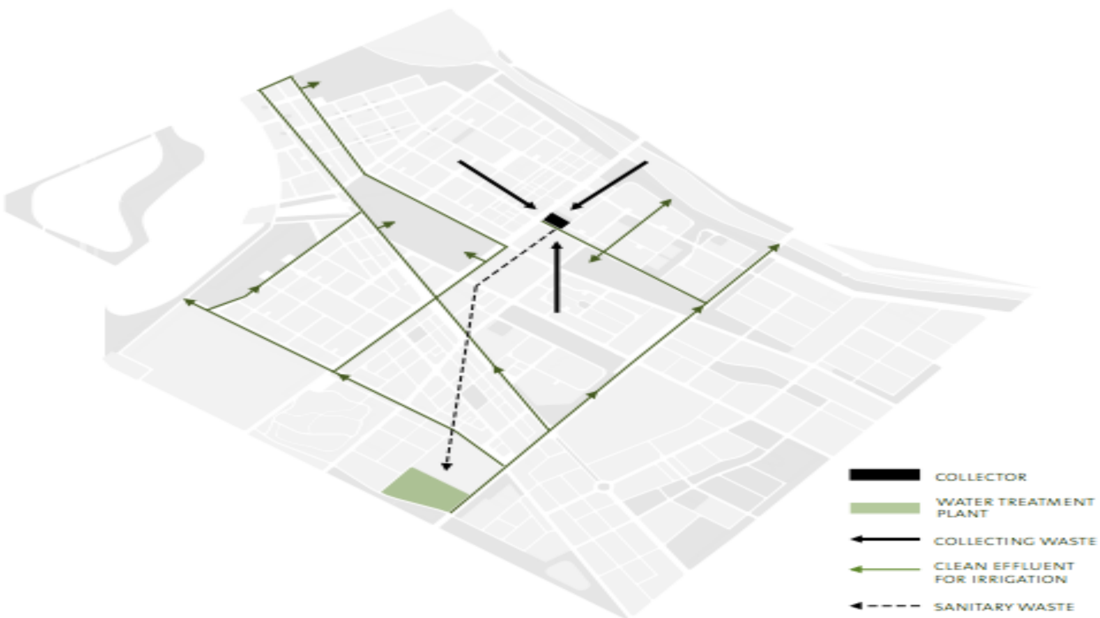
(40ppm), Total Phosphorus (2ppm), and Colon Bacillus (3,000 ea/ml) (Veolia Korea, 2014).

Wastewater reuse

There are a total of 7 wastewater reuse treatment facilities in South Korea and they are mostly used for industrial purposes or as river maintenance water. These facilities are compliant with the government's environmental policy. The government's water resource policy has changed to promote the wastewater reuse system for new buildings since January 2001. It requires that those who want to build or remodel buildings should install the wastewater reuse system and reuse more than 5 percent of total effluence. This standard is set by the MOE law and therefore, the municipality supports the whole or part of the installation costs which are going to establish the water reuse treatment facility for sewage and wastewater. The government also offers special reduced rates for reused water users. In 2006, almost 420 millions sewage was reused out of 6.1 billions of wastewater, which comprises about 7.0 percent of the total amount of sewage (Incheon Metropolitan city, 2000).

In order to enhance the position of the environmental city and thus secure the competiveness as a free economic zone, the city built the Songdo Wastewater Reclamation and Reusing Plant.

Figure 4.3 Songdo wastewater reclamation and reusing plant



Source: Gale International & Kohn Pedersen Fox, 2014

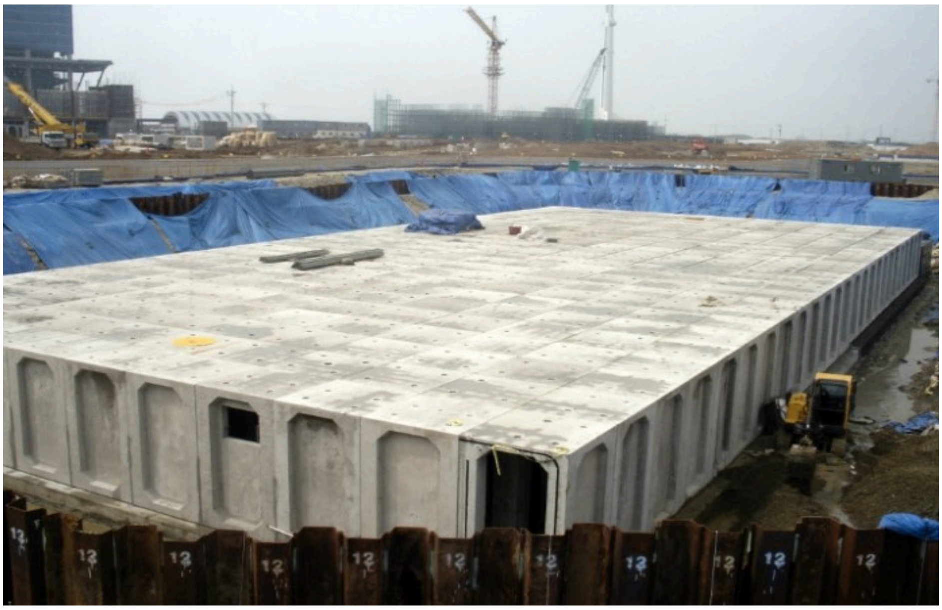
The main purpose of this facility is to treat the wastewater and reuse it for residential purposes, not just providing for the industrial one. The whole district of Songdo is part of the pilot project for the promotion of the wastewater reuse facilities. In this regard, the urban infrastructure was originally designed to install wastewater pipes throughout the city. It is intended to save between 10,000 ~ 13,000 cubic metres of freshwater per day. Wastewater from across the city is collected and delivered to the wastewater treatment facility (see Figure 4.3). After the biological treatment, the clean effluent moves to the secondary treatment, which entails sand, active carbon filtration and the chlorination process. Currently, a total of 22.3 kilometres of underground pipes are installed in Districts 1~4 to distribute the clean and disinfected water for toilet flushing, road cleaning, and irrigation of public parks and urban green spaces in Songdo. The fountains on the central road, Sunrise Park, Mituhol Park, the Sheraton Hotel, and Songdo International school are the highest wastewater consumption places (Kim & Sung, 2010).

One of the advantages of the reused water is that it could save resource costs. Compared to the price of freshwater (1000 Won/ton = equivalent to US$1), the price of the reused water is almost 50 percent cheaper than the freshwater (464 Won/ton). This system is expected to eliminate the use of potable water for landscape purpose. Consequently, it attaches value to the wastewater as a potential water resource and thereby could be one of the green policy's examples that respond to the current climate change, especially for the shortage of water resources. Songdo Wastewater Reclamation and Reusing Plant has been operating since 2009 (Kim & Sung, 2010).

Rainwater collection system

At Songdo Central Park, there are 7 underground storage facilities that can capture approximately 190,700 ft^3 of rainwater falling during the summer rainfall season. Rainwater is stored when water demand is low, especially in the winter. In the spring, when the temperature increases, the stored water is used for irrigation or road cleaning purposes. One storage facility could save approximately 5 million Won (= US$ 5,000) of freshwater expense. Moreover, the rain collection system also has an impact on the prevention of flooding in the rainy season and drought in the winter time (Arup, 2014).

Figure 4.4 Construction of rainwater storage system



Source: Incheon Free Economic Zone, 2013

4.2.2 Waste collection and treatment system

Waste generation has moderately increased as population growth and urbanisation have been facilitated over the last decades. In dealing with these issues, the South Korean government has implemented the volume-rate garbage disposal system since 1995. However, problems that resulted from the waste collection have not yet been solved. Therefore, it is becoming increasingly acknowledged that a new way of collecting and delivering waste is necessary for addressing current problems, such as the smell of the garbage, a bad urban landscape, and traffic safety. In this regard, the pneumatic waste collection system that collects the waste through underground pipes has emerged as an alternative option for the current drawbacks of the waste collection (Yoon & Park, 2012).

Songdo has installed and operated the pneumatic waste collection system to transport solid waste to a central waste processing facility, by using large underground pneumatic pipes. In this chapter, the thesis will examine the overall flow of the solid waste, especially focusing on the pneumatic waste collection system and the incineration centre in Songdo.

Pneumatic waste collection system

It is essential that cities should manage waste properly for the smooth functioning of the city and the resident's welfare. However, a waste collection system with garbage trucks causes several problems. As the system stores the waste for around 3 ~ 4 days in the dustbins, it causes bad smells from garbage and attracts vermin. When the garbage trucks pick up the trash on the street, they make a noise (90~120dB) and occupy parking places thus causing traffic jams in the urban area. The leakage of wastewater from the garbage trucks ruins the urban landscape and pollutes the roads. Furthermore, garbage collection jobs are commonly known as the "3D Jobs", which is dirty, dangerous or difficult. For this reason, the majority of people are reluctant to work as waste collectors. Most of all, the human-labor based system has reached its limits to deal with the increasing amount of the trash that has resulted from urbanisation. Even though most urban residents are aware of these problems, the traditional garbage pickup system is difficult to change due to administrative and financial reasons (Yoon & Park, 2012).

Figure 4.5 Overall flow of waste

Source: Author

Songdo breaks with the traditional waste collection system and builds a unique way of collecting municipal solid waste. The system does not require garbage trucks in the urban area and it is operated by a citywide pneumatic waste collection system. The garbage from the waste collection machine is automatically delivered to the central waste processing facility through the underground pneumatic pipes in the city (see Figure 4.5). At the waste processing facility, waste is sorted and sent to the recycle facility or the incineration plant. At the incineration plant, heat generated by the incineration process is distributed to the buildings in Songdo (Gale International, 2014).

The pneumatic waste collection system consists of three major processes – the waste collection machines, the pneumatic pipes and the central waste processing facilities. When it comes to the waste collection machine, there are indoor and outdoor waste collection machines in Songdo. The indoor machine is mostly located inside the residential area for the sake of the occupant's convenience whereas the outdoor one is generally distributed in the commercial area. Each household or commercial shop has a Radio Frequency Identification (RFID) key to operate the machine. From the RFID system, the users are able to check their accumulated waste generation from the screen.

Figure 4.6 Guideline of waste collection machine

Source: Author

General waste and food waste is collected independently by the different types of machine. The green machine takes the general wastes, which includes flammable, non-flammable and recycle wastes. Since it manages the different kinds of waste, there is a designated day and time for the disposal of the waste. In addition, it is mandatory to purchase a volume-rate garbage bag, otherwise the person will be fined by South Korean environmental law. The orange machine takes food waste and it normally available 24 hours a day. Besides, in order to help people understand the system more easily, there is a simple guideline on the front of the machine (see Figure 4.6). The machine also indicates on the screen when the waste machine is not available (Yoon & Park, 2012).

The waste pipeline connects the waste collection machine and the central waste processing facility. The system uses air pressure to deliver the trash through the waste pipes. So far, the city has installed around 60.8 kilometres of waste pipe in Zones 1 ~ 7 (see Table 4.1).

Table 4.1 Status of the pneumatic waste treatment facility

Zone	Date of Completion	Number of Waste Processing Plants	Amount of collection (tons/day)	Length of pipes (km)	Remark
District 1	2010.12	2	60	10	
District 2	2005.11	1		10	
District 3	2011.11	1	30	7.8	
District 4	2008.06	1	30	11	
District 5,7	2012.04	2	45	22	
District 6,8	2014.06	2	50	20	Under Consideration
District 9,10,11	2018	4		40	Under Consideration

Source: Incheon Free Economic Zone, 2013

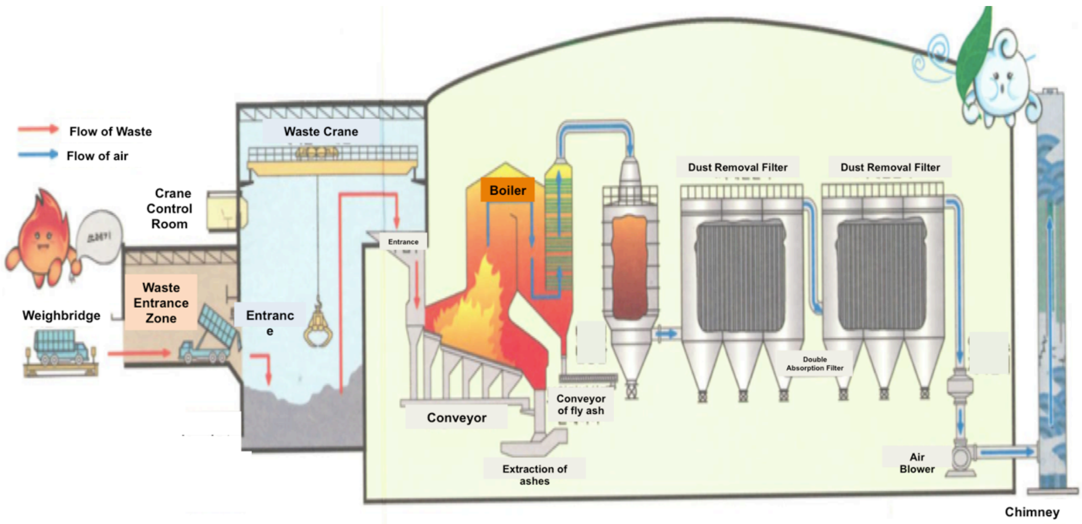
At the central waste processing facility, all of the wastes are collected, sorted and compressed into containers. After that it is delivered to the recycle centre or the incineration centre. Furthermore, the facility has a ventilation system to remove the bad smell that results from the waste sorting process. The whole process is operated by an automatic computer system so that only 1 ~ 2 supervision personnel are required for the operation of the facility. After the process, the sorted waste is redistributed to: the incineration facility for flammable and food wastes; the landfill for non-flammable waste; and the recycle centre for the recycling waste (Lee, et al., 2007).

The pneumatic waste collection system can make an essential contribution to the sustainability of the city. With regards to environmental aspects, the system is more hygienic than conventional waste removal techniques because it fundamentally eradicates the cause of the dust, harmful insects, disease germs, and bad smells. Therefore, it leads to the minimisation of the civil complaints. Moreover, it alleviates the problems of garbage trucks that would have been required to transport waste, such as the traffic congestion and emission of carbon dioxide. Put briefly, as the new system solves the problems of the previous waste pickup system, it could provide a pleasant environment to the residents of Songdo. In line with the social benefits, the government is no longer required to deal with the shortages of the cleaning workers. For the individual household, it reduces the time needed for daily chores and makes life easier. Economically, the system prevents unnecessary energy consumption from the waste collection process – fuel for the garbage pickup trucks, water for cleaning the roads and the electricity for elevator usage (Lee, et al., 2007).

Songdo material environmental centre

ECI operates the Songdo Material Environmental Centre in order to prevent the environmental pollution and to contribute to the upgraded social welfare of the residents. When it comes to the environmental aspects, the centre operates the incineration plant and the food waste recycle facility that manage 500 tons/day of household waste and 200 tons/day of food waste separately. For the sake of social welfare, a sport complex centre, including swimming pool, gym and sauna, a 9-hole mini-golf course and natural grass soccer field are provided for the Songdo residents.

Figure 4.7 Waste incineration treatment facility

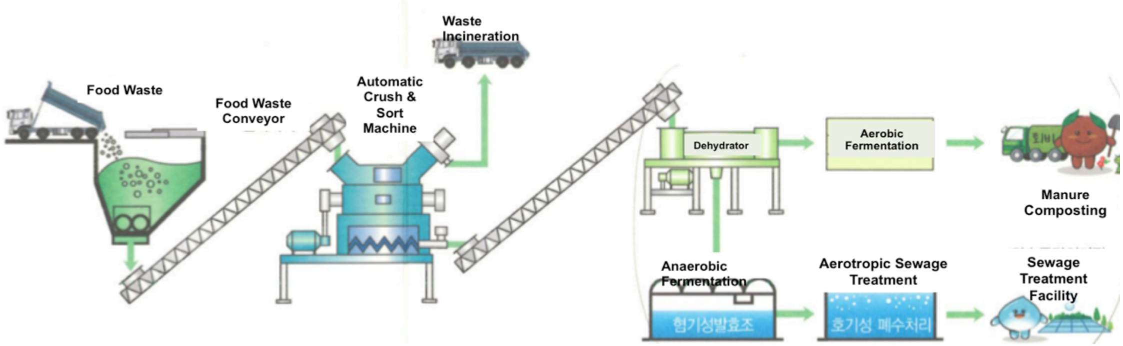


Source: Environmental Corporation of Incheon, 2014

After the pneumatic waste collection process, the general waste is finally delivered to the Songdo incineration plant (see Figure 4.7). Once the garbage truck arrives at the plant, the waste is dumped and broken into pieces for incineration. After 2 or 3 days in the dehydrating process, the waste crane puts the fragmented waste into the boiler. During the incineration process, air pollutants, such as nitrogenous compound, acid vapor, dioxin, heavy metal and dust are generated. In response to these pollutants, there are three different dust removal filters that remove the polluted substance. After this process, the purified air is released into the atmosphere. MOE establishes the environmental index system to oversee the management of the incineration facilities in South Korea. The MOE staff randomly examines the density of the emission gas from the plants in accordance with the environmental index. In addition, heat generated during the incineration process is reused for the buildings in Songdo through a district hot-water system. The leachate from the facility is also completely purified in compliance with the standard for wastewater reuse and supplied as cleaning or gardening water. Currently, the facility treats the waste not just from Songdo but also from other Incheon areas, especially from the South Yeonsu-gu, Namdong-gu, Bupyeong-gu, Yoongin-gu areas (ECI, 2014).

The separately collected food waste is treated into compost through the composting facility (see Figure 4.8).

Figure 4.8 Food waste recycles facility



Source: Environmental Corporation of Incheon, 2014

Food waste has to get through the sorting process first. The automatic crush and the sorting machine handle the separation of waste process. If the waste is too dried or mixed with other wastes, it is not appropriated for recycling purposes and thus sends to the incineration treatment facility. After that, an aerobic fermentation process is applied to the waste in order to compost it as food resources. In addition, the Methane gas, which originates from the leachate treatment, is utilised for the boiler. The facility produces around 24 tons of fertilisers daily, which is provided free to farmers or the fertiliser production companies. Food waste is collected from most of the IFEZ Areas and the plant manages around 200 tons of food waste a day (ECI, 2014).

4.2.3 Energy network

Given the rapid acceleration of fossil-fuel depletion and its related side effects, such as climate change, the demand for fossil fuel energy is going to be the most serious environmental issue for the next 50 years. In the case of South Korea, the national population accounts for 0.75 percent of the world's population whereas its CO_2 emissions represent 1.6 percent of the world's emission (KEPCO, 2014).

Over the last decades, the objective of South Korea's energy policy has changed from ensuring a stable supply of energy to seeking a sustainable energy development. In the 1970s, in order to build infrastructure and achieve economic growth as soon as possible, the energy policy mainly focused on oil, since it was relatively easy to operate and cheap to purchase. However, since the oil shock hit the South Korean economy massively in the late 1970s, the government has realised that their energy production has to be more stabilised and diversified to minimise the impact from internal and external effects. The government established a stable supply and demand system, including diversification of energy supply resources and expanding the energy supply infrastructures. In this regard, nuclear power and coal were selected and have been provided as major sources of electricity production up to the present. From the late 1990s, the government has been promoting the privatisation of the energy industry to improve efficiency in the public sector. Furthermore, as the UN Framework Convention on Climate Change has strengthened the environment regulation, sustainable development has emerged as the major turning point of the energy policy (Kim & Kim, 2011).

General Energy supply flow – Electricity

South Korea has very limited fossil fuel resources and thus the country's energy production is heavily reliant on the import of energy. Almost 97 percent of South Korea's total energy production is dependent on outside resources. In addition, since the country is geographically isolated, it is impossible to export and import electricity to and from neighboring countries. While the production of electric power is mainly distributed in the southern provinces, the major consumption takes place in the northern metropolitan areas. Therefore, an appropriate independent power plant, as well as long-distance transport of electricity is necessary for the nation's stable power supply (KEPCO, 2014).

KEPCO is a state-owned company that was intended to supply electricity to the entire nation. It comprised one generation-transmission and two distribution-sales companies. KEPCO made an important contribution to the industrialisation of South Korea by supplying sufficient power at a low price without outside subsidies. Consequently, the company built a successful capacity for the generation, transmission and distribution of the national grid. It can be seen that the growth of KEPCO was synonymous with the rapid industrialisation of the South Korean economy. In the 1980s, it became the nation's largest company by asset value, and the second largest one by number of employees (Lee, 2011).

Figure 4.9 Structure of South Korea's electricity industry

Source: Korea Electric Power Corporation, 2014

As mentioned earlier, the government has attempted to minimise the power of the public companies, and therefore the role of KEPCO is now also restricted to the transmission and distribution of electricity. Put briefly, now their main duty is to transport the electric power from the Korea Power Exchange and sell it to general customers (see Figure 4.9). With regards to electricity production, 6 power generation companies, independent power producers, and community energy systems are generating electric power in partnership with KEPCO (KEPCO, 2014).

After power plants produce the electricity, they send it to the power supply substation. Since long distance transmission is required, the voltage is increased up to 154,000V, 345,000V and 765,000V and sent to the distribution substation. At this substation, it drops the voltage to 22,900V and supplies electricity to commercial and residential buildings. In Songdo, two distribution substations are currently operating and supplying electricity to the city under the management of KEPCO. Each station receives 154,000V and changes the capacity of voltage to 22,900V for household and commercial distribution purposes (Kim & Kim, 2011).

General Energy supply flow – Gas

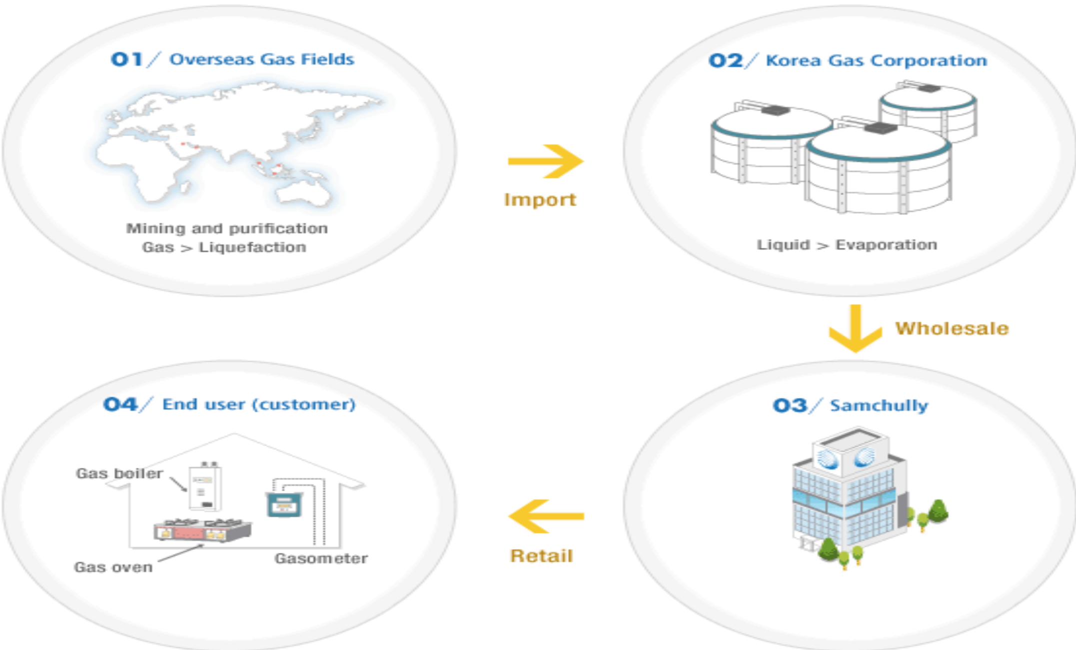
There is an increasing consensus that natural gas is fast becoming a major energy resource, by replacing coal and oil. Compared to other fossil fuels, it is more convenient to use and the increasing demand for natural gas has become a global trend. South Korea is the second largest importer of LNG in the world after Japan. 10 percent of the nation's energy use derives from LNG and it is used for domestic, industrial and commercial purposes (KOGAS, 2014).

The domestic natural gas market operates in the following way. As a state-owned company, Korea Gas Corporation (KOGAS) is in charge of the natural gas in the South Korean domestic market. They exclusively import LNG and provide it to the power generation plants and city gas companies across the country. In the past, the main business area of KOGAS was the transport process of direct supply through pipeline networks to gas companies and consumers. However, in order to supply cheap and stable gas, KOGAS has changed its major business area to the pre-liquefaction operation and the transport process, including exploration, extraction and development of the natural gas (KOGAS, 2014).

The retailers, a total of 33 city gas companies, supply the gas directly to the end of consumers in households and industrial sites. The households and corporations purchase the natural gas from these retail suppliers. The interesting point is that the retail companies are operating as a regional monopoly system. The retail companies divide the nation into 33 districts and each company exclusively supplies the natural gas to their own region. This designated area is described as 'Supply Zone'. 'Supply Zone' is granted for the private companies in order to encourage the capacity development of the natural gas industry and to avoid excessive investment or overlapped investment. Hence, in order to conduct the urban gas business, permission is required from the local government in accordance with the Urban Gas Business Act (Samchully, 2014).

Out of 33 private gas companies, the Samchully Gas Corporation provides natural gas to Incheon and the metropolitan area, including Songdo (see Figure 4.10). They used to import natural gas from Indonesia and Qatar through the LNG ship, which is operated by KOGAS. However, as KOGAS's business strategy has shifted from transport to exploration and development, they now receive the natural gas from the pipeline on the east coast. The provision of natural gas to the urban gas and the power plants is the company's main business area. The Samchully's supply zone has the biggest population in the country and the demand for natural gas is likely to keep increasing in the next decades (Samchully, 2014).

Figure 4.10 Structure of South Korea's gas industry



Source: Samchully, 2014

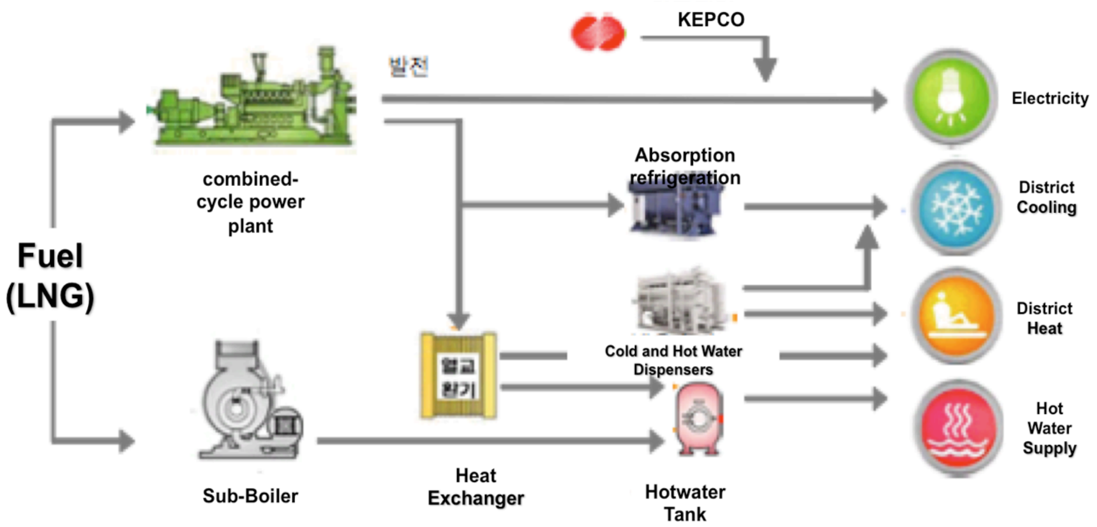
District heating and cooling system

The energy-use for residential and commercial heating accounts for almost 20 percent of the total energy consumption in South Korea. As the increasing oil price and greenhouse gas emission are recognised as a serious, worldwide public concern, the need for energy-use reduction and renewable energy is increasing. Furthermore, the South Korean government ratified the Kyoto Protocol agreement in 2013 in order to reduce the emission of carbon dioxide in South Korean business and industry. Besides, as urbanisation progresses, the residential trend is also changing from individual housing to the communal residence. In light of this trend, the district heating system is considered to be a more realistic option than the separate and central heating system in terms of cost saving and efficiency (Chang, 2008).

With this background, Incheon Total Energy Company (INTECO) was founded in July 2004 to supply district heating and cooling services to Songdo and surrounds. The main purpose of this company is to create comfortable living environments and to contribute to national energy-use saving activities. The company was established with different shareholders, including 20 percent of Samchully, 30 percent of IMC and 50 percent of Korea District Heating. District heating is a large-scale hot water supply system, which is produced by a centralised heating facility and delivered through underground hot water pipes. This system replaces the individual heating facilities installed in local areas such as apartment complexes, houses, shopping centres, office buildings, etc. In addition, INTECO also provides the district cooling system to the Songdo area. In contrast to the heating system, the cooling system converts the hot water to cold water and uses it for decreasing the building temperature during the summer time (INTECO, 2014).

In order to supply the district heating and cooling system, a combined-cycle power plant and its exclusive hot water pipes are necessary for cities. A combined-cycle power plant consists of one gas turbine and one steam turbine and uses LNG as an energy resource. When the plant produces electricity, it also generates waste heat. This waste heat is recycled in the form of hot water and distributed throughout Songdo for building uses such as heating, domestic hot water and cooling. It supplies approximately 250 megawatts electric (MWe) of power and 200 megawatts thermal (MWth) of district heat around Songdo, which will save 20~30 percent of operation costs (Mirae Asset, 2007). In addition, the plant has an absorption refrigeration process, which converts residential heat into district cooling. This system prevents electricity power shortages during the hot summers in South Korea. As a communal energy activation plan, a combined-cycle power plant has been applied to large scale residential and commercial buildings across the nation (Kang, 2010).

Figure 4.11 District heating and cooling system



Source: Mirae Asset

There are a number of advantages to the combined-cycle power plant: energy efficiency, fewer environmental effects and improvement of quality of life. First, it utilises energy more efficiently than the existing power generating system. Assuming that the power plant produces the same amount of electricity and heat, the energy efficiency of the existing power generation is about 49 percent, while the efficiency of the combined heat and power plant is 75 percent. In the latter case, it is able to enhance energy efficiency almost 26 percent. Second, when it comes to the environmental aspects, the CO_2 emissions of the effective district-heating systems are approximately 25 percent lower than the emissions of other existing boiler systems. According to the Korea Energy Management Corporation, through strict management and the pollution preventing technology system, such as the desulfuriser, 22.99 percent of CO_2 and 29.8 percent of sulfur oxides were diminished in 2005. Third, the special gas tariff is applied to the residence of the district heating system and therefore, it costs less than the individual heating system. Lastly, it makes our lives safer and more convenient; hot and cold water are available 24 hours a day; it is relatively easy to maintain; there is no risk fire or explosion in the residential area; and it is not noisy when operating (Mirae Asset, 2007).

INTECO provided district heating and cooling services to a total of 48 buildings in Songdo, including 9 communal residential buildings, 23 commercial buildings and 5 public buildings in 2009. As the NSC project is in accord with the national energy policy that encourages the reduction of energy-use, it was able to create a pleasant environment and thus receive a favorable feedback from the residents (Jung, 2010).

4.2.4 Public Transportation

South Korea's rapid economic growth and a rise in national income is directly reflected in the increasing number of the cars owned. The country had only 40,000 cars in 1965, but now it has more than 16 million cars, which is almost one car for every three of South Korea's 49 million citizens. The private car has become the dominant mode of transportation in most cities. It follows that automobile emission gas is a major contributor to climate change and smog-causing pollutants (Gale International, 2014).

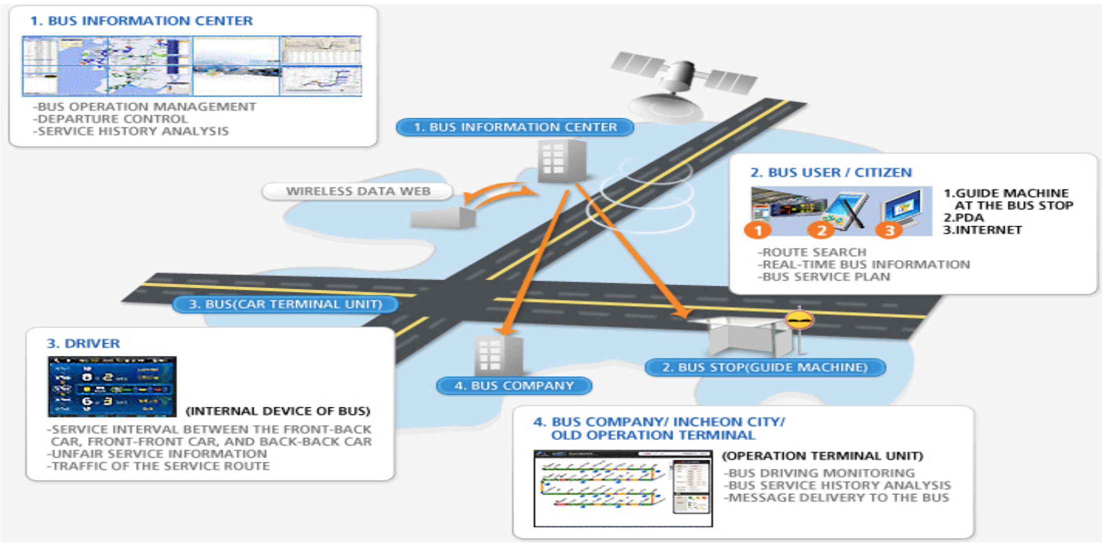
In order to address the growing environmental problems, the South Korean government has strengthened environmental control, changing the diesel fuel bus to natural gas, improving the public transportation service and promoting electric vehicles. Given that a person travels the same distance, the public transport systems use less than half the fuel of private vehicles, significantly reducing CO_2 emissions and smog. In addition, there is a high possibility that if the citywide transportation networks provide a more punctual and comfortable public service to people, private automobile use can be greatly reduced. In this regard, Songdo actively encourages public transport use, by providing an upgraded public service based on the resident's convenience and environmental aspects, such as Bus Information System (BIS), Compressed Natural Gas (CNG) bus, bicycle lane and car sharing system (Gale International, 2014).

Bus

In the 1990s, the number of registered cars reached more than 10 million in South Korea. It naturally led to traffic congestion and the demand for the advanced public service was increased as an alternative. Since the urban train required a massive amount of construction expense, the public bus was considered as an economical public transport option. However, the main problem was that the bus system could not provide the transport service in a timely manner due to traffic jams. Consequently, the number of passengers decreased and the role of buses was diminished. In the 2000s, the world faced major environmental issues such as global warming and exploitation of resources and thus the demand for an environmentally friendly transport system has emerged again. The problem with the former bus system was that since the system is fully reliant on private companies, the priority was the profit for the companies, not for the passenger's convenience. Therefore, the reform of the bus system focused on the transformation of the bus service in terms of passenger friendly service. At this time, the government and the private companies cooperated with each other in order to provide an improved bus service. In doing so, the government decided to launch the following services - the exclusive bus lane, the discount fee for the public transfer system and the smart card system – in collaboration with different private companies. As a result, the bus transportation service was strongly upgraded and started to play a pivotal role in public transportation (Lee & Lim, 2013).

As a part of the nation's public transport planning, different characteristics can be observed from Songdo's bus system. First, the BIS enables checking the status of the bus so that passengers are able to save time at the bus station. Second, CNG bus and its natural gas station contribute to the reduction of CO_2 emissions. Third, an integrated transport card is available for the bus and the train with discount fare for the public transfer. Lastly, bus stops are located within one-quarter mile of all residential and commercial buildings for the sake of the resident's convenience.

Figure 4.12 Bus Information System



Source: Incheon Transit Corporation, 2014

First, the BIS provides real-time bus service information for bus users to save their valuable time (see Figure 4.12). The intention is to make the public transportation system more efficient and convenient. One is able to access the system through the screen at the bus stop or via a smartphone application. Specifically, the system offers information on the current location of buses, arrival times, bus lines, transfer, bus stops, and traffic conditions in real-time through the internet for the user's convenience. Users who download the application to their smartphones or hold membership on the website can easily access this information. Bus drivers are able to get information on the service and bus intervals, real time locations, bus network status and service history and statistics. Most of all, it makes a positive contribution to the time accuracy and safe driving environment through information about bus operating intervals (Incheon Transit Corporation, 2014).

Figure 4.13 BIS screen at the bus station

Figure 4.14 CNG Station

Source: Author

Incheon Transit Corporation (ITC) manages the BIS as can be seen at Figure 4.12 The bus information centre collects and processes the location information by GPS satellite and the vehicle terminal. After the collection of transport information, the centre provides it to the users through various means such as web, PDA, bus stop guide machines, etc. In addition, it offers important information such as schedules to passengers and bus drivers through the bus-equipped terminal. Efficient management of schedules is conducted, by cooperating with the bus company managements and the Incheon city official support system (Incheon Transit Corporation, 2014).

Second, all the buses operating in the Songdo area are equipped with the CNG system (see Figure 4.14). The bus uses CNG as a fuel and therefore makes less air pollutions and noise compared to the diesel car. Generally, the CNG vehicle is assumed that only 31 percent of nitrogenous compound, 41 percent of carbon monoxide and 16 percent of hydrocarbon are produced compared to the diesel vehicle. However, the high cost of vehicles could be a burden for the government's financial budget. The structure of CNG bus is similar to the diesel vehicle except for the fuel system. The difference is that the natural gas is compressed, stored in the gas chamber and send to the engine with a mixture of air. In 1998, the first CNG bus was operated on a trial basis and widely distributed in the metropolitan area in 2002. A total of 38,106 CNG buses and 178 natural gas stations were operating across the county in 2013 (Lee & Lim, 2013).

Lastly, the bus service is easily accessible throughout the city since the bus stops are located within one-quarter mile of all residential and commercial buildings (see Figure 4.15).

Figure 4.15 Public transportation network

Source: Gale International, 2014

Depending on the district, the bus route is divided into three different types - village bus, metropolitan bus, and express bus. The village bus mainly operates within Songdo, while the metropolitan one extends the service to Incheon area. These buses run every 10 ~ 15 minutes. At the express bus terminal, one is able to travel across the nation with the express bus service. All of this information is available from the BIS. Moreover, each bus has the integrated bus card system so that one can pay the fee with a transit card or credit card, without using cash. In addition, the discount fare is provided to passengers when they transfer to other public buses or the subway.

Subway

Within Songdo, the Incheon subway line 1 is extended and has provided a public transport service to the resident since 2009. There are a total of 6 train stops located in Songdo, which are the Campus Town, Techno Park, BIT zone, University of Incheon, Central Park and International Business District Station. This subway line links to all the major business and residential areas of the Seoul and Incheon Metropolitan areas, as well as the express train to Incheon International Airport. Similar to the bus stops, the train station is also located within a half-mile walk of most residential areas. In addition, every station installed the train information screen, which provides the current status of the train for passengers (see Figure 4.16). The subway timetable is accessible to everyone and it mostly offers very punctual service. A screen door is installed at every station in order to prevent any unexpected accidents at the station.

Figure 4.16 Campus town station

Figure 4.17 Entrance of subway station

Source: Author

Subway users have to purchase a ticket at the automatic fare system. The system consists of the transportation card issuing machine and the deposit return machine. Customers can purchase new cards or recharge the previous cards at the issuing machine. After travel, users who hold a single-use transportation card, are able to return the deposits at the deposit return machine. The returned card is recycled for the next use. If one already possesses a monthly transportation card, one may pass through the automated gate and board the subway (see Figure 4.17). The station monitoring system collects all data related to single-use transportation card sales, balance, reload and accumulated usage for each station. Furthermore, the system shares the necessary information such as peak time train users or malfunction information with each station and the central office. This enables the automatic fare system to function more efficiently with other stations (Incheon Transit Corporation, 2014).

Bicycle lane

Songdo's bicycle lane and the rental service is the most distinctive feature of the public transport system compared to other cities in South Korea. Following this, Songdo is known as 'Bicycle Town'. The city has a total 43.8 kilometres of segregated bike lanes and sidewalks adjacent to all the main streets providing safe and comfortable pedestrian-friendly environments and accessibility across the new city. A short-term rental bike system allows residents to commute to and from work, shopping, and recreational activities by cycling. Designated bike storages are accessible throughout the city for the safe storage of private or rental bikes (IFEZ, 2010).

Figure 4.18 Bicycle lane and pedestrian road

Figure 4.19 Bicycle rack

Source: Author

Since the urban planner considered the bicycle lane when they originally designed the city, the bicycle lanes are more spacious and well connected with other public infrastructures than other cities. Furthermore, there are 100 public bicycles available free of charge at the 6 train stations in Songdo. As the majority of Songdo residents own their bicycle, the real users of public bicycles are tourists or business travellers;

therefore the existing number of bicycles is enough to meet those demands so far. However, as the numbers of visitors is increasing, the city is planning to hire 100 extra bicycles in the near future. For the foreign visitors, English service will be also provided. In addition, total of 39 bicycle pumps are distributed around the city for the self-maintenance of bicycles.

The department of Ubiquitous city (U-City) in the IFEZ is in charge of the bicycle infrastructures in Songdo. According to their recent survey, Songdo residents have 1~2 bicycles per household. However, there are not enough bicycle racks or parking spaces to meet the increasing demand of bicycles in Songdo. According to the Yoo Jaeho, a government official of U-City, “due to the concern of bicycle theft, the registered bicycle system has launched recently. We are aware of the increasing number of bicycles and the lack of bicycle infrastructure. Hence, we are planning to extend the bicycle infrastructures, such as bicycle parking space and storages in the near future”. In addition, another concern of the existing bicycle system is that there are not enough signs for the bicycle roads, thus it may confuse new people in terms of the purpose of the roads (Bike Magazine, 2014).

Car sharing system

Besides providing an efficient public transport service, the city in also operating a car sharing system as well as encouraging carpools and the usage of fuel-efficient vehicles. Simply stated, the car sharing system is sharing a vehicle with a certain group of people by taking advantage of the short-term, self-accessed use without the burden of car ownership. A fee will be charged based on the type of vehicle and its usage through a card-key system. Everyone with a valid driver’s license with a minimum of a year’s driving experience is eligible. The shared car will be stored and parked throughout Songdo in reserved spaces. Additionally, in order to promote an energy-saving culture, five percent of parking capacity within each project block will be set aside as parking for the fuel-efficient and the low emission vehicles. Parking space is mostly located underground or under a canopy to minimise the urban heat island effect and maximise pedestrian-oriented open space above ground (Gale International, 2014).

Figure 4.20 Car sharing service

Figure 4.21 Membership card for car sharing service

Source: Incheon Free Economic Zone, 2013

4.3 Conclusion

In this chapter, the thesis explored a detailed description of the primary urban infrastructure system in Songdo - water, sanitation, solid waste, energy, and public transport. Most of the urban infrastructure facilities are operated by the public or private companies under the management of the IFEZ. From the research, one can see how the city developers attempted to transform the city as a sustainable city in terms of their infrastructures.

Songdo provides residents with reliable and sustainable urban infrastructures – clean water supply and sewage treatment, the pneumatic waste collection system, district heating and cooling system and easy access to mass transit without relying on personal automobiles. First, with regards to the water network, the city supplies the water from the Han River. The Veolia is in charge of the sewage treatment in Songdo. After the biological treatment process, the treated water is sent to the wastewater reusing treatment facility and reused for gardening or road cleaning. A rainwater collection system is installed around the central park to save the fresh water usage in the city. Second, the city operates the pneumatic waste collection system to improve previous waste collection problems – smell of the garbage, bad urban landscape, and traffic safety. The collected solid waste is incinerated at the plant and the generated heat from the process is reused as a district heat around the city. Food waste is separately collected, composted and distributed to the farmers free of charge. Third, the KEPCO and Samchully are providing electricity and natural gas to the residents. To make a contribution to the energy efficiency of the city, a combined-cycle power plant for the district heating and cooling service was constructed and is currently managed by INTECO. Lastly, for the sake of the promotion of public transport, the BIS system, CNG bus, integrated card system, discount for public transfer, exclusive bicycle lane, free bicycle rent service and car sharing service are being offered to Songdo residents. All of these alternative transportation systems work to limit automobile congestion, improve air quality and increase individual mobility citywide.

Chapter 5: Implication of a sustainable city approach – a metabolic flow perspective

5.1 Introduction

In the previous chapter, it was explored how urban infrastructures are organised and operated in the Songdo. Subsequently, in this chapter, Songdo's urban infrastructures will be examined from a metabolic flow perspective and suggest improvements for sustainable cities.

An urban MFA will be performed to determine the flow of inputs (water, electricity and gas) and outputs (wastewater and solid wastes) to and from Songdo. In particular, a detailed quantification of the total consumption of water (kilolitres), electricity (kWh), LNG (m^3), and the generation of sewage (kilolitres), and solid waste (that goes to landfill and that goes into recycling) (tons) per person per annum will be analysed in order to determine the current sustainability of Songdo's urban infrastructures and to identify opportunities for improvement.

5.2 Applying Material Flow Analysis (MFA) to Songdo

5.2.1 Data sources

The main data sources used for this study were the databases and reports generated by K-water, KEPCO, IMC, MOE, ECI and Gale International. To study material and energy flow, a framework of indicators was developed in the study. This framework includes the following categories: (i) inflows and outflows for the years selected and (ii) intensities of resource consumption or generation per capita (see Table 5.1).

Table 5.1 Flows, indicators and data sources used in Songdo

Flow inputs	Indicators		Data sources
	Inflows	Intensity	
Water	Kilolitres/year	Water consumption per capita	IMC
Electricity	kWh/year	Electricity consumption per capita	KEPCO
Gas	m^3/year	Gas consumption per capita	IMC

Flow outputs	Indicators		Data sources
Sewage	Kilolitres/year	Wastewater generation per capita	IMC
Solid wastes	Tons/year	Solid waste generation per capita	ECI
Greenhouse gas emission	CO_2eq/year	Emissions per capita	Gale international

*Greenhouse gas emission is Gale's estimated levels of CO_2 emissions

Regarding greenhouse gas emission, there is no data available at the moment, thus Gale's target CO_2 emission for the future was used.

Songdo's population has drastically increased over the past 5 years. According to the Yeonsu-gu Municipality, the number of residents that officially registered in Songdo in 2009 was 33,293 and this has increased to 70,663 in 2013 (see Table 5.2). Therefore, the population has more than doubled in four years and according to IFEZ, the city expected to reach around 100,000 residents by the end of 2014. This number is predicted because since 2013 international corporations, such as Samsung, POSCO, BMW, and IBM opened branch offices there.

In addition to the residents, even more people are present in the city due to the work, since Songdo is designed as a business hub district, there are a number of people commuting from other cities to work there. The reason for this is that the majority of residential buildings in Songdo are targeted at the upper-middle income households and are not affordable for everyone. An average apartment in Songdo costs 500 million Won (=US$ 500,000), while the average South Korean house cost 300 million Won (=US$ 300,000). Songdo is the most highly-priced district in terms of housing in Incheon. As a result, the rental fee is also more expensive than the average rental fee in South Korea and therefore many people rather live in another city and commute to Songdo to work. Additionally, there are approximately 10,000 students at the Yonsei University, Incheon University and the State University of New York. In this research, the officially registered population of Songdo obtained from the Yeonsu-gu Municipality is used as demographic data. It represents those people who are actually residing in the residential buildings in Songdo on a permanent basis and who are registered at the Yeonsu-gu Municipality as residents.

Table 5.2 Statistics of Songdo's population

Year	Total population			Households	Population per household
	Total	Male	Female		
2009.12	33,293	16,491	16,802	10,121	3.29
2010.12	40,616	20,230	20,386	12,259	3.31
2011.12	55,178	27,490	27,688	16,479	3.35
2012.12	61,608	30,533	31,075	18,702	3.29
2013.12	70,633	34,956	35,677	21,531	3.28
2014.08	79,395	39,197	40,198	24,378	3.26

Source: Yeonsu-gu Municipality, 2014

5.2.2 Water consumption

For the sake of efficient water management, Songdo has installed a wastewater reusing treatment facility and a rain collection system (IFEZ, 2013). This brings us to the question of how much these facilities contribute to reducing total amount of the water consumption in the city. In order to find the answer to this, the total water consumption per capita (litres per person, per annum, and per day) was examined and compared with other cities' consumption.

The international standard water consumption for a family of five people is 100 litres per day. The average daily water use per family ranges from 200 to 300 litres in most European countries to 575 litres in the USA to less than 10 litres per day in countries such as Mozambique, Rwanda and Haiti. In the case of South Korea, the percentage of national water supply is 86.1% and the nation's water use per person was 388 litres per day in 2013. IMC consumed less water than the South Korean average, in the same year, which was 338 litres of water per person per day (K-water, 2014).

In 2013, Songdo consumed 10,335,853 kilolitres of water and 146 kilolitres per person, which is higher than the global average of 57 kilolitres per person. Compared to the average South Korean water consumption index, Songdo's daily water consumption per capita (402 litres/day) is higher than the general water consumption in South Korea (388 litres/day) and the average water consumption of IMC (338 litres/day). These averages in water consumption show that sustainable approaches to water management have not yet influenced the overall water consumption in Songdo, compared to the average water consumption per capita in South Korea (K-water, 2014).

Table 5.3 Songdo's water consumption in 2013

Unit: kilolitres

Industry/area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Residential	340,614	356,898	339,797	335,064	357,511	365,838	389,164	396,349	408,946	387,005	371,727	386,386	**4,435,299**
Social institutions	89	76	75	83	86	94	92	92	98	85	81	89	**1,040**
Army	3,650	1,566	1,569	1,513	1,774	2,044	1,757	1,638	1,750	1,522	1,366	1,387	**21,536**
Commercial industries	218,466	197,315	180,743	204,480	248,216	264,527	300,814	310,324	340,456	330,173	291,721	270,733	**3,157,968**
Manufacturing industries	151,143	143,926	138,721	137,077	140,369	120,545	146,439	158,256	163,516	147,521	135,314	141,489	**1,724,316**
School	73,108	38,674	37,217	66,359	83,384	83,050	93,039	75,321	68,472	82,322	78,272	80,988	**860,206**
Public baths	15,950	17,228	14,840	12,724	12,680	10,830	9,358	10,150	11,000	13,082	12,328	15,318	**155,488**
Total	803,020	755,683	712,962	757,300	844,020	846,928	940,663	952,130	994,238	961,710	890,809	896,390	**10,355,853**

Source: Incheon Metropolitan City: Internal data, 2013

Table 5.3 shows the distribution of water consumption in Songdo in 2013 by district and purpose. Residential, commercial, and public areas contributed 42%, 49% and 9% to the total water consumption, respectively. As can be seen, water consumption in the city had steadily increased and reached a peak in September. The high water consumption between July and October are attributed to the high temperature during the summer season and the increasing population. Something to take note of is that the public bathhouses account for two percent of the total water consumption in Songdo. In South Korea, people go to public baths with family or friends to sanitise or to relax. There are two public bathhouses located in downtown Songdo.

5.2.3 Sewage generation and reuse

Approached from an urban metabolism perspective, water consumption and wastewater generation are directly linked. If cities consume high volumes of water, it consequently generates high volumes of sewage. Table 5.4 shows the inflow and outflow of Songdo's wastewater treatment in 2013.

Table 5.4 Songdo's sewage treatment in 2013

Unit: kilolitres

-		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Inflow	Daily	23,479	23,969	24,206	23,765	24,023	25,079	29,292	28,462	27,378	25,593	24,741	24,442	**25,382**
	Total	727,840	671,134	750,398	712,942	744,705	752,359	908,065	882,322	821,349	793,389	742,241	757,689	**9,264,433**
Outflow	Daily	22,157	22,475	22,371	22,361	23,094	24,173	28,260	27,662	25,686	24,512	22,243	16,014	**23,423**

	Total	686,880	629,290	693,498	670,828	715,922	725,175	876,049	857,516	770,575	759,857	667,275	496,439	**8,549,304**

Source: Incheon Metropolitan City: Internal data, 2013

In 2013, Songdo produced 9.2 million kilolitres of wastewater, which is almost consistent with its water consumption (10.3 million kilolitres). Songdo's daily average of sewage production is 25,382 kilolitres, which amount to 359 litres of sewage per capita per day. In comparison, the USA produces between 275 and 375 litres of wastewater per capita per day on average and Incheon produces on average 320 litres wastewater per capita per day (IMC, 2013). Therefore, Songdo's sewage production is higher the Incheon's average and almost the same as in the USA.

With respect to the wastewater treatment and reuse, from the total water consumed in Songdo, 313,643 kilolitres are delivered to Songdo's wastewater reclamation and reusing plant. After undergoing an extra treatment process, 265,755 kilolitres of water were redistributed to the city in 2013. Only three percent of wastewater is recycled, which is lower than the original target (30 percent). This is because wastewater is currently only used for road cleaning and sanitation purposes. The reason for that is that the wastewater treatment facility does not desalinate (remove salt from) the wastewater and therefore the salinity of the water is too high to use for irrigation and gardening. According to the original plan, the recycled wastewater should have provided water for the irrigation of the golf courses and other green spaces, including the central park. However, this is not the case. Furthermore, even public buildings that are supposed to be using recycled wastewater for sanitation purposes are reluctant to do so because the high level of salt in the water may cause their pipes corrode.

According to the IFEZ, if the facility were to add desalination technology to their equipment, it would cost 30 billion Won (= US$ 30 million), which is almost the double expense to set up the entire wastewater facility. The high cost is, amongst other things, due to the fact that the facility was approved and constructed to operate without a salt removal process. Because of the high cost, the second wastewater treatment facility, which is in the process of being built is also constructed without the consideration of adding desalination technology (Dailyhankook, 2014).

To sum up, 10,355,853 kilolitres of water were consumed in Songdo in 2013 and 9,264,433 kilolitres of wastewater were generated in the same year. A total of 8,549,304 kilolitres of wastewater were treated and released into the sea and

265,755 kilolitres of wastewater were reused for the city, which amounts to three percent of total water usage (see Table 5.5).

Table 5.5 Summary of Songdo's water flow in 2013

Contents	Water flow (kilolitres)	Remark
Total water consumption	10,355,853	402 (litres/day/capita)
Total inflow of sewage to the sewage treatment facility	9,264,433	359 (litres/day/capita)
Total treated wastewater	8,549,304	-
Total inflow to be reused after wastewater treatment	313,643	-
Total reused water for the city	265,755	Three percent of sewage is reused in total

Source: Incheon Metropolitan City: Internal data, 2013

The data indicates that the production of wastewater shows the same trends as water consumption. Furthermore, it increases in parallel with the increase in income of the upper middle class families as these families generate higher amounts of sewage than average income families. Likewise, the general trends of water consumption and sewage generation in Songdo is likely to increase at a similar pace as wealthy countries. Its average consumption per capita is more than the average in South Korea and more than in Incheon. In addition, as the wastewater reuse facility is operating on a limited basis, it does not affect to the overall consumption of the freshwater and generation of sewage. According to the IFEZ officials, "The wetland reclamation and construction on site are still ongoing; therefore the demand for reused water is still low". In this regard, as the demand for reused water increases, the overall efficiency of water usage is also expected to increase in the near future. Consequently, one might argue that Songdo's sustainable approach to the water sector has to be made first to reduce the usage of freshwater and then to increase the reused wastewater consumption.

5.2.4 Electricity consumption

As mentioned in the Chapter 4, the electricity supply in South Korea is managed by KEPCO on a national scale. In this section, the nation's electricity generation from fossil fuels and alternative energy sources will be examined. The electricity consumption per person day and per annum (kWh) in Songdo will be presented. By comparing those figures with that of other cities, it should be possible to demonstrate how energy efficient Songdo is.

Table 5.6 indicates the gross generation of electricity by energy source in South Korea. Between 1980 and 2013, the electricity generation has greatly increased from 37,209 GWh/year to 517,149 GWh/year, which is a more than tenfold increase over 33 years. This massive increase in electricity generation (caused by increased electricity consumption) is due to rapid economic growth and the spiralling population growth between the 1980's and the 2000's. Even after the 2000's, the generation of electricity is still increasing steadily in order to meet the increasing demand for energy in the nation (KEPCO, 2014).

Table 5.6 Gross generation of electricity by energy sources

Unit: GWh

Item		1980	2009	2010	2011	2012	2013
Hydro		1,984	5,641	6,472	7,831	7,695	8,543
Thermal	Oil	29,297	19,912	25,356	24,921	48,244	31,584
	LNG	-	65,273	96,483	101,702	113,984	127,724
	Coal (Anth)	2,481	5,559	4,613	3,269	6,489	3,912
	Coal(Bitum.)	-	187,657	189,156	196,855	174,263	196,532
Nuclear		3,447	147,771	148,596	154,723	150,327	138,784
Alternative		-	1,791	3,984	7,592	8,571	10,068
Total		37,209	433,604	474,660	496,893	509,573	517,147

Source: Korea Electric Power Corporation, 2014

In 1980, oil and coal were the predominant energy sources, whereas in 2013, nuclear, coal and natural gas were predominant. To be more specific, thermal power generation based on oil and coal was the major energy source in the 1980s. In the 1980s, approximately 85 percent of South Korea's energy was generated from fossil fuels. However, the use of fossil fuels is gradually decreasing and now comprises 70 percent of the total amount of energy sources. In the 1990s, the Ministry of Knowledge Economy devised a long-term energy plan, the "Energy Security Initiative", aimed at increasing the nation's self reliance and diversifying its energy sources. Since then, the energy sources have diversified, the use of nuclear energy has increased significantly and the use of renewable energy sources is slowly increasing. Currently, the electricity consumed in Songdo is generated from the following sources – fossil fuels (70 percent), nuclear energy (26 percent) and renewable energy (four percent).

The electricity consumption in South Korea per capita is presented in Table 5.7.

Since 2009, the electricity consumption (8,902 kWh per capita) in South Korea has gradually increased to 9,331 kWh per capita in 2012 and then slightly decreased to 9,285 kWh in 2013. In 2009 and 2010, the South Korean economy was shocked by the financial crisis. Subsequently, there was a slight decrease in electricity consumption during this period. However, the figure had increased again as the economy recovered since 2011. In 2013, the electricity consumption slightly decreased because the nuclear power plant temporarily broke down due to some technical malfunctions at that time. Therefore, the government actively encouraged the industrial, commercial and residential sectors to save electricity.

Table 5.7 Electricity consumption per capita in South Korea

Unit: kWh/year

Item	2009	2010	2011	2012	2013
Per capita	8,902	8,838	9,142	9,331	9,285

Source: Korea Electric Power Corporation, 2014

*A population of 51,141,463 is used for 2013's calculation

During 2013, 889,807,521 kWh of electricity was consumed in Songdo in total the equivalent of approximately 0.2 percent of South Korea's total energy consumption. In terms of the per capita usage, Songdo residents' consumed 14,443 kWh of electricity per person in 2013. In comparison with Incheon (7,813 kWh/year) and Seoul (4,523 kWh/year) in 2012, Songdo's electricity usage is much higher (see Table 5.8).

Table 5.8 Comparison of electricity consumption in South Korean cities per capita in 2012

-	Population	Total electricity usage (kWh/year)	Per capita (kWh/year)
Seoul	10,442,426	47,234,102,000	4,523
Incheon	2,891,286	22,590,022,000	7,813
Songdo	61,608	889,807,521	14,443

Source: Korea Electric Power Corporation, 2014

The reason why the electricity consumption is different in each city is that each city has a different industrial structure. In 2012, the service industry accounted for nearly 60 percent of the total electricity consumption in Seoul, whereas the manufacturing industry accounted only four percent. In Incheon, 52 percent of the total electricity consumed was used in the manufacturing sector and 28 percent in the service sector. From this, it can be assumed that there are a number of factories operating in Incheon, making the need for electricity higher in that city (KEPCO, 2014).

The question that comes to the fore is: What is the main cause of the high electricity consumption in Songdo? Even though the detail electricity consumption by industry in Songdo is currently not available, there are three main factors that can be assumed from observation during the field trip, to be the cause of high electricity consumption. Firstly, the city is still under construction, therefore it requires extra electricity in order to build urban infrastructures and buildings. In addition, those who are working on the construction sites in Songdo are not included in the demographic figures, which contribute the high electricity consumption per capita. Secondly, the pneumatic waste collection system utilised in Songdo uses a large amount of electricity to remove waste 24 hours a day. Since the machine uses vacuum pressure, it requires a high amount of energy to operate and to maintain. Lastly, since there are many high-income households in the city, who generally consume more resources than the average income households do, they are also likely to cause an increase in electricity consumption.

5.2.5 Liquefied natural gas (LNG) consumption

South Korea's energy resource diversification policy lead to an increase in LNG consumption. In Songdo, the city operates on a combined-cycle power plant in order to increase its energy efficiency. In this section, there will be looked at the city's LNG consumption.

Table 5.9 LNG supply and demand in South Korea

Unit: 1,000 ton

Year	Supply		Demand				
	Production	Import	Total	Power generation	District heating	Gas manufacturing	Others
2003	-	19,308	18,610	5,853	615	11,978	165
2004	163	21,781	21,809	8,242	576	12,504	487
2005	398	22,317	23,350	8,359	685	14,077	229
2006	355	25,256	24,619	9,860	619	13,957	183
2007	271	25,569	26,664	11,295	631	14,595	141
2008	181	27,259	27,439	11,175	603	15,489	173
2009	383	25,822	26,083	9,705	524	15,634	220
2010	415	32,603	33,083	14,268	651	17,522	213
2011	347	36,685	35,608	14,759	1,760	18,255	214

2012	334	36,184	38,485	16,132	2,046	19,558	200

Source: Korea Energy Economics Institute, 2013

Table 5.9 describes the supply and demand of LNG in South Korea from 2003 to 2012. Over the last ten years, both of these have constantly increased. The LNG consumption had, however, decreased during the economic crisis in 2009 and the demand for a district heating network has drastically increased since 2011. Similarly to electricity consumption, it can be seen that the LNG usage is influenced by the economic situation of the country. In 2012, South Korea consumed 38,485,000 tons of LNG in total, which was used for power generation (42 percent), district heating (six percent), gas manufacturing (51 percent) and other purposes (one percent).

Table 5.10 Songdo LNG gas consumption in 2011

Unit: 1000m^3

	Total	Home use	Business Use	Office Use	Industrial Use
LNG consumption	21,835	21,046	613	117	59

Source: Incheon Metropolitan City: Internal data

The most recent data on LNG consumption in Songdo is not available at the moment. The latest available data are from 2011 (Table 5.10). That year, Songdo consumed 21,835,000 m^3 of LNG, which amounts to 396 m^3 per capita. Residential usage significantly contributed to the overall gas consumption of the city (96.39 percent). Other sectors, such as businesses (2.81 percent), offices (0.45 percent) and industrial areas (0.27 percent) consumed relatively low amounts of LNG.

Table 5.11 Comparison of LNG consumption of South Korean cities per capita in 2011

City	Population	Usage (1000m^3)	Per capita
Seoul	10,528,744	4,173,311	0.396
Incheon	2,851,491	1,014,085	0.356
Songdo	55,178	21,835	0.396

Source: Seoul Metropolitan City, 2013, Incheon Metropolitan City, 2013

Comparing the per capita consumption of LNG in different cities, a metropolitan city, like Seoul and Incheon consumed 396 m^3 and 356 m^3 LNG per person respectively in 2011. Songdo's figure (396 m^3/person) was the same as Seoul's that year (see Table 5.11). The question could be asked why there is no difference between Songdo and Seoul's figures, despite the fact that Songdo built a combined-cycle power plant to increase energy efficiency?

This question can be linked to the current debate around the energy efficiency of the district heating system versus individual heating systems. As mentioned in Chapter 4, the district heating network has been proven to be more energy efficient and has less of a harmful environmental impact than existing power plants. However, the current research argues that the district heating system is still not as energy efficient and costs effective as individual heating systems. According to the Yearbook of Energy Statistics (2013), in order to generate 10,000 kcal of heat, using a district heating system will cost 706 Won (=US$ 70 cents), whereas using an individual heating system will cost 667 Won (=US$ 65 cents). From a customer's perspective, it would be less costly to live in an area where there is a district heating network because the government provides a subsidy. However, if one ignores the government's subsidy, the general economic efficiency of the district heating system is only 60 percent of that of the individual heating network. According to Hwang Tae Yeon, a representative of local resident in Nowon district, Seoul, "If the city is planning to install the district heating network, it is necessary to check characteristics of region, kinds of heat sources and heating efficiency. The efficiency of the district heating system is different depending on the regional situation". In this case, their residence changed the system from a district heating system to an individual heating network due to the high communal management price of the district heating system. In addition, he said, "There were not much complaints for the individual heating system because residents are able to use the heating system with their preference and pay the expense based on their own consumption". Therefore, clearly more research is needed to illuminate the energy efficiency of the district heating system in Songdo (SG Energy, 2014).

5.2.6 Solid waste generation

Solid waste is mainly divided into residential waste and industrial waste. Residential waste is generated by households, offices and restaurants. While industrial waste is produced during installation and operation that forms part of industrial activities. A third type of waste is construction waste, which is produced during construction work and has been managed separately from industrial waste in South Korea since 1996. According to the National Waste Statistics Survey (see Table 5.12), which was conducted by the MOE, South Korea's total solid waste in 2012 was 382,009 tons per day, which shows a 2.3 percent increase since the previous year (373,312 tons/day). In the same year, the total residential waste generated was 48,900 tons per day. There was only a 0.1 percent increase compared to 2011 whereas the industrial waste generation showed a 6.1 percent increase during the same year. Construction waste accounted for 49 percent of the total solid waste in 2012; therefore it can be reasoned that construction business were very active during that period.

Table 5.12 Generation and treatment of residential, industrial and construction waste in South Korea (2012)

Unit: ton/day

		2006	2007	2008	2009	2010	2011	2012
Total solid waste		318,928	337,158	359,296	357,861	365,154	373,312	382,009
Waste type	**Residential waste**	48,844	50,346	52,072	50,906	49,159	48,934	48,990
	Per capita (kg/day)	0.99	1.02	1.04	1.02	0.96	0.95	0.95
	Industrial waste	101,099	114,807	130,777	123,604	137,875	137,961	146,390
	Construction waste	168,985	172,005	176,447	183,351	178,120	186,417	186,629
Treatment	**Landfill**	25,433	37,554	37,784	39,794	34,306	34,026	33,698
	Incineration	17,209	17,957	18,709	18,518	19,511	20,898	22,848
	Recycling	266,554	273,561	295,863	292,557	304,381	312,521	322,419
	Discharge to sea	9,732	8,086	6,940	6,992	6,956	5,867	3,044

Source: Ministry of Environment, 2013

Even though the total amount of solid waste has been increasing over the last few years, the finally treated amount of waste has been decreasing due to the increasing rate in recycling. In 1996, around 54.9 percent of solid waste was recycled in South Korea and by 2012 this percentage has increased to 82.4 percent, which is high compared to the international standard. Out of the total amount of solid waste, 10.3 percent went to the landfill, 6.3 percent was incinerated, 82.4 percent was recycled and one percent was dumped into the ocean. As the proportion of waste being incinerated and recycled is increasing every year, discharge into landfills and the sea shows a decline.

When it comes to the comparison of residential waste generated by different countries, South Korea's waste generation per capita is much lower than in other OECD countries (see Table 5.13). The average South Korean generated 359 kg of household waste in 2011, almost half of the household waste compared to Germany (610kg) and the USA (730kg) and equivalent to that of Japan (360kg) (MOE, 2014).

Table 5.13 Comparison of the OECD countries' residential waste generation per capita

Unit: kg/year

Country	2006	2007	2008	2009	2010	2011
Poland	320	320	320	320	320	310
Czech	300	290	300	320	320	320
Japan	410	400	380	360	360	360
South Korea	369	378	388	378	363	359
Turkey	430	430	400	420	410	410
Finland	490	510	520	480	470	500
Greece	440	450	450	460	520	500
Spain	590	580	560	550	520	490
France	540	540	540	540	530	540
UK	590	580	540	530	530	490
Italy	560	550	550	540	540	520
Austria	600	600	600	590	560	560
Netherland	600	610	600	590	590	570
Germany	560	580	590	590	600	610
U.S.A.	780	770	750	720	730	730

Source: Ministry of Environment, 2013

Table 5.14 compares the production of residential solid waste in three South Korean cities for the years 2011 and 2012 (Seoul's waste generation in 2012 was not available).

Table 5.14 Comparison of residential solid waste by city

City	Year	Population	Waste generation		Treatment (ton)		
			kg/capita	ton	Incineration	Recycle	Landfill
Seoul	2011	10,528,744	327	3,445,600	855,925	2,187,445	402,230
					25%	63%	12%
Incheon	2012	2,891,286	261	755,806	240,280	468258.5	47267.5
					32%	62%	6%
Songdo	2012	61,608	338	20,842	5,804	15,038	-
					28%	72%	

Source: Seoul Metropolitan City, 2012, Incheon Metropolitan City, 2013

In 2011, Seoul generated 3,445,600 tons of household solid waste. Of that total, 25 percent was incinerated and 63 percent was recycled. 12 percent of the waste was disposed of in landfills. In 2012, Incheon produced 755,806 tons of waste, of which 32 percent was incinerated, 62 percent was recycled and six percent was disposed of in landfills. In the same year, Songdo produced a total of 20,842 tons of household waste of which 5,804 tons were incinerated (28 percent) and 15,308 tons were recycled (72 percent). Comparing the per capita production of solid waste, the results reveal that the residents of Seoul (321 kg/year) and Songdo (338kg/year) generated more household waste than Incheon's residents (261 kg/year) did. The data show that Songdo's waste generation is almost similar to the South Korean average (359 kg/year). The reason for this is that the city's waste management policy is aimed at providing a "pleasant" waste management environment to the residents, not to minimise the volume of waste.

Meanwhile, the city is struggling to deal with unexpected problems arising from the solid waste management process. More particularly, one of the major concerns is that operating and maintaining the pneumatic waste collection system costs too much. According to the Incheon Development Institute (2010), the traditional waste pickup system costs 6,100 Won (=US$ 6) per month per household. The monthly expense of the pneumatic waste collection system is 11,500 Won (=US$ 11) per household, which is almost double the price of the conventional waste collection system. If the number of households serviced by the system is less than 20,000, the profitability of the system is very low. Most of the areas in Songdo show such low profitability, except for District Zone 8. The IFEZ estimates that approximately 6 billion Won (=US$ 6 million) is required per annum to operate the system.

Another problem faced in terms of household waste removal, is that although general and food waste are collected separately, both are delivered with the same wastepipes when they reach the central waste processing facility. This means that general and food waste are mixed and, therefore, the food waste could not be recycled anymore or cause malfunction in the system. Even if the system has waste pipes that are used exclusively for food waste, this waste will not be recycled as a food resource, as long as the system uses pipes filled with vacuous air to transport the waste. The reason for this is that it is difficult to compost food waste materials, when food waste is delivered with strong air pressure. According to Yoon Hayeon, a senior researcher at the Incheon Development Institute, "Since the idea of the waste pneumatic collection system comes from the advanced countries, it is not fit well into the Korean waste system. The problem arises when they try to apply the advanced technology to the existing system without enough consideration. If they install extra pipes for wastes, the financial burden is too much for the municipality". Therefore, the method of food waste collection through wastepipes has to be reconsidered in order to solve the current problems of the system (Kyeongin, 2014).

From observation during the research process, the residents of Songdo do not seem to be fully aware of the pneumatic waste collection system because abandoned waste bags were commonly observed on the streets (see Figure 5.1)

Figure 5.1 Mishandled household's waste in Songdo

Source: Author

To improve awareness, the IFEZ should promote their waste collection system and guide residents to perform proper waste management and encourage recycling, especially in households.

5.2.7 Greenhouse gas generation

When combusting fossil fuels to generate electricity or using fuel in engines, a substantial amount of air pollutants are released into the air, of which greenhouse gas is a significant one. Total generated greenhouse gas emissions in South Korea between 1990 and 2011 are shown in Table 5.15: 295.7 million tons of CO2eq in 1990 and 697.7 million tons of CO2eq in 2011. This shows a 136 percent increase over the last 20 years. Comparing the statistics of 2010 (667.6 million tons of CO2eq) and 2011 (697.7 million tons of CO2eq), the total greenhouse gas emissions had increased about 4.5 percent in one year.

Table 5.15 Total generation of greenhouse gas in South Korea

Unit: million ton

Sector	1990	2000	2009	2010	2011	Increase rate (1990/2011)	Increase rate (2010/2011)
Energy	241.0	410.8	515.1	568.9	597.9	148.1%	5.1%
Industrial	20.2	58.5	57.8	62.6	63.4	213.5%	1.1%
Agriculture	24.6	24.4	22.1	22.1	22.0	-10.8%	-0.7%
Waste	9.9	17.6	14.1	14.0	14.4	46.1%	2.5%
Total emission	295.7	511.3	609.1	667.6	697.7	136%	4.6%

Source: Greenhouse Gas Inventory & Research Centre of Korea, 2013

These greenhouse gas emissions are mainly produced by burning fossil fuels, especially in the energy of transport sector. In 2011, out of the four main sectors that contributed to the emission of greenhouse gas emission sectors, the energy sector accounted for 85.7 percent of the total amount of greenhouse gas emission, by generating 597.9 million tons of. In addition, the industrial sector (63.4 million tons of CO2eq), agriculture sector (22 million tons of CO2eq) and waste sector (14.4 million tons of CO2eq) were responsible for 9.1 percent, 3.2 percent and 2.1 percent of the total greenhouse gas generated, respectively.

Table 5.15 also shows that the energy sector has the highest *increasing* rate of greenhouse gas emissions. In particular, the production of electricity and generation of heat were the main reasons for this rising rate in 2011 (5.1 percent). Despite the rising rate in the industrial (1.1 percent) and waste (2.5 percent) sectors, the emission from the agriculture process showed decrease (0.7 percent) in the emission of greenhouse gas because the rice production area of South Korea has drastically decreased during the last decade. It is worth noting that increasing rate of greenhouse gas is synonymous with economic growth. When South Korea's economy was suffering from the financial crisis in 2008, there was a sharp decline in greenhouse gas emissions. The average increasing rate of gas emission was 4.2 percent over the last 22 years but it only showed a 0.1 percent increase in 2009 (see Table 5.16). However, as the economy recovered from the recession, the demand for energy has risen again and this resulted in a 9.1 percent increase in 2010. According to the per capita calculation, each South Korean produced 14 tons of CO2eq in 2011. Compared to 1990, the greenhouse gas per capita had increased 103.2 percent by the year 2011. According to the International Energy Agency data, South Korea is placed 19th in the world's greenhouse gas emission rankings, placing 6th out of the OECD countries (Greenhouse Gas Inventory & Research Centre of Korea, 2013).

Table 5.16 Greenhouse gas generation in South Korea per capita

	2004	2005	2006	2007	2008	2009	2010	2011
Total emission (ton)	566.1	569.5	575.2	591.4	605.4	609.2	667.8	697.7
Population	48,039	48,138	48,372	48,598	48,949	49,182	49,419	49,799
Per capita (ton)	11.8	11.8	11.9	12.2	12.4	12.4	13.5	14
Increase rate (%)	0.9	0.4	0.5	2.3	1.6	0.1	9.1	3.7

Source: Greenhouse Gas Inventory & Research Centre of Korea, 2013

Unfortunately, there is no data available at the moment for specifically Songdo's greenhouse gas emissions. According to Gale International (see Table 5.17), Songdo is projected to decrease its CO_2 emissions by 2020 by about 25 percent compared to an average city's emissions through the implementation of LEED. Given that a city has 350 buildings and 65,000 residents, the average city is expected to produce 783,200 tons of CO_2 per year, whereas Songdo is likely to generate the 257,740 tons of CO_2 per year (3.85 tons per capita) in accordance with the LEED standard. In order to achieve this goal, the Northeast Asia Trade Tower is, for example, designed to use natural light, which minimises electricity usage during daytime. Moreover, the elevator use only a quarter of the electricity compared to elevators in general (JoongAng Daily, 2014).

Table 5.17 Comparison of Songdo's CO_2 emissions versus that of "normal" cities

Unit: ton

	"Normal" cities	Songdo (target amount)	Remark
Buildings	674,000	250,000	
Transport	109,200	7,740	(70 percent of natural gas bus in Songdo)
Total	674,000	250,000	
Per capita	10.37	3.85	

Source: Gale International 2014

* Population of 65,000, 350 buildings

However, given the high-income level is found to be proportional to high energy consumption, Songdo's greenhouse gas emission is also expected to be increased. Therefore, a question arises in terms of credibility of the Gale International's figure.

These are tentative projections that need to be refiend and confimred by means of further research.

5.2.8 Summary

To sum up, the average Songdo resident consumes more water and electricity than the average South Korean, as depicted in Table 5.18. The high rate of water consumption consequently leads to a high amount of sewage being generated. LNG consumption per capita is similar to that in other cities and the level of waste generation per capita is relatively low in Songdo. Data on the city's greenhouse gas emissions is unavailable at this point.

Table 5.18 Summary of material consumption in South Korean cities

Unit: per capita

City	Year	Water	Sewage	Electricity	Waste	LNG	CO_2
		kilolitre/year	kilolitre/year	kWh/year	ton/year	m^3/year	ton/year
Seoul	2011	110.49	176	4,455	0.327	0.396	Not available
	2012	110.42	181	4,523	Not available	0.407	Not available
Incheon	2011	123.26	Not available	7,769	0.279	0.356	Not available
	2012	Not available	117	7,813	0.261	0.336	Not available
Songdo	2013	146.55	131	14,179	0.110	0.396	Not available

5.3 Findings and Recommendations

MFA conducted in this chapter has led to the following observations and recommendations to the NSC project.

As the households' incomes are rising, they consume more electricity, gas and water and consequently generate more sewage, solid waste and greenhouse gas at the same time. Furthermore, the economic situation has a major impact on resource consumption as well. This general trend is reflected by Songdo's high consumption of resources. The majority of residences in Songdo are built for high-income earners. It follows that their material footprint is higher than the average South Korean's. In this regard, the city has to make special efforts to encourage higher conservation practices by its residents. Controlling demand is even more important than managing reuse - and particularly for the rich. This could take the form of higher and incremental taxes on water and sewage, energy, parking, traffic, etc.

In response to urban problems, a holistic approach is necessary to ensure the sustainability of Songdo. The current approach the city is taking towards urban problems is from a green design approach – a linear system that is typically designed only to fulfil a single purpose. The city's urban infrastructures focus primarily on the "use" cycle, with no emphasis placed on interactive aspects as part of a complete system. A solution to the problems posed by the traditional waste collection system, such as smelly garbage, an unsightly urban landscape and low traffic safety, the pneumatic waste collection system that delivers waste through an underground pipe could be implemented. However, this new system also has its drawbacks: It leads to higher electricity consumption and does not allow for food waste recycling. Furthermore, when it comes to green building designs, building environmental assessment tools, such as LEED, are mainly focusing on the individual performance of buildings rather than encouraging synergetic interaction with other buildings and/or the surrounding ecological environments, which is needed for a 'green building' to truly succeed. Such a green building is typically dependent on green technologies to meet a certain level of individual performance. Consequently, it leads to a neglect of the overall material consumption of the city. Hence, Songdo's current approaches to sustainability indicate reductive and fragmented thinking. Instead of this, a holistic view is required which sees the world as an integrated whole rather than a dissociated collection.

5.4 Conclusion

Like all ecosystems, cities also have to balance inputs and outputs to make them sustainable. Energy and materials are the major inputs, sewage, solid waste and greenhouse gas are the major outputs and the main environmental problems result from the increase in these inputs and outputs. If one analyses the urban resource flow from a metabolic flow perspective, it is possible to recognise which part of a system is not harmonious with the natural processes and how the environmental problems that are caused by this can be improved.

Given this theoretical background, this chapter examined Songdo's infrastructures from a metabolic flow perspective. The overall water flow could be observed, from the input of fresh water for usage to the generation of wastewater and the proportion of this water that is recycled. However, in terms of electricity generation and consumption, it was not possible to determine the entire scope of energy flow due to limited data available. Hence, the input and outputs of the construction materials, oil and food as well as the amount of greenhouse gas emissions have to be determined first to perform a proper evaluation of Songdo's sustainability.

Even though Songdo has invested heavily in infrastructures to ensure sustainability, the results discussed in this chapter indicated that their efforts are merely contributing to the overall material consumption. However, from the data obtained regarding the overall water flow, an increase in recycling and reuse of wastewater could be noted. This is a key element in the reducing the use of freshwater and limiting sewage generation. If the city reaches the original target amount of wastewater reuse, which is 30 percent of the total wastewater generation (currently standing on only three percent), the general as well as sewage generation is likely to decrease. In a similar way, in order to reduce the amount of solid waste, the proportion of solid waste being recycled has to be increased. In addition, the drawbacks of the pneumatic waste collection system, such as its high electricity consumption and the way it disables food waste recycling, should be addressed through a holistic approach.

In terms of the electricity consumption, when the NSC project is completed and the original target population (250,000 residents) is accommodated, the general electricity consumption per capita is expected to decrease. At the moment, external factors, such as business commuter and construction workers in Songdo, prohibit one from evaluating Songdo's electricity consumption per capita properly. Songdo's LNG consumption is similar to the nation's average but further research is required to determine the energy efficiency of the district heating system. Songdo generates almost same amount of household solid waste compared to the South Korean average since the waste management policy is aimed at providing a 'pleasant' waste management environment to the residents, not to minimise the volume of the waste. In addition, the system that is able to monitor the emission of greenhouse gas is required to demonstrate the efficiency of LEED, public transportation and other efforts towards sustainability.

Chapter 6: Conclusion

In this thesis, an attempt was made to sketch out the main characteristics of sustainable urban infrastructures and their material consumption through a case study of the city Songdo, South Korea. The increasing role of cities and their negative effects have led to the emergence of sustainable cities as an alternative. To ensure sustainability in cities, urban infrastructures play a vital role to achieve decoupling in the urban context.

Chapter 1 presented the overall direction of this research by setting the following research objectives:

1) Explore the background of NSC project and sustainable development strategies.
2) Describe Songdo's urban infrastructures in terms of sustainability.
3) Apply MFA to Songdo and analyse annual resource flow for the following areas: water, sanitation, energy, solid waste and public transportation.
4) Estimate the material footprint of the average Songdo resident and suggest guidelines for the realisation of sustainable cities

To meet the objectives of this study, a literature review and case study were conducted. The first research objective was attainable through a literature search of documents published by the Incheon Association of Museums, IFEZ and Gale International. The Incheon Association of Museums' documents provide the history of the NSC project from the 1980's to the 2000's. Information about Songdo's turning point, when it started developing into a free economic zone and its associated sustainable development strategies, was obtainable from IFEZ and Gale International's documents. The second research objective was accomplished by undertaking a field trip to Songdo. During this field trip, the author visited the following infrastructures: the sewage treatment facility, the wastewater reuse treatment facility, the waste incineration facility, the pneumatic waste collection system, the combined heat plant and public transport hubs including bicycle lanes. Documents about above infrastructures were obtained from the people in charge of these facilities. In order to conduct an MFA to reach the third research objective, the author personally requested data from each of the organisations due to the limited data available publically. Based on the analysis of these data, the last research objective was reached, namely to calculate an estimate of the material footprint of the average Songdo resident and suggest guidelines of the realisation of sustainable cities.

The purpose of Chapter 2 was to provide a theoretical background for this research. In this chapter, various articles on sustainable cities were reviewed and it was pointed out that the role of urban infrastructures is crucial for the sustainability of cities. It was found that the increase of urban populations is related to resource consumption, which can lead to environmental problems, especially influencing climate change. However, given the current dominant capitalistic system, economic development is essential for cities as well as the protection of the environment. In light of this situation, the concept of decoupling was examined in the literature review as a core value of urban sustainability. This chapter also explained why the research specifically focused on the urban infrastructures in Songdo. Furthermore, the concept of urban metabolism as a tool for analysis as well as its advantages were indicated, to be applied later in the Chapter 5. This approach allows urban processes and activities such as construction, transportation, consumption and waste disposal to be linked to one another systematically, along with their inputs and outputs. Therefore, urban metabolism is useful to determine urban sustainability and make suggestions to improve the sustainability of cities. Lastly, a brief background of Songdo was provided and reasons were given why it was chosen for the case study.

In Chapter 3, before having a look at Songdo's infrastructure, an overview of the NSC project was given in order to further the understanding of the city. Unlike other urban projects, the NSC project is mainly driven by a private developer, namely Gale International. Under the general management of Gale international, the city is designed, built and operated by different private companies, such as POSCO E&C, KPF, Arup, Cisco and G&E. The city was originally built as part of the new town project to solve issue regarding the lack of housing in the late 1980s. However, as the project went through a financial crisis in 1997, the main purpose of the project had to be changed to encourage economic growth through a FEZ strategy. Furthermore, the South Korean government launched the NSSD and designated Songdo as a pilot project. From a developmental perspective, transforming Songdo to a sustainable city was beneficial in terms of obtaining a competitive edge over other countries' FEZs. The sustainable city project officially commenced in 2006 and came into the spotlight as a sustainable city in the early 2000's. From this, one could logically assume that the NSSD had major impacts on implementing the sustainable city project in Songdo.

Chapter 4 examined the urban infrastructures in Songdo based on Gale's sustainability report. According to this report, they built five main sustainable infrastructures: connectivity, public transportation, water use, waste collection and energy networks. Since the geographic advantage of this city had already been mentioned in Chapter 3, this chapter focused mainly on the four infrastructures. Firstly, the overall water flow in Songdo was traced, from supply to discharge into the sea. K-water is responsible for the water supply and it delivers water from Paldang to Songdo with 40 kilometres of water pipes. Used water is then treated by a biological filtering process at the Veolia and Samsung sewage treatment facility. In addition, the city has installed wastewater reuse pipes in order to recycle the treated wastewater and thus minimise freshwater usage. Secondly, it was observed that the city has a pneumatic waste collection system to enable it to manage waste without operating garbage trucks and consequently reduce the undesirable side effects of the conventional garbage removal system. The collected waste is sent to the incineration facility and the generated heat during the incineration process is recycled and distributed to the city. Thirdly, with regards to energy supply, it was determined that KEPCO and Samchully supply electricity and gas to the city, respectively. In order to increase energy efficiency, a combined cycle power plant was built to generate electricity and to supply a district heating network to Songdo's resident. Lastly, it was found that since South Korea has an integrated regional public transport, most of Songdo's public transport systems are similar to those in the other South Korean cites, except for its exclusive bicycle lane and car sharing service. Currently, Songdo is gradually gaining a reputation as a bicycle city.

In Chapter 5, the urban infrastructures that are mentioned above were analysed from a metabolic flow perspective. Specifically, the consumption of water, electricity and gas and the generation of sewage, solid waste and greenhouse gas were analysed and calculated per capita. In general terms, it was found that there is no evidence that the sustainability-oriented technologies have resulted in decoupling. This is partly because of the fact that the high-income households consume more resources than the average income households do. This general trend could also be observed in terms of Songdo's material consumption. This result lead to the following conclusion: Considering the high proportion of high-income households in Songdo and their related high levels of resource consumption, controlling resource demand has to be recognized as an important part of resource management. Because Songdo's greenhouse gas emission statistics were not available, it was not possible to identify how much public transport and other infrastructures contribute to the deterioration of the atmospheric environment. In this chapter, the author came to the conclusion that in order to complete the MFA and thus indicate the sustainability of Songdo, more quantified research is needed to determine the following: the amount of material consumed and waste generated in the construction sector, the level of food consumption, and the level of oil consumption.

6.1 Limitations and directions for future research

During the research process, there were a number of limitations and constraints to access the urban infrastructures and to collect data on material consumption. Here are some of the details:

- Data on food consumption, oil consumption, greenhouse gas generation and construction material consumption for Songdo are currently not available. The reason for this is that because of its size Songdo is categorised as a 'dong', which forms part of the greater Yeonsu-gu and IMC (see Figure 3.1). Songdo's residents account for only 0.2 percent of the total South Korean population and there are a total of 2100 dongs in South Korea. For this reason, the majority of national surveys are conducted on the level of a 'gu' or 'metropolitan city', not on the level of a small city like Songdo-dong. For instance, the data collected to determine Songdo's oil statistics, that were announced on the Korea National Oil Corporation's (KNOC) website, were only collected on the 'gu' and not the 'dong' level of the city. This means that Songdo's oil consumption is included in the greater Yeonsu-gu's figure. Similarly, the statistics regarding the greenhouse gas emissions and the construction materials consumed are collected on the level of a metropolitan city, such as Incheon. Furthermore, numbers for the overall food consumption were not even available even on a national level.
- The city is still in the process of construction and thus it is too early to check its material flow. The city is designed to accommodate a population of 250,000, but there are currently only 78,978 people residing in Songdo August, 2014. Moreover, there are no clear statistics on the population that is commuting from other cities to conduct the business and to work in Songdo.

In order to complete the MFA, a more concrete survey of the population is required.

- In recent years, numerous studies have attempted to determine efficiency of the district heating system, but the results are still inconclusive. Therefore, it can still not be concluded whether the district heating system or the individual heating system used in South Korea is the most energy efficient and this subject needs to be researched further. For this reason, the recent LNG consumption was not attainable from Samchully and INTECO.
- Due to the economic recession in the construction industry in 2013 in South Korea, there is a lack of interest in sustainable development in general. In Songdo, even though most of the residential buildings are sold out, a number of empty commercial buildings were observed during the field trip. Because of the project financial problems, focus is placed on the financial aspects of the project instead of paying attention to sustainability issues. Therefore, the author was not able to meet Gale International's staff to get the detail explanation of Gale's estimated levels of CO_2 emissions.
- Research on urban metabolism and specifically applied to South Korea is still limited. Therefore, there are not much data available to compare with Songdo's material consumption.
- In order to clarify Songdo's high electricity consumption, electricity consumption in the following sectors need to be researched – residential, commercial and industrial use. Moreover, it is required to check the electricity consumption of the pneumatic waste system.
- The research is descriptive case study, therefore it is difficult to generalise to other situation since findings may vary depending on author's experience. The study only offers of a limited scope therefore is has been criticised for use a small number of subjects and thus it offers no basis for building reliability or generality of findings (Yin, 2003). The inclusion of more subjects would have increased the credibility of the study.
- When it comes to the limitations of urban metabolism, cities do not have a complete function of metabolism. In reality, unlike solid waste and sewage, it is not possible to recycle greenhouse gas emissions with modern technology. For example, all carbon products will eventually end up as CO_2 and this is not possible to recycle without using enormous amounts of energy and generating waste (Golubiewski, 2012).

Songdo city has claimed itself as the first sustainable city in the world. However, without concrete data, Songdo cannot be acknowledged as a sustainable city and the results of this study showed that more statistics have to be gathered to determine and prove the sustainability of this city. Therefore, there are several topics in need of further investigation, specifically more quantified data is needed to demonstrate sustainability. For instance, it is required that a monitoring system is used to determine the city's energy consumption and waste generation. For the next six years, urban designers have to create a system that provides quantified material flow in the city. A MFA will then likely be a useful to make use of quantified data to examine the current sustainability of the city and to lead the project in a more sustainable way.

6.2 Conclusion

As has been mentioned in the literature review, there are different ways of defining sustainable cities. However, all have in common that they refer to efficient resource management as the core value of sustainable cities. Therefore, the question to be answered in order to ensure sustainability in cities is: How can material inputs and outputs be reduced through efficient urban infrastructures to develop sustainable cities? This thesis attempted to answer this question by examining sustainable urban infrastructures in the city of Songdo, South Korea, from a metabolic flow perspective. Even though only a partial MFA was conducted due to limited data, the data showed that Songdo's material consumption is higher than the average South Korean figures. However, given that the city is still under construction, it is debatable whether an MFA is the appropriate approach to analyse Songdo's infrastructures and sustainability. Nevertheless, the main objective of this research was not to evaluate whether the NSC project is successful as a sustainable city or not, but rather to analyse from a metabolic flow perspective and thus suggest improvements for sustainable cities. In that regard, this thesis provides a stepping-stone towards the realisation of sustainable cities.

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Appendix A: The History of the New Songdo City (NSC) Project

- 1979. Basic plan for reclamation of Songdo
- 1988. Announcement for Songdo new town master plan
- 1991. Approval for reclamation of Songdo
- 1994. Reclamation of Songdo wetland
- 1997. Asia Financial Crisis
- 1998. Bankruptcy of Daewoo – Stop SNTD project
- 2001. Open Incheon International Airport / MOU with Gale International & Posco E&C
- 2002. Establishment of Joint venture - New Songdo International City (NSIC)
- 2003. Designation of Free Economic Zone / Approval for the NSIC project
- 2004. Development of master plan
- 2005. Sign with Mogan Stanley for financial investment
- 2005. Phase one construction – roads, sewage treatment plant, Incheon Bridge, Incheon Subway
- 2006. Korea Launches National Sustainable Development Plan / Organize the Green Charrette workshop
- 2007. Second phase development - pneumatic waste-collection system Approve for green urbanism
- 2008. New Songdo City becomes LEED ND pilot project / Global Financial Crisis
- 2009. Launched National Green Growth Policy / Partnership with CISCO for Smart city Project / Completed Incheon Bridge.

Source: Gale International, 2014

Appendix B: Six core design principles of New Songdo City (NSC)

1. Open and Green Space

- Songdo IBD has been designated with 40% open space — 600 acres — to maximise the connection to nature within the city for residents, workers and visitors.

- A 100 acre Central Park is the city's centre piece — further highlighting the commitment to providing open and green space.
- All blocks connect pedestrians to open space, walking/biking corridors and public gathering areas.
- Open spaces and public gathering areas are arranged to optimize access to sunlight, views and open sky.
- Native or adapted species shall be utilized throughout the development. High water demand plants will be minimised or eliminated from landscape designs.

2. Transportation

- Incheon subway line will run through the centre of Songdo IBD. Expanded Incheon City bus service will enhance the easy access to surrounding areas.
- A 25 kilometres network of bicycle lanes within the project will facilitate safe, carbon-free transportation.
- 5% of parking capacity within each project block will be set aside as parking for fuel-efficient and low-emitting vehicles. Office and commercial blocks will reserve an additional 5% of parking capacity for carpool vehicles.
- Parking is primarily located underground or under a canopy to minimise the urban heat island effect and maximise pedestrian-oriented open space above ground.
- Infrastructure for electrical vehicle charging stations will be integrated into parking garage designs to facilitate the transition to low emissions transportation.

3. Water Consumption, Storage and Re-sue

- The Central Park canal uses seawater instead of fresh water, saving thousands of litres of potable water per day.
- Irrigation-based potable water use will target a 90% reduction versus international baseline, reduced through the use of efficient landscape design, water-saving irrigation systems, reclaimed stormwater and re-use of treated greywater from a city-wide central system.
- Potable water consumption in plumbing fixtures will target a 20–40% reduction based on the use type of the project.
- Stormwater runoff will be reused to the maximum extent possible given the

project's climate zone and annual rainfall pattern.

- Vegetated green roofs will reduce stormwater runoff, mitigate the urban heat island effect and promote biodiversity and species habitat preservation.

4. Carbon Emissions and Energy Use

- All **NSIC, LLC** projects will be built to or above ASHRAE standards — an internationally- recognized benchmark of design quality. These guidelines will create comfortable, energy efficient buildings.
- A central, city-wide co-generation facility fuelled by natural gas will provide clean power and hot water to the project.
- Energy efficient LED traffic lights and energy efficient pumps and motors are planned for installation through- out Songdo IBD.
- A centralized pneumatic waste collection system will be installed to collect wet and dry waste, eliminating the need for waste removal vehicles.

5. Material Flows and Recycling

- 75% of construction waste is targeted to be recycled.
- Recycled materials and locally produced/manufactured materials will be utilized to the maximum extent possible.
- Some projects will realize a Portland cement reduction of 20% or more through the utilization of flash-content concrete.
- Low-VOC materials will be incorporated into all buildings.

6. Sustainable City Operations

- Sustainable procurement goals and recycling guidelines will be integrated into the operational structure of the city through the facilities management digital interface.
- Facilities management and maintenance contracts will mandate environmentally friendly (low/zero VOC, Eco Label, Good Recycled designations or equivalent) products.
- Smoking will be prohibited in public areas and office buildings except for specially designated areas.

Source: Gale International & Kohn Pedersen Fox , 2014