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Case Report

Solid Waste Management in Ho Chi Minh City, Vietnam: Moving towards a Circular Economy?

Petra Schneider [1,2,*], Le Hung Anh [3], Jörg Wagner [4], Jan Reichenbach [4] and Anja Hebner [5]

1 C&E Consulting and Engineering GmbH, Jagdschänkenstraße 52, D-09117 Chemnitz, Germany
2 Department for Water, Environment, Civil Engineering and Safety, University of Applied Sciences Magdeburg-Stendal, Breitscheidstraße 2, D-39114 Magdeburg, Germany
3 Institute for the Environmental Science, Engineering & Management, Industrial University of Ho Chi Minh City, No. 12 Nguyen Van Bao, Ward 4, Ho Chi Minh City 00000, Vietnam; lehunganh@iuh.edu.vn
4 INTECUS GmbH Abfallwirtschaft und umweltintegratives Management, Pohlandstr. 17, D-01309 Dresden, Germany; wagner@intecus.de (J.W.); reichenbach@intecus.de (J.R.)
5 Vita 34 AG Business Unit BioPlanta, Deutscher Platz 5a, D-04103 Leipzig, Germany; anja.hebner@vita34.de
* Correspondence: petra.schneider@hs-magdeburg.de; Tel.: +49-391-886-4577

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Abstract: The paper presents the current situation of the waste management system of the megacity Ho Chi Minh in Vietnam, and the options for waste and land recycling in a low income country. Generally, there is a large potential for circular economy in the city as the main proportion of the waste flows are recyclables. Due to the missing selective collection system, this potential is not used in the full extend yet, even if the collection of the entire waste volumes is envisaged in the National Waste Management Strategy by 2025. The waste stocks are the landfill locations in the region of Ho Chi Minh City (HCMC), two of them being in operation and two of them already being closed. A special focus is given to the landfill GÈ Cát, which was subject to an option analysis in terms of waste and land recycling options. The results indicate that there are several reuse options: the use of the landfill material in a waste-to-energy process after landfill mining, the reuse of the re-gained land in case of landfill mining, the reuse of the capped landfill for energy crop cultivation, and the gasification in a biogas plant in case of a remaining landfill.

Keywords: waste management; stocks and flows; circular economy; landfill management and reuse options under tropical conditions; landfill mining

1. Introduction

The General Statistics Office (GSO) forecasts that by 2024, Vietnam's population will reach 100 million [1], making Vietnam the 14th most densely inhabited country in the world, and resulting in a constant pressure on the natural resources. Since 1986, when the Doi Moi reforms were introduced, Vietnam has developed from a centrally planned system to a "socialist-oriented market economy" facing the highest economic growth rates in Asia [2]. The process of urbanization accompanied by immigration from rural to urban areas leads to pressure on the environmental quality. Further pressure is caused because people living in urban areas use 2–3 times more natural resources than rural inhabitants. Vietnam's economy is still mainly based on agriculture, which employs more than 70% of the population. The industrial contribution accounts for 40% of the Gross Domestic Product (GDP). Vietnam's nominal GDP in 2015 was 199 billion USD with a respective growth rate of 6.6% during the year 2015, backed by a low inflation rate of 2.0%. The macro-economic factors are positive due to several pillows of the economic strategy: Viet Nm's participation in the Trans Pacific Partnership, the ASEAN Economic Community, and several other bilateral agreements. Vietnam has a vital base of about 45% of the population being between the ages 25 and 54, and another 42% under the age of 24. This situation and the slowing population growth rate (at 0.97%) [1] indicates that Vietnam's economy is maturing and forming a growing middle class that is increasingly seeking a higher standard of living in cities. This leads to an increasing demand for urban housing in the cities, driving the property prices in the cities upwards.

As a result of the rapid economic growth there is also a steadily increasing volume of Municipal Solid Waste (MSW). Other things being equal, the amount of waste generated is generally proportional to population, but it increases faster if the household income increases. Vietnam produces more than 27.8 mil tons/year waste from various sources. The main sources of waste generation are municipal, agricultural and industrial waste. More than 46% (12.8 mil tons/year) are from municipal sources, including households, restaurants, markets, and businesses. The five biggest cities in Vietnam, namely Hanoi, Ho Chi Minh City (HCMC), Haiphong, Da Nang and Can Tho are the country's hotspots with 70% contribution to the total waste generation. In 2015, the average MSW of big urban areas increased to 0.9–1.3 kg/person/day [3]. The mean waste generation rate in Vietnam is 0.7 kg/cap/day in urban areas and 0.4 kg/cap/day in rural areas. The MSW composition has a high percentage of biodegradable residues of about 60.1%–70.0% by wet weight [4]. MSW is commonly regarded as waste generated from human settlements and small businesses, commercial and municipal activities. The second significant source of waste is agriculture.

HCMC is the core of Vietnam's largest urban area, heading towards a population of 12 million in 2025, including peri-urban areas [5]. It is a mega city and the economic center of the country. The administrative area covers 2095 km^2. Currently, about 8.2 mil inhabitants live in the entire territory of the city, resulting in an average density of 3400 persons/km^2 [1]. The economic and industrial development led to massive immigration into HCMC in the recent years, causing an average immigration rate of 200,000 people per year from 2007 to 2013 [1]. The city comprises two million households; more than 10,000 restaurants, hotels, guesthouses, enterprises, and thousands of training institutions; more than 184 hospitals, 600 public health centers and 9000 clinics; more than 400 markets; and about 12,000 industrial enterprises [5]. The state-owned sector retains a major role in the city's economy, but also the number of private enterprises has increased by more than 50,000 since 2000 [6]. These businesses contribute 30% of HCMC's total industrial output and 78% of retail sales [6], and are the main reason for the migration into the city. A total of 15 industrial parks were established in suburban areas [7]. Like Ha Noi, HCMC is facing the steadily increase of the MSW volume, and municipal waste takes the main part of the solid waste generated. The total volume of MSW is estimated about 7200–7800 tons/day (excluding waste sludge).

The increasing MSW generation rate in HCMC of 10%–15% [3], resulting from expanding urban areas and developing urban areas, is higher than in the rest of Vietnam (8%–10%). The composition and the generation of municipal waste fluctuated according to a few factors such as lifestyle, affluence, season, cultural activities and location. The current solid waste streams in the HCMC central city core are given in given in Figure 1. An additional waste stream is formed by 5000–6000 tons of sludge from several sources [8], which is not considered as a solid waste flow. The MSW collection rate was increased systematically from 73% in the urban area in 1995 (30% rural) to 85% in the urban area in 2015 ([9] updated with recent data). Collection is done by private (70%) and public institutions (30%).

Even material recovery facilities exist in the HCMC waste management (WM) system [10], the general system is organized in linear way with a part of the waste flows ending up in landfills, similar to many other cities in the developing world. Although the regulatory framework has the objective of establishing the circulation economy in Vietnam and has set up respective collection and recycling targets, HCMC still faces major challenges. Figure 2 and Table 1 give an overview on the main HCMC landfills (closed and in operation). Table 2 provides the average percentage of the waste composition in HCMC in the time period 2003 to 2014.

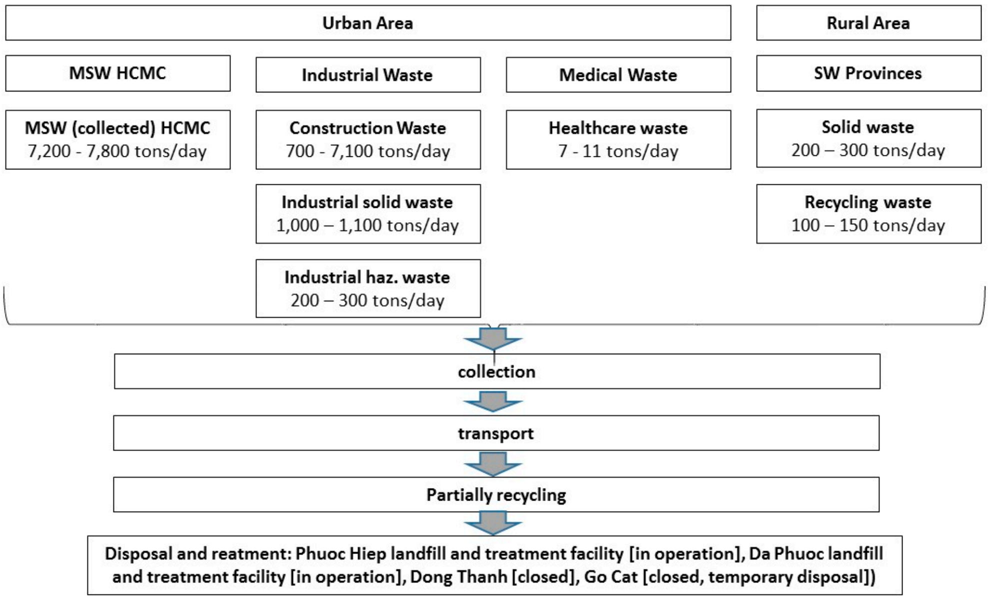


Figure 1. Solid waste flows in Ho Chi Minh City.

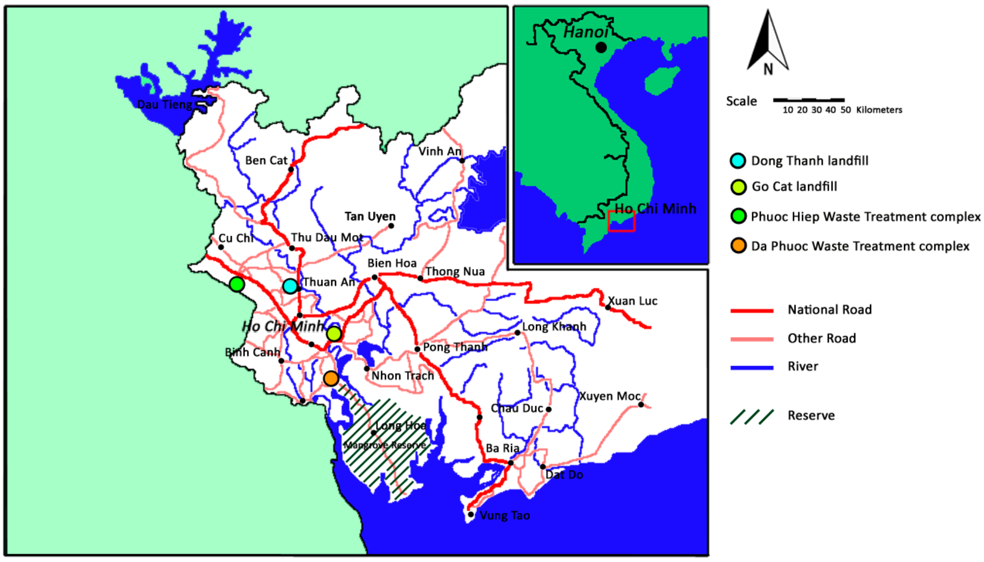


Figure 2. Location of HCMC with the location of the main landfills and waste treatment facilities.

Table 1. Overview on HCMC main landfills.

Characteristics	Dong Thanh	GÈ Cát	Phuoc Hiep	Da Phuoc
Operation period	1991–2002	2000–2007	Phuoc Hiep I 2003–2006 Phuoc Hiep 1A 2007–2008 Phuoc Hiep II since 2008 Phuoc Hiep III 2013–2014	since 2007
Surface	43.5 ha	25 ha	45 ha (I + IA), 99 ha (II) *, 7.2 ha (III)	128 ha **
Disposal volume (designed)	3.2 mil tons	5.8 mil tons	Phuoc Hiep I 9.2 mil tons Phuoc Hiep 1A 1.7 mil tons Phuoc Hiep II 18 mil tons Phuoc Hiep III 4.4 mil tons	10.8 mil tons
Distance to HCMC	25 km	18 km	48 km	24 km

*/** The total waste treatment site including recycling facilities has a surface of 660 ha/640 ha.

Table 2. Municipal solid waste profile in HCMC (% by wet weight).

Component	GÈ Cát Landfill in 2003 [11]	Phuoc Hiep Landfill in 2007 [12] *	Transfer Station in 2009 [13]	Phuoc Hiep Landfill in 2014 [3]
Organics				
Food waste	70.84	38.10	85.81	61.3–68.9
Paper	1.04	1.70	4.18	3.2–4.2
Cardbord			0.66	n.d.
Plastics and nylon	16.03	30.40	5.70	16.1–17.3
Textiles	n.d.	10.30	0.83	4.1–6.4
Tampon/napkin	n.d.	n.d.	n.d.	3.0–4.1
Rubber	0.42	2.4	0.12	0.4–1.6
Leather	0.3	0.2	0.07	
Yard waste	1.22	13.3	0.38	n.d.
Wood	1.15	0.5	0.34	0.5–0.6
Misc. organics	1.77	0.6	0.36	0.1–1.4
Inorganics				
Tin cans	0.02	n.d.	0.37	n.d.
Other metal	0.16	1.0	0.02	0.3–0.6
Glass	0.29	0.2	0.24	1.4–2.2
Dirt, ash, etc.	1.1	1.2	0.99	

* Phuoc Hiep waste treatment facility is equipped with a composting site; n.d.: not determined.

The waste profile shows that the main component of MSW is organic taking up to 65% of total the MSW volume, about 25% of MSW are recyclables such as: plastic, paper, metal. Some hazardous waste is being mixed into the municipal waste with 0.12%. In order to manage the waste streams in the region of HCMC, the Phuoc Hiep and the Da Phuoc Solid Waste Treatment Complexes have been built. They consist of several landfills and a composting plant with a capacity of 700 tons/day.

The general organization of the WM system in HCMC is given in Figure 3, according to [8].

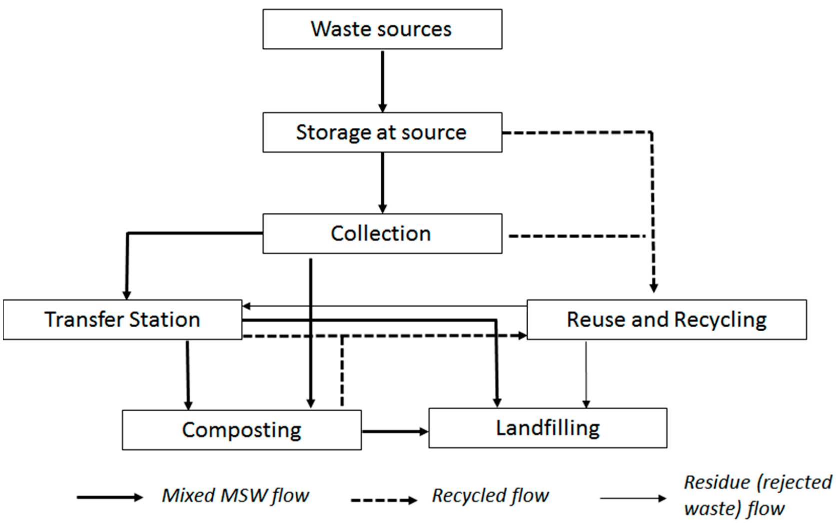


Figure 3. Organization of the waste management system in HCMC [8].

The administrative management in solid waste has basically two levels, the city and the district level. The city level comprises the People's Committee and departments under the People's Committee (Department of Natural Resources and Environment, Department of Planning and Investment, Department of Finance, Department of Science and Technology). The waste transportation and waste treatment is done by CITENCO (Ho Chi Minh City Urban Environment Company Limited). The district level comprises the People's Committee of district which appoints the Department of Natural Resources and Environment of the district to manage the environment in the district areas. About 70% of the MSW in HCMC and the surroundings is collected by private institutions (companies, societies of informal waste collectors, etc.). These private institutions determine the fees for the households. There are many locations where households which are served by private institutions pay 150,000 VND/month instead of 20,000 VND/month as locations served by the communal service CITENCO. However, the city faces problems in terms of: (a) the cost coverage of the waste collection fees; and (b) the control of the private collection institutions. Since 2008, the garbage fee in HCMC is calculated under the Decision No. 88/2008/QD-People's Committee of HCMC since 2008, as presented in Table 3.

Table 3. Garbage fee in HCMC.

Location of Waste Collection		**Monthly Fee**	
Households in the City	**Type of Waste Collection**	**Vietnamese Dong (VND)**	**US$**
Dowtown	Front Line	20,000	0.89
	By road	15,000	0.67
Suburban area	Front Line	15,000	0.67
	By road	10,000	0.45
Type of Waste Generating Institution		**Monthly Fee**	
Other Customer Group	**Type of Business**	**Vietnamese Dong (VND)**	**US$**
Type 1: Generated waste volume <250 kg/month	• Bars and restaurants (indoor and sidewalk, half day) • Small business • School, library • Administrative offices	60,000	2.68
Type 2: Generated waste volume >250 kg/month and >420 kg/month	• Bars and restaurants (indoor and sidewalk, half day) • Small business • School, library • Administrative offices	110,000	4.92
Type 3: Generated waste volume >1 m^3/month or >420 kg/month	• Bars and restaurants (full day) • Hotels, Big business • Markets, supermarkets, shopping malls • Production facilities, healthcare, entertainment venues, construction, etc.	176,800	7.91

As in other low income countries, one of the driving factors for the improvement of the waste management system is the availability of financial resources. As the average income is in Vietnam still low, there are only limited possibilities to increase the waste fees. Thus, the city is searching for further financial options to foster the acquisition of financial resources in order to improve the waste management system towards a circular economy. In this regard, one intensively discussed option is the potential use of existing landfill sites to generate financial resources. In parallel, Vietnam is experiencing a convergence of macro- and micro-economic factors that lead to an increasing demand for residential properties across the country, especially in HCMC. The property market has experienced a brisk growth in the last two years, docked to the dynamic economic development. Continued landfilling at the present rate implies a loss of about 10 ha of land per year in HCMC with a high probability that this number could increase significantly in the coming years.

In the focus of this discussion is the closed landfill GÈ Cát, which was the first regulated landfill in Vietnam. Its design served as an example for the construction of Phuoc Hiep landfill in the HCMC area. The base sealing was done with a layer of HDPE material to provide leakage prevention. The surface sealing was built as a multilayer concept with a total thickness of 1.3 m including a 2 mm geomembrane and a mineral sealing of at least 0.3 m thickness. GÈ Cát landfill was in active operation from the end of December 2000 until the end of July 2007. The construction of this landfill was done under the

EC-ASEAN COGEN program with the help of Dutch specialists. The GÈ Cát landfill site has a total coverage area of 25 ha, out of which 17 ha are occupied by the waste body. The physical characteristics of the GÈ Cát landfill fit completely to the criteria that MoNRE established together with the World Bank and the Canadian International Development Agency (CIDA). Even though GÈ Cát landfill was designed according to international standards, it was far too small to cope with the increasing waste volumes resulting from the growth of HCMC and its capacity was exhausted much faster than planned. Further, the plan of the city administration was not successful to finance an appropriate closure system for GÈ Cát from the financial resources obtained from the landfill gas utilization. HCMC has a tropical climate with an average humidity of 78%–82%. The rainy season is from May until November, with an average precipitation of about 1800 mm/year. The large leachate volume, lead to the blockage of the landfill gas collection system at GÈ Cát. The waste treatment complex of Phuoc Hiep, including the landfills which were built using GÈ Cát as model, are the current waste management facilities of HCMC. Anyhow, the local administration concluded that waste recycling activities are needed urgently in order to reduce the waste volumes going to landfills.

Scope of the study was a holistic analysis of the waste management system in HCMC through the DPSIR framework, with focus on options for the reutilization of GÈ Cát landfill, which ideally create a steady flow of funds to be used to improve the communal waste management system in HCMC. In this regard, GÈ Cát landfill plays a central role as potential source for the creation of financial resources. Several options were investigated in order to create financial benefit for HCMC:

- Valorization of the landfill gas of GÈ Cát landfill;
- Valorization of materials from GÈ Cát landfill body after landfill mining;
- Valorization of energy produced from GÈ Cát landfill body after landfill mining;
- Land recycling and valorization of the land after deconstruction of GÈ Cát landfill; and
- Valorization of GÈ Cát landfill surface through a biomass utilization plant in case the landfill remains.

The investigations have been performed in the frame of the research project "SAFEUSE—Options for the rehabilitation and management concept for the landfill GÈ Cát in Ho Chi Minh City (HCMC), Vietnam". Scope of the present paper is a holistic view on the HCMC's path to a circular economy under consideration of the linkages within the country and intersectoral relationships. Overall scope is the assessment of the potential for circular economy approaches according to Braungart and McDonough (2002) [12] in terms of waste and in terms of land. In the strong sense of circular economy, the focus is to transform a resource-based linear economy (cradle-to-grave system) into a resource-cycling circular economy (cradle-to-cradle system), wherein not only biotic and abiotic resources are considered to be recyclable, but also land resources. With respect to land recovery GÈ Cát site serves also as example for the assessment of the feasibility of landfill mining in the present study. This investigation is motivated by three facts: (a) during the operation of GÈ Cát, the disposed material was not pre-treated, resulting in a large percentage of disposed recyclables; (b) due to the growth of HCMC, the closed landfill site GÈ Cát is no longer located at the periphery of the city but surrounded by industrial and residential buildings; and (c) the property prices in HCMC have risen significantly in the last years making affordable properties very rare.

2. Materials and Methods

For the present study, the following methods have been used:

- Analysis of the WM system in HCMC through the DPSIR framework in order to get insights in drivers and pressures in a holistic way;
- Waste flow analysis on the HCMC level, through an on-site data collection in collaboration with the operator CITENCO;
- Investigation of the waste composition 8 years after closure of GÈ Cát landfill including heating value determination of the waste according to DIN 51900;

- Data collection on the metabolism of HCMC metropolitan area and the ecological footprint;
- Variant assessment on valorization potential of the GÈ Cát landfill site with the scope to create financial benefit in order to improve the WM system in HCMC;
- Impact assessment for the environmental factors at GÈ Cát landfill and risk assessment on the long term; and
- SWOT analysis of the existing situation in order to evaluate existing strengths and future opportunities.

The DPSIR framework was developed by the OECD [13] to describe relationships in an environmental system as a causal chain of driving forces (activities that may cause pressure on the environment), pressures (resulting stress), state (state of environmental factors), impact (specific effect caused by environmental stressors), and responses (response/reaction to stress). SWOT (Strength, Weakness, Opportunities, Threats) analysis was developed as an instrument for positioning and strategy development [14,15]. The existing strengths, weaknesses, opportunities and risks are compared. The goal is a view of the situation on the basis of strategic decisions that are taken by Strengths (obtained or expanded), Weaknesses (to be reduced), Opportunities, and Threats (to be eliminated).

3. Results

3.1. Analysis of the WM System in HCMC through the DPSIR Framework

The first step towards a holistic assessment of the situation was the preparation of a drivers–pressures–state–impact–responses (DPSIR) analysis (see Figure 4). The DPSIR analysis was used to obtain an overview on the whole socio-economic system, in which the WM system in HCMC is embedded, and to get information about the main driving forces, the resulting current and future impacts on the environment, and an information if the pressure can be managed with the existing capacities. In this respect the prognosticated waste streams in the next decades are notably relevant, and the Ecological Footprint caused by them. The main driving forces in the current situation are the population growth and the migration into the city leading to a further permanent growth of the megacity. This results in a permanently increasing environmental footprint of HCMC caused by increased resource consumption in a linear economy.

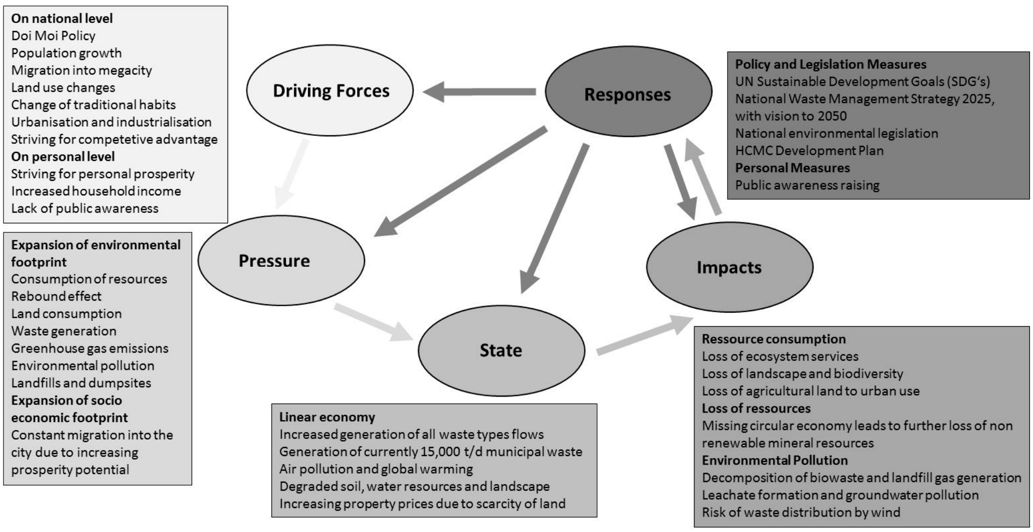


Figure 4. Analysis of the Waste Management in HCMC through the DPSIR framework.

The main driving forces which affect the WM system in HCMC are urbanization, population and economic growth, and in particular the increasing population as well as the increasing household income, which allows for increasing consumption. Higher income levels and rates of urbanization lead to greater amounts of solid waste [16]. Higher urban consumption increases the Ecological Footprint (see Table 4).

Table 4. Development of selected socio economic indicators over time in HCMC [1,17].

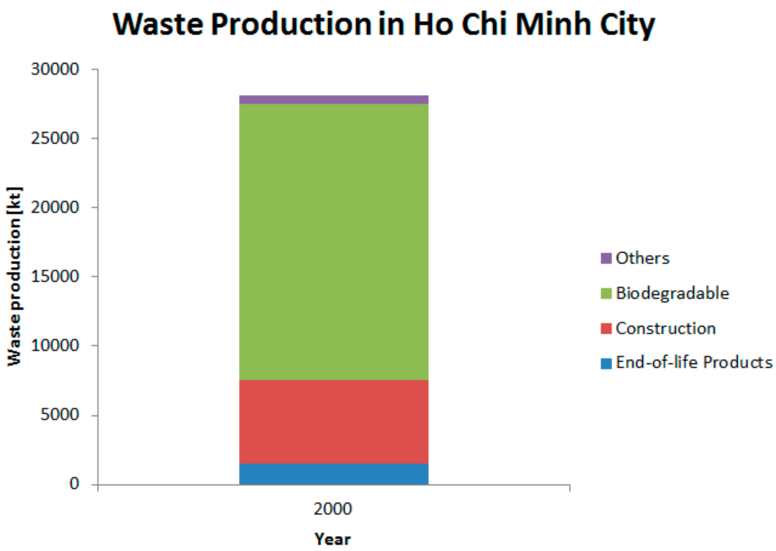
Year	Population	GDP Per Capita in HCMC in US$	Waste Generation HCMC (kg/Capita/Day)	Ecological Footprint in Vietnam (GHA/Capita/Year)
1980	1,860,000	384	no data	0.6
1985	2,543,000	444	0.22	0.6
1990	2,852,000	583	0.38	0.6
1995	4,640,400	937	0.58	0.8
2000	5,274,900	1365	0.77	0.9
2005	6,230,900	1850	0.77	1.2
2010	7,378,000	2800	0.88	1.7
2015	8,244,400	5540	0.90	1.7

HCMC contributes 29% (2013) to the total economic growth rate and fiscal revenue in Vietnam, and with this to the ecological footprint in Vietnam as well (Table 5). The Ecological Footprint is a measure of how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices (definition of the U.N. Food and Agriculture Organization). The Ecological Footprint is measured in global hectares (GHA). The economic growth of HCMC is reflected in the increase of the GDP per capita in the city, starting from US$384 in the year 1980 (5.3 mil inhabitants) before the Doi Moi reforms, reaching US$5540 in 2015 (8.2 mil inhabitants). Change in the consumer behavior, including the tendency to use high-quality, branded goods, is also caused by the increased per capita income. By 2015, 40% of the households in HCMC had US$500–US$1000 as household income, while 28% had a budget below US$500, and 7% above US$2000 [18]. Nineteen percent of the households in HCMC had US$1000–US$1500 as household income, and 6% US$1500–US$2000.

Table 5. Recovered gas volumes, 2005–2015 at the landfill GÈ Cát (data source: CITENCO).

Year	Recovered Gas Volume (m^3)
2005	2,217,792
2006	3,296,111
2007	2,947,148
2008	2,468,869
2009	781,484
2010	601,929
2011	92,249
2012	378,772
2013	287,320
2014	638,112
2015	366,583

With respect to the resource consumption, the prognosis of future waste streams is notably relevant. As the future development of the whole material flow system in a megacity is particularly difficult to predict, the methodology of the urban metabolism was developed in the literature, going beyond a conventional material flow analysis (MFA). Urban metabolism may 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" [19]. An MFA considers the whole life cycle from the cities consumption of materials, the different activities associated with those processes across sectors, and the wastes produced. The main material flows in HCMC are biomass—for food production—and nonmetallic minerals—for the growth of the housing areas of the megacity. In 2000, the direct material input (DMI) of HCMC Metropolitan Area was 52.1 million tons [6]. Domestic material consumption (DMC) was estimated at about 48.4 million tons, or 17.2% of Vietnam's DMC, which corresponds to 3.6 tons per capita for HCMC [6]. The specific consumption is 3 to 5 times greater than other countries [20]. Generally, the consumption situation in HCMC represents medium-to-high shares of biomass and nonmetallic minerals, and low shares of fossil fuels. Out of the generated wastes, 95% goes to a landfill (wet weight basis), and 5% is turned into compost [21]. The urban metabolism of HCMC was investigated by the Asian Development Bank [6], and indicates a huge potential for circular economy, especially in terms of biomass and future construction and demolition waste. The waste generation by waste type in the year 2000 and in the following 50 years is correlated to the materials consumed in the HCMC Metropolitan area since the year 2000. Figure 5 indicates an above-average increase in building material consumption, as well as the fact that a significant refurbishment of the urban infrastructure, resulting in significant volumes of construction and demolition waste (CDW) is not to be expected before 2050.



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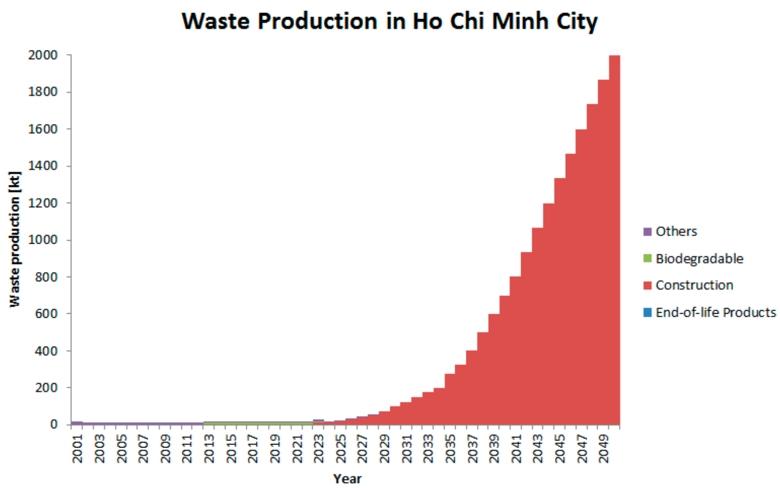

(**b**)

Figure 5. Waste production of Ho Chi Minh City metropolitan area: (**a**) by waste type in 2000; and (**b**) in the following 50 years [6].

The huge material consumption in a linear way leads to a large waste volume which is currently managed at the Phuoc Hiep and the Da Phuoc Solid Waste Treatment Complexes. According to the estimation in [6], excluding fossil fuels, 62% of the materials consumed within the urban area are estimated to have been disposed of as wastes in the year 2000, while 36% are expected to be converted to residues after 35 years. In this framework, with respect to the existing situation, small-scale experiences can be obtained from the example of GÈ Cát site which might support management conclusions for the implementation of circular economy approaches in HCMC. The regulatory framework for the implementation of circular economy is given through the National Strategy of Integrated Solid Waste Management up to 2025, with a vision towards 2050 [21], which strongly forces circular economy approaches. Further, a socio-economic master plan of the city [22] was developed to meet the demand of a projected population of about 9.2 million inhabitants in the city center by 2020 and 10 million by 2025. Up to 2025, the government sets the goal that the complete household wastes generated in the urban area shall be collected, treated and 90% of it will be recycled, reused, processed into organic fertilizer or the energy recovered.

3.2. Variant Assessment for the Reutilization of GÈ Cát Landfill Site as Small Scale Sample for Material and Land Recycling

The investigations on options for the valorization and re-use of the stocks consider following options for the closed landfill GÈ Cát: valorization of landfill gas, landfill mining for material recovery or the recovery of the energy potential, use of the biomass potential, and use of other renewable energies as derived from comparable investigations [23,24].

3.2.1. Valorization of Landfill Gas from the Existing Landfill Body

The use of landfill gas poses an energy source that can provide additional income during landfill operation or after its closure. Landfill gas has a methane content of up to 50% and an energy content of about 17 MJ/Nm^3 [25], suggesting a potential for the energy recovery of the gas. Landfill gas can be used similar to biogas for the energy recovery in combined heat and power plants (CHP). HCMC has experiences on electricity production from biogas and connection to the grid via operation of GÈ Cát landfill. The landfill has a gas collection and extraction system consisting of 21 vertical gas-collecting wells. All wells are connected to a piping system made out of polyethylene. The gas has to pass through a dehydrating device and is eventually forwarded to landfill gas to power generators. At full capacity, the gas recovery system was intended to capture 879,650 tons of gas (646,050 tons of CO_2 and 233,000 tons of CH_4). The installation of the landfill gas recovery system at the GÈ Cát site was the first ever example for such system at a landfill in Vietnam and it is still in operation, even though it is no longer efficient. Table 5 shows the recovered gas volumes 2005–2015.

The data show that after the closure of the landfill in 2007 the recovered gas volume decreased significantly. The reason is an incomplete surface sealing of GÈ Cát landfill which allows precipitation to enter in the landfill body. As the precipitation rate in HCMC is quite high, the result of the incomplete capping is that the gas collection system is blocked with leachate. For some reuse options, it would be necessary to dewater up to 50% of the waste in the landfill body. One option to do this would be the use of the gas collection wells for extraction of the leachate from the landfill body. The selective extraction would take more than a year. The extracted leachate has to be treated before discharge. Another option would be to completely relocate the material to another landfill, (e.g., Phuoc Hiep) for further processing, an option which is often practiced on international level. The results for this option show clearly that the valorization of landfill gas from GÈ Cát landfill does not contribute to a sufficient re-use of the site.

3.2.2. Assessment of the Feasibility of Enhanced Landfill Mining

Enhanced landfill mining (ELFM) is proposed and defined as the “the safe conditioning, excavation and integrated valorization of landfilled waste streams as both materials (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE), using innovative transformation technologies and respecting the most stringent social and ecological criteria", and emphasized the material and energy recovery [26–30]. The landfill deconstruction (LD) process involves the excavation process to remove the waste from the landfill. The excavated waste is segregated to recover the fractions of the recyclable material. Figure 6 shows the typical process flow scheme for a landfill mining process.

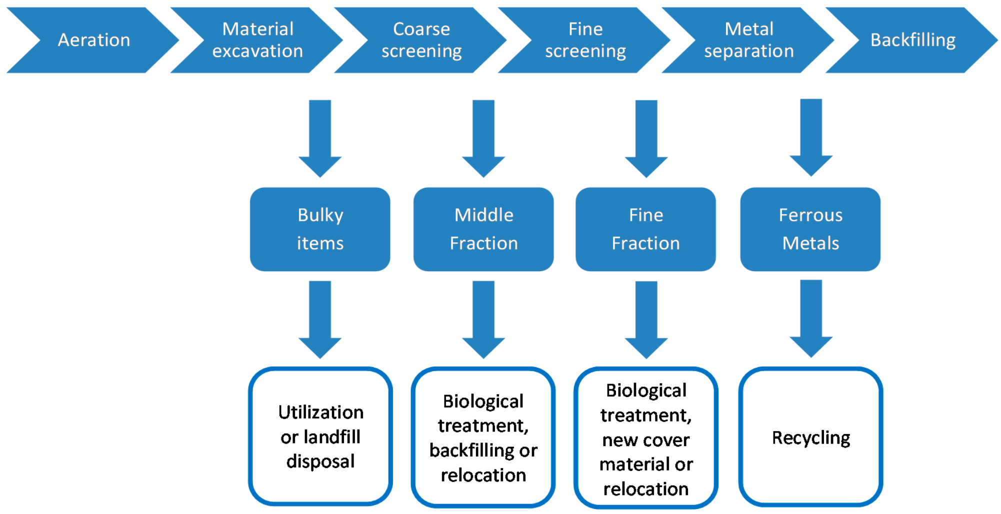

Figure 6. Typical LD process flow scheme.

The approach presented in Figure 6 is based on the European understanding of circular economy, the WM hierarchy as established in the Waste Framework Directive 2008/98/EC [31], which gives advantage to the raw materials recycling over energetic utilization. The feasibility of an enhanced LD application according to the European understanding of circular economy is shown in Figure 7 for Vietnamese landfills. In case of Vietnamese landfills the application of a LD concept indicates that up to 70% of LD material might need backfilling, as concluded from Austrian and German LD pilot site investigations (Austria: landfills in Spitzau, Theresienfeld, and Tyrol; Germany: landfills in Reiskirchen, Hechingen, Wiesbaden, Vaihingen/Horrheim, Pohlsche Heide, and Schöneicher Plan [32–34]). Separating the GÈ Cát landfill material (screen at 60 mm) is considered to be extremely difficult with conventional technique based on dry-mechanical screening due to the inconsistent mixture and highly different degree of decomposition [35]. Due to the fact that GÈ Cát landfill is nearly waterlogged, a material separation without prior drying is impossible. Further, recyclable materials are of minor relevance at GÈ Cát landfill.

Usually, total LD cost range at international scale from US$15–US$190 per m^3 deconstructed landfill volume. Having in view the particular situation at GÈ Cát landfill, the cost might reach US$20–US$40 per m^3, divided into 20%–30% for preparatory measures, 30%–40% for machinery/processing, and 30%–40% for residues transport as well as disposal. Nevertheless, net costs of LD must be balanced with the monetary savings and benefits of GÈ Cát landfill site. Land occupied by the landfills could be reclaimed for the usage of urban and industrial development or societal benefits (e.g., building a park on the landfill site), or the air-space could be recovered for a new landfill cell [36]. With respect to material recycling from GÈ Cát landfill body the conclusion leads to an unfavorable cost-benefit-ratio, if not other valorization options like land recycling apply.

The official property price in the Binh Tuan District, where GÈ Cát landfill is located, is 3.0 to 6.0 mil VND/m^2 (compared to US$135–US$260 per m^2), resulting in a minimum value of the landfill area of approximately 34 mil US$ in case of a clean property. The achievable price on the property market might be even higher as the HCMC metropolitan area is characterized by a strong competition for land. As HCMC city administration is said to have costs of about US$830,000 per year for maintaining a safe state at the GÈ Cát landfill, the financial pressure leads to the consideration of a particular approach to land recycling: the energetic use of the material of GÈ Cát landfill in order to recover a valuable property in the city near industrial area. Recent examples in Switzerland on energetic use of deconstructed landfill material show a large potential for this kind of solution [37]. A recent feasibility study for a landfill in Switzerland having 320,000 m^3 waste volume highlighted 210,000 m^3 recovered landfill volume and between 3.240 MJ/t and 4.510 MJ/t energy recovery potential. The energy necessary for transport and deconstruction cumulates to 1.5% of the heating value of the respective landfill. Additionally, the benefit from the recovered landfill volume in monetary terms must be considered.

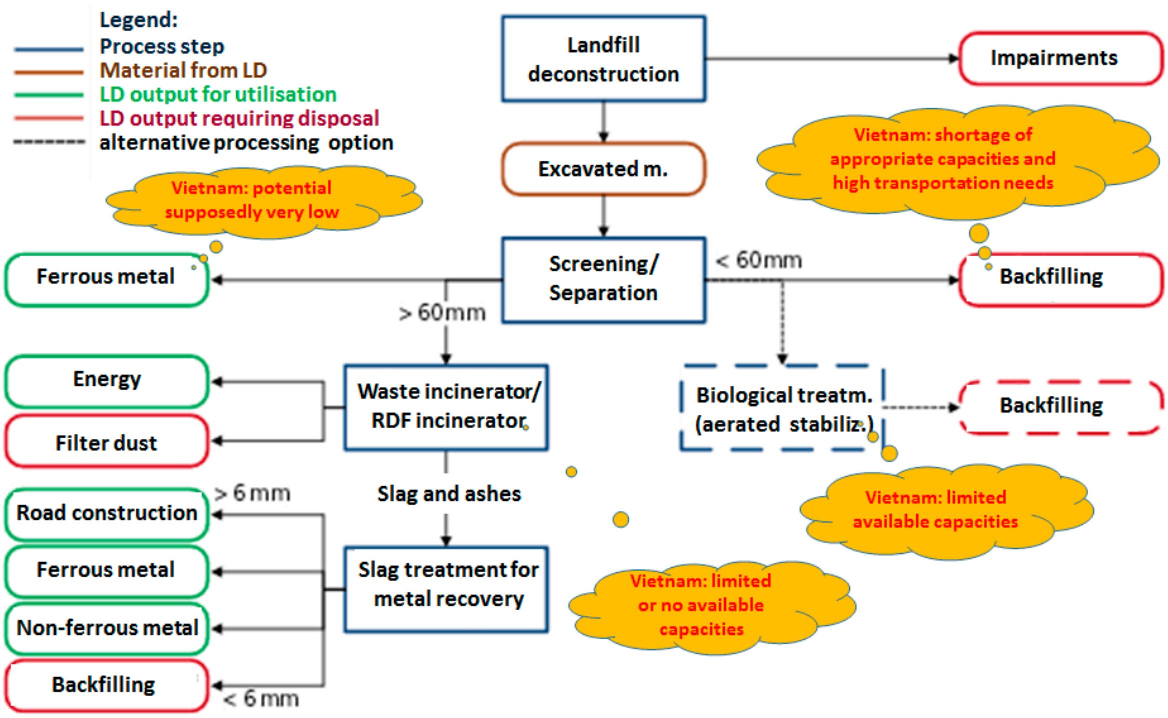

Figure 7. Enhanced LD concept and feasibility in Vietnam.

To assess the ELFM potential at GÈ Cát landfill, residual solid waste samples have been taken from landfill body during operation in 2003. Those samples had about 100–250 kg and were taken from about 1–2 m depth from the surface. Because waste disposal ended in 2001, most of the easily decomposable organic fraction was already decomposed. After that, the taken residual solid waste sample was screened and classified into the three main components: soil, burnable waste and inert waste (such as glass, porcelain, ceramic, etc.). Scope of the investigation of the waste composition was to understand the geochemical composition after altering of the landfill content and to prepare a basis for the assessment of the energy potential of GÈ Cát landfill.

Figure 8 shows the waste composition GÈ Cát landfill in 2003. The result shows:

- Organic wastes formed the highest percentage (81.4%), represented by food waste (70.8%), by textiles (1.8%), wood (1.2%), yard garbage (1.2%), rubber (0.4%), and leather (0.3%).
- Plastic formed the second highest proportion (16.0%). Among the plastic materials, the fractions were nylon (13.8%), foam boxes (0.7%), multi-component plastic (0.2%) and plastic bottles (PET).
- Paper was included with an average proportion of 1.0%, caused by household paper and magazine printing paper (0.6%) as well as cardboard and corrugated cardboard (0.4%).
- CDW formed a very small proportion such as ferrous metals (0.2%), non-ferrous metals (0.02%), glass (0.3%), and potential hazardous other wastes (0.1%).

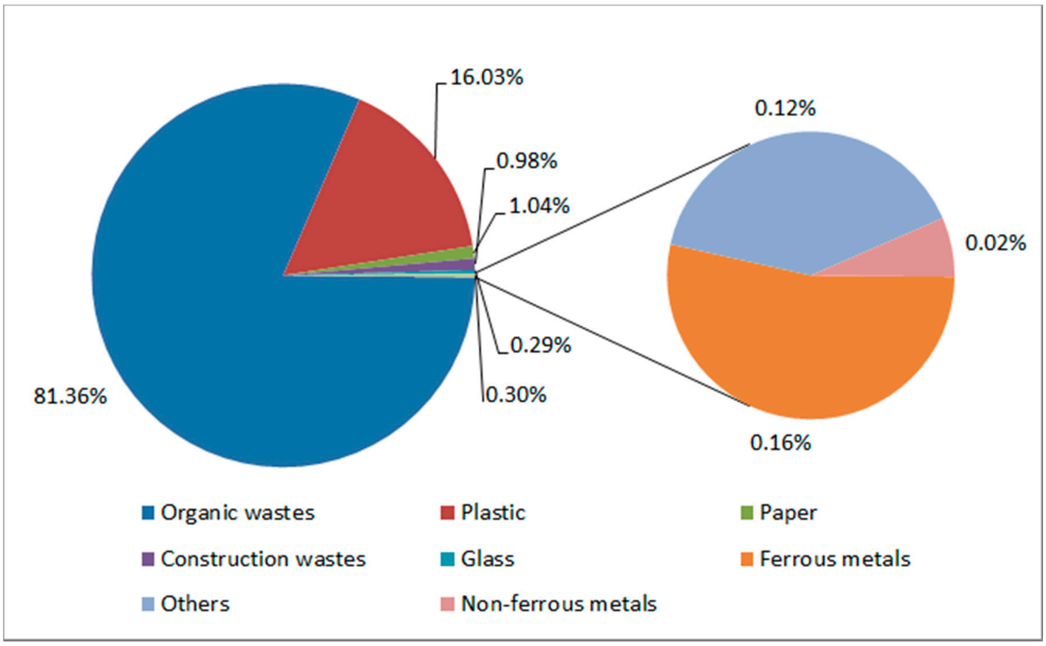

Figure 8. Waste composition of GÈ Cát landfill in 2003.

For the recent investigation in the SAFEUSE project the total amount of waste sampling was 20.9 kg. After sieving and sorting, the soil-like materials weight was 15 kg, the weight of the combustible wastes (nylon, textiles, etc.) was 5.6 kg and the weight of the inert waste (glass, metal, etc.) was 0.3 kg. Even the size of the recent waste sample was small it can be used for a first general screening of the development of the waste composition. Figure 9 shows the actual percentage of the waste composition at GÈ Cát landfill in comparison with earlier results. The results of Figure 9 indicate that the composition of the main components of the disposed waste at GÈ Cát landfill has changed significantly. The burnable waste percentage decreased from 98.9% to 26.8% due to waste decomposition, and this part of the waste was transformed into soil-like matters.

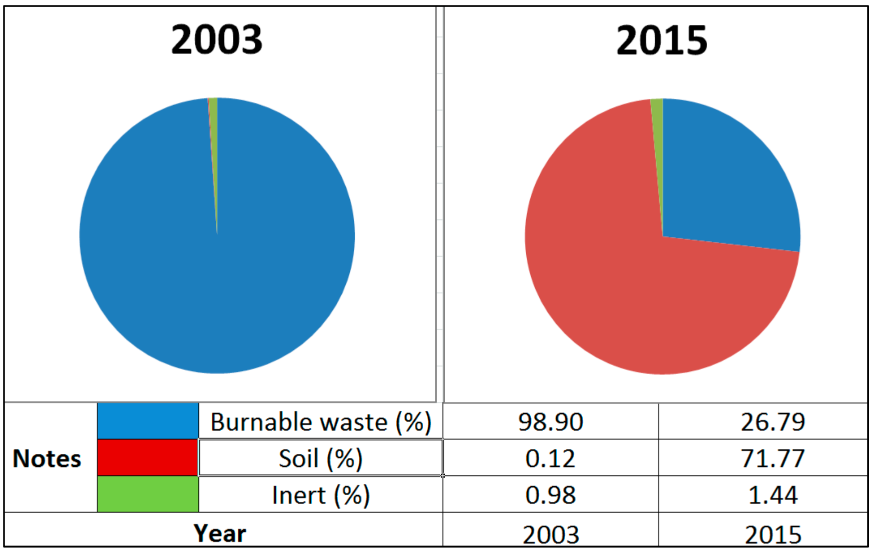

Figure 9. Development of the waste composition of GÈ Cát landfill body over time.

The inert percentage has not undergone a significant change due to its properties. In the current waste composition investigation, the burnable solid waste fraction in terms of the caloric potential was analyzed to determine the heating value by means of a bomb calorimeter. The lower heating value (LHV) is calculated from the higher heating value by subtracting for the evaporation energy of water formed from combustion of hydrogen. The results are given in Table 6.

According to the investigation result, the average heating value of residual solid waste from GÈ Cát landfill was determined as LHV = 5.950 MJ/kg (with a calorific value of 5.950 MJ/kg = 4.38 kWh/kg). Thus, it is comparable to some fuels but higher than the average heating value of solid waste in Vietnam, because usually it is not altered. At the GÈ Cát landfill, almost all organic waste has decomposed. The remaining burnable fraction has a share of approximately 27% of the whole landfill body which means around 1.25 mil tons. The efficiency in terms of feed of electrical energy to the grid of a state-of-the-art waste incineration plant (not available in Vietnam currently) is approximately 25% [30]. Insofar the release of electrical energy can be estimated to 520.625 MWh. Under consideration of the current electricity prices for projects generating direct burning of solid waste in Vietnam due to Governmental Decision 31/2014/QD-TTg, which is 2114 VND/kWh (approximately 0.09 US$/kWh) for developing mechanisms to support power generation projects, the benefit which could be earned from GÈ Cát landfill is 1.1 billion VND (compares to around US$49,000). The costs of landfill deconstruction range US$20–US$40 per m^3 which results in approximately US$85–US$170 mil for the whole landfill body of about 4.2 mil m^3. The result shows that energy recovery from GÈ Cát waste might support to reduce the LD costs but is of minor relevance due to the overall costs of landfill deconstruction. The most important financing source for the LD is the property value which can be gained after the site clearance.

Table 6. Lower Heating Value (LHV) result of the residual solid waste sample of GÈ Cát landfill after determination by calorimeter.

Lower Heating Value (LHV)		
Landfill Cell Number	**Heating Value (MJ/kg)**	**Average Heating Value (MJ/kg)**
1	7.231	5.950
2	3.889	
3	5.527	
4	7.567	
5	4.512	
6	6.975	

3.2.3. Assessment of the Feasibility of the Biomass Use at the Capped GÈ Cát Landfill Site

Several approaches and experiences for the reuse of capped landfills are already existing, for example in livestock farming or installation and operation of solar power plants. In addition, the utilization for leisure activities after green capping and rehabilitation or the industrial reuse is a common practice in Europe. For the landfill site GÈ Cát, the reuse potential of the landfill site for the development of a biomass utilization plant was investigated [38]. This option combines the following two issues:

(1) Professional landfill capping, cultivation of energy crops on the landfill cover and utilization of the biomass together with other organic matter, e.g., biodegradable waste (food leftovers), agricultural and industrial residues.
(2) Installation and operation of a biomass converter for the generation of biogas. The produced biogas would be used to generate energy in a Combined Heat and Power plant (CHP).

The plantation of the recultivation layer with aim of energy recovery from green biomass can take place for example by cultivation of Miscanthus or seeding of grass. For the cultivation Miscanthus, rhizomes can be used [39,40] that are received by self-recovery on donor areas, seedlings of in vitro reproduction or pre-cultivated plants from rhizomes. About 1 kg Miscanthus having a water content of 14% provides an energy content of about 4.4 kWh. It takes approximately 2.27 kg of Miscanthus to produce 1 L of extra light heating oil with about 10 kWh/L. The biomass cultivated on the entire landfill body (about 19 ha) can be harvested at least once a year. Depending on the type of utilization, Miscanthus is chopped with an existing technology or baled. During gasification, the shredded material is converted into a fuel gas that can be used for energy as well as high effective heat generation.

Alternatively, instead of the plantation of Miscanthus, the sowing of grass can be considered as biomass source [41]. The silage from meadow grasses can be used as fermentation substrate for biogas plants. The grass silage can be used as co-substrate together with organic waste and sewage sludge, where is converted together with the basic substrate into biogas through fermentation by bacteria. The resulting biogas can be used for energy needs (cogeneration). Grass silage provides a biogas yield from 170 to 200 m^3/t fresh weight (FW). The calorific value of biogas is given as 21.6 MJ/m^3. Therefore, from 1 t FW approximately 3.7 to 4.2 GJ of energy might be obtained. According to the case study in [34], the potential of financial income from the biomass gasification can reach around 230,000 US$/year. Based on a biogas plant with a feed rate of 130 m^3/day, a generator output of 7000 kWh/day (2,555,000 kWh/year), and under consideration of the current terms and conditions for CITENCO to feed the energy to the grid (0.09 US$/kWh) might be obtained 230,000 US$/year from such a biogas plant. The substrate feed is composed of the mown biomass and additional feed of biomass for instance from biowaste from the surrounding of the GÈ Cát site.

The long-term development of the estimated costs and benefits of this solution are highlighted in Figure 10.

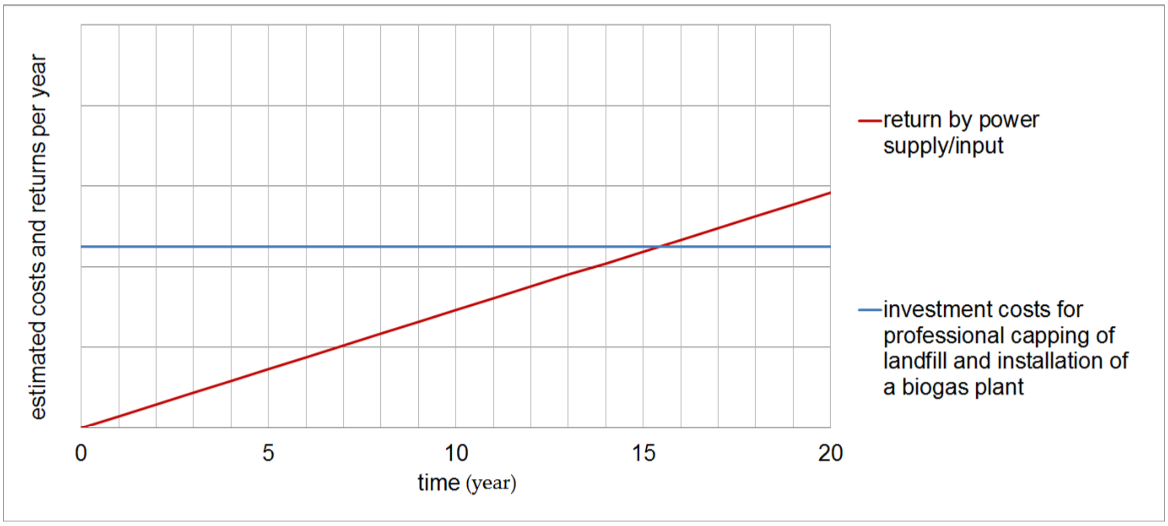

Figure 10. Long term development of the estimated costs and benefits of the energy crop utilization.

4. Discussion

Conclusions from the data collection, investigations and assessments are to be drawn on the large scale for the long term (10 to 50 years), as well as on the small scale for the short term (<10 years). On the long term, the largest waste streams are predicted to be biowaste and CDW. Both of them are recyclable waste streams and can be subjected to circular economy. Biowaste is already a big waste stream, while CDW because of the still growing infrastructural development will become a significant waste stream starting from around 2030. The large scale is represented through the HCMC Metropolitan Area, which is facing further growth. Beside the future circular waste streams on the long term, a circular economy potential on the short term, which concerns a potential for land recycling after landfill mining (for instance at GÈ Cát landfill site), exist. Another option would be reusing the landfill site surface for the conversion of biomass into biogas. Currently, the final decision on the further policy in terms of GÈ Cát landfill has not been taken by the administration yet, due to complex decision procedures.

A general assessment of the advantages and disadvantages of the potential reuse options is given in Table 7, which reflects the recent state of the discussion process.

Table 7. SWOT analysis for the assessment of the advantages and disadvantages of the GÈ Cát landfill re-use options.

Strengths	Weaknesses
• Energy utilization potential: The waste body of GÈ Cát landfill does have a certain waste-to-energy potential, even if it does not justify the deconstruction of the landfill body in monetary terms as such. Partially the incinerated material would need backfilling. This could be done at the landfill Phuoc Hiep which is still in operation. • Land recycling potential: The location of GÈ Cát landfill has a large land recycling potential as the megacity needs space for its further growth. • Biomass utilization potential: GÈ Cát landfill has a long term biomass utilization potential, which could be unlocked through energy crop cultivation on the capped landfill. • Authority supervision of HCMC landfills: Generally, environmental supervision of the monitoring of the landfill sites in operation is done by the authorities. Closed landfill sites are monitored under supervision of the authorities.	• Material utilization potential: The waste body of GÈ Cát landfill does not contain a large potential for a material use in the sense of the European waste management hierarchy. • Landfill gas utilization potential: The landfill gas potential of GÈ Cát is exhausted due to decomposition of the biodegradable waste proportion and the blocked gas collection system. • Landfills situation: HCMC landfill sites are not maintained state-of-the-art, both operating and closed sites. At the closed sites, the landfill capping is not applied properly, the leachate collection system works only temporarily, both causing emissions. At the operating sites are problems with air emissions. • Handling of hazardous waste: Hazardous waste is often dumped with MSW. About 90% of industrial hazardous waste in HCMC is untreated and often burned. Hazardous waste could appear when the landfill is deconstructed.
Opportunities	**Threads**
• Monetary valorization All discussed re-use options are technically feasible and contain a monetary valorization potential. The largest margin could be achieved through landfill deconstruction with subsequent land recycling. The use of recycled land would reduce the land consumption. • Pilot project GÈ Cát landfill could become a pilot project for: (a) landfill deconstruction with subsequent land recycling; or (b) after-use through energy crop cultivation and utilization in a biogas plant. With this kind of attention GÈ Cát landfill could have a lighthouse function for Vietnam, as well as for capacity building of environmental awareness and environmental qualification (teaching). • Investors There are already interested investors to obtain the recycled land.	• Insufficient Landfill Capacity The high economic growth and progressive urbanization mean waste continues to rise. There is a risk that the development of the National Strategy for integrated waste management cannot keep up with the rapid social and economic changes. • Management In the authorities might lack the will and/or options against state-owned enterprises and foreign investors to enforce the existing laws. • Investors There is a financial risk for the investors as the subsoil situation of GÈ Cát landfill is not yet investigated. Even GÈ Cát landfill was built with a basic sealing according to international standards, there could appear polluted soil below the landfill location which must be decontaminated.

The recycling of land is not regulated, but a market driven process. As the location of GÈ Cát landfill, which was in the periphery of the city when the landfill was built, is now in a central part of a settled area, the property value increased. The results of the investigations at GÈ Cát landfill show that reuse of the landfill site is feasible in several ways: (a) the land recycling after deconstruction of the landfill including the use of the disposed waste for waste to energy generation after landfill mining; or (b) the use of the energy crop cultivation of the capped landfill, development of a system for selection organic waste, e.g., from food industry and from food product markets, and the valorization in a bio-gas plant. The landfill gas was already used, but the use is no longer economically feasible due to insufficient gas collection, as the collection system is blocked with leachate due to the incomplete surface sealing.

5. Conclusions

The recycling targets of the National Waste Management Strategy provide a sufficient framework for a circular economy in Vietnam, focusing on a complete waste collection by 2025. The achievement of this vision would raise the waste management situation of Vietnam to a level comparable to that in Germany today, with landfilling left for inert materials and the non-usable or dangerous residues from treatment operations only. Practically, this would mean a phasing out of almost all ordinary disposal sites and landfills for municipal solid waste that are nowadays still operated in large number and spread to hundreds across the country. A lack of the National Strategy a missing waste avoidance concept as sustainability strategy as the growth of the Vietnamese economy is given priority. The necessary recycling facilities have been built, but still the waste is not separately collected.

The results of the investigation show that even a part of the waste flows in HCMC is organized according to common waste management principles, the waste disposal still faces challenges and lack of operational experience. The operation of the landfills in function requires improvement in terms of state-of-the-art technologies and leachate management, as well as the closure of the filled landfills. Particular challenges for the landfill closure are the tropic climate with high humidity and large rainfall volumes, leading to an insufficient gas collection system. Thus, generally, there are two options for the implementation of circular economy approaches in HCMC: (a) the recycling of the recyclable components of the household waste; and (b) the recycling of land. The base for the improvement of the recycling level of the recyclable components of the household waste is given with the recycling targets in the National Waste Management Strategy of Vietnam, to be achieved by 2025. This ambitious target becomes even more challenging under consideration of the further rapid growth of the megacity HCMC, even though the legislative framework exists.

The landfill GÈ Cát has a special function in the history of the HCMC waste management system. It was the first landfill ever set up in Vietnam according to international standards, equipped with a gas collection and leachate treatment system. According to the current situation it would be feasible to be GÈ Cát landfill even the first landfill in Vietnam being used for landfill mining as the property cost allows this solution. The results show that the situation at GÈ Cát landfill is significantly different from the European or even German situation in terms of landfill rehabilitation and landfill mining. While Europe applies the waste management hierarchy as given in the Waste Framework Directive of the EU, highlighting the avoidance of waste as priority, prior to waste recycling, treatment and disposal, the Vietnamese legal framework does not require such a priority. In terms of recycling, the priority of the European legal framework is given to material recycling before energetic use. These requirements lead to the situation that in Europe landfill mining usually is not considered economically feasible because the recycling of recyclable materials is much more costly than the energetic valorization. Regarding the existing situation, such requirements do not apply in Vietnam. This leads to the situation that the feasibility of urban mining is ensured through two aspects: (a) the waste can be valorized for energetic purposes without further material recycling; and (b) the growing economy leads to the growth of the megacity resulting in increasing land prices.

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Conflicts of Interest: The authors declare no conflict of interest.

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