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Solid Waste Management in Vietnam

Current situation, challenges and strategies for development

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Vietnam has seen many changes in economy. Together with the development in economy, many urban areas have been built; thus, urbanization rate in Vietnam is very quick. These changes within 2 decades have brought many environmental challenges to Vietnamese as well as the authorities. In this thesis, many aspects in solid waste management are studied. Firstly, the paper starts with a quick overview of how society and economy in Vietnam has been changing and how solid waste is generated in the country. Then, the aspects on how the governmental institutes are legally responsible in solid waste management are shown. The most important part in this paper is solid waste treatment technologies that have been practiced recently in Vietnam, the good and bad sides of those methods. It is followed by a study of European Union's directives in two main waste treatment methods, incineration and landfilling. Together with that, a list of all major important parameters in organic waste treatment technologies are mentioned. Finally, the paper ends with a number of proposing action for the development of waste management system in Vietnam.

Keywords	Solid waste, generation, management system, urbanization

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1. Introduction

Nowadays, there are more and more people moving from rural areas into large cities with a dream of making more money to support their families and improve their living standards. Therefore, urbanization has now become one of the most important issues and challenges for Vietnam in efforts to pursue sustainable development.

Vietnam's population in 2018 is approximately 96 million. According to World population review (1), population density of Vietnam in 2018 is 291.33 persons per kilometre squared. This makes Vietnam the 15th most densely inhabited country. It is obvious that urbanization at a quick pace and without any proper planning will lead to many issues such as accommodation, education, health care, public services, transportation and waste management. Without proper planned system of waste management, people are more likely to be exposed to diseases and other health risks. Recently, there are many cases of environmental violation discovered in the country; the results of those cases are very serious, and it takes a long time for the environment to recover. They also impacted negatively on the economy and health of many people. There were cases where many villages in Vietnam are called cancer villages because the locals there have had to use polluted water as their only water supply over a long time.

In this thesis, the main objectives were studying the current situation of municipal solid waste management in Vietnam at both governmental and operational level, as well as identifying challenges in management. Finally, the aim was also to propose action plans to help developing and improving the system of waste management as well as people living quality in Vietnam.

2. Waste generation and composition in Vietnam

2.1 Social-economic development

The National socio-economic development strategy, which was proposed by the Party and the Government and approved by the National Assembly, pointed out that their main target for the period 2006-2010 was to industrialize and modernize the country. As part of this mission, numbers of economic sectors including industry, construction and services were planned to increase their proportion in the total GDP of the country. According to the 2011 statistics from General Statistics Office of Vietnam (GSO) in Table 1, industry, construction and services have always contributed about 80% of the total GDP for the country in the period of 2006-2010.

Table 1. Structure of GDP at current prices between 2006 and 2010 (2)

	National Assembly resolution	Achieved value (%)				
		2006	2007	2008	2009	2010
Agriculture, forestry, and fisheries	15-16	20.40	20.34	22.21	20.91	20.58
Industry and construction	43-44	41.54	41.48	39.84	40.24	41.10
Services	40-41	38.06	38.18	37.95	38.85	38.32

Together with the bloom in economic growth, there are more and more people living in rural area migrate into large cities with the hope of looking for a good job. In 2009, according to GSO, there were 25.59 million people living and working in urban areas which accounts for 29.74% of the total population in Vietnam. And this figure had reached 26.22 million in 2010, which accounts for approximately 30% of the total population in the country. Also, it is forecasted that the total urban population in 2025 will be 52 million. This means by 2025 almost 50% of the total population in Vietnam will be living and working in large cities. This change is of course considered as a considerable and impressive improvement in people's living standard and a good achievement for the country's economy. However, environmental management, and especially municipal solid waste management will become one of the most important issues in city planning and managing. As people are making more money, there will be more waste generated, and landfill which has been one of the main traditional waste of handling waste is going to be filled very soon.

2.2 Solid waste generation and composition

Solid waste can be classified in different ways. One way is classification based on sources of solid waste generation, for example, domestic waste, construction and demolition waste, industrial waste, agriculture and crafting village waste, and medical solid waste. Another way of classifying solid waste is based on the toxicity level and its impact on human health. This way, solid waste can be grouped as ordinary solid waste and hazardous solid waste.

According to data from the document National State of Environment published in 2011 (2), the volume of solid wastes generated in 2003 and 2008 is described as in Table 2. Urban solid waste in 2003 was 6.4 million tonnes and this number increased to 12.8 million tonnes in 2008. The amount of solid waste generated in urban areas had been observed to increase remarkably, by more than 200%. Industrial solid waste also increased by 181%. In 2003, there was 2.6 million tonnes of industrial solid waste generated and this amount has increased to 4.7 million tonnes in 2008. Also, from the report, it is forecasted that there would be about 42-46% of solid wastes generated nationwide coming from urban areas and 17% of that is contributed by industrial production. The proportion of solid waste generated in 2008 is demonstrated in Figure 1.

Table 2. Volume of solid wastes generated in 2003 and 2008 (tonnes/year) (2)

Type of solid waste (SW)	**2003**	**2008**
Urban SW	6,400,000	12,802,000
Industrial SW	2,638,400	4,786,000
Medical SW	21,500	179,000
Rural SW	6,400,000	9,708,000
SW in craft villages	774,000	1,023,000

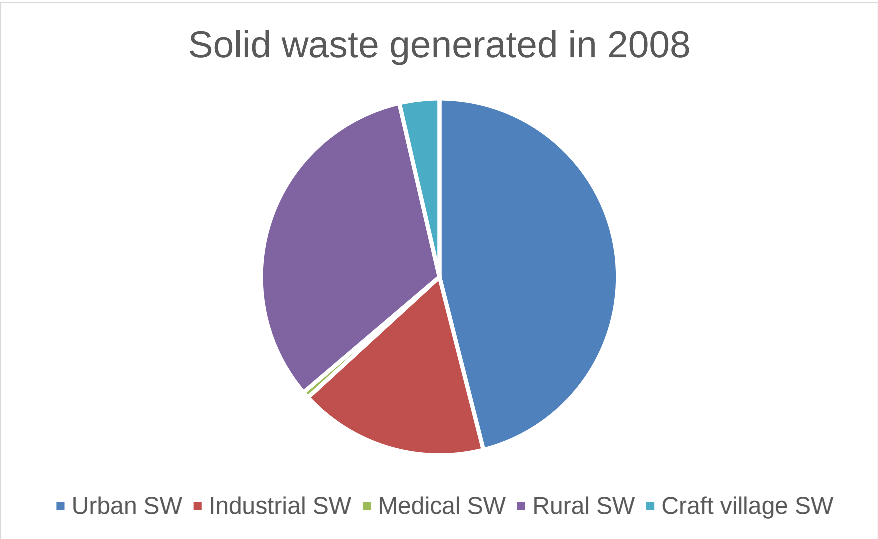

Figure 1. Proportions of different categories of solid waste generated in 2008 (2)

2.3 Urban solid waste generation

According to the 2011 report of Department of Natural Resources and Environment (DoNRE) (2), the amount of municipal solid waste generated in urban areas only increased roughly 10-16% every year from 2007 to 2010. Table 3 shows that the total volume of urban solid waste generated in 2007 was 17.682 tonnes/day and increased to 26.224 tonnes/day in 2010. And it can be observed that the amount of solid waste generated per capita per day also increased from approximately 0.75 kg/person/day to almost 1.0 kg/person/day. This can be understood as the living standard of people in urban areas has been improved.

Generally, urban areas in Vietnam are classified into five different levels. They can be listed as Level 1 which is special cities and include Hanoi, the capital, and Hochiminh city (its former name was Saigon); Levels 1 to 3 are defined as cities, Level 4 is defined as town; and Level 5 is defined as township. Also, according to this 2011 report of DoNRE (2), there are total 755 urban areas in the whole country and this number is forecasted to reach 1000 urban areas in 2025. Urban solid waste is generated from many different sources, which in general can be listed as household, street, office, market and commercial waste. In 2011, Hochiminh city, one of the two largest cities in Vietnam, generated 8,700 – 8,900 tonnes/day. Municipal solid waste generated 6,200-6,700 tonnes per day. And this rate is expected to increase around 8-10% per year.

Table 3. Urban solid wastes generated between 2007 and 2010 (2)

Content	2007	2008	2009	2010
Urban population (million people)	23.8	27.7	25.5	26.22
% of the urban population in the total population	28.20	28.99	29.74	30.2
Urban solid waste generation indicator (kg/person/day)	~ 0.75	~ 0.85	0.95	1.0
Total volume of urban SW generated (tonne/day)	**17,682**	**20,849**	**24,225**	**26,224**

The most basic components of solid waste are organic and inorganic waste. Inorganic waste includes, for example, glass, porcelain, metals, paper, rubber, plastic, nylon plastic, fabric, and electronics. Organic waste includes mostly left-over or spoiled food, falling leaves, spoiled fruits, manure, and dead bodies of animals.

As people are making more money, they also spend more money especially in food, clothes, paper and wrapping plastic. As people are nowadays becoming busier with their work, they spend less time cooking at home and instead prefer buying more processed food, which is more convenient. Together with the development of food industry and packaging industry, the volume of food wastes also increases remarkably. Paper waste also increases due to the strong investment and development of education. There are more and more books printed every year. Wrapping, packaging of import and export goods also make the volume of paper waste generated more and more every year. Nylon and plastic bags are being used substantially in Vietnam due to the growth of packaging industries. Also, people in Vietnam are not aware of the negative impacts of nylon and plastic on the environment; thus, the amount of plastic waste in Vietnam is also increasing rapidly.

Table 4 shows the components as well as the proportions (percentages) of those components of municipal solid waste which ended up in landfills of large cities in 2011. It is reported that organic matter accounts for more than 50% of municipal solid waste in the landfills. This shows that there are still much room for the investment in developing waste treatment plants for organic matter such as composting and biogas plants. Another significant figure in the tables is the percentage of plastic ending up in landfills, which is roughly 15% in Hochiminh city and 10.96% in Hanoi.

Table 4. Municipal Solid Waste composition in percent at landfills in big cities in Vietnam (14)

Composition	Ha Noi	Hai Phong	Hue	Da Nang	Ho Chi Minh
Organic waste	57.30	56.37	77.10	68.47	63.67
Paper	5.95	4.98	1.92	5.07	7.34
Textile	3.79	4.85	2.80	1.55	2.99
Wood	4.57	4.32	0.59	2.79	4.39
Plastic	10.96	12.81	12.47	11.36	14.19
Leather and rubber	0.18	1.48	0.28	0.23	0.69
Metal	0.56	0.36	0.40	1.45	0.48
Glass	3.47	1.52	0.39	0.14	0.63
Porcelain	0.82	0.86	0.79	0.79	0.76
Soil and sand	5.86	3.02	1.70	6.75	1.84
Coal slag	2.72	5.88	0.00	0.00	0.42
Hazardous waste	0.49	0.05	0.00	0.02	0.04
Sludge	2.98	2.15	1.46	1.35	2.41
Others	0.31	2.50	0.00	0.03	0.09
Total	*100*	*100*	*100*	*100*	*100*

Table 5. Composition of solid waste in Hanoi (2)

Components of SW	Percentage (%)
Organic matter	51.9
Inorganic matter	16.1
Paper	2.7
Plastic	3.0
Leather, rubber, wood	1.3
Textile	1.6
Glass	0.5
Rock, clay, porcelain	6.1
Metal	0.9
Particles < 10mm	31.9
Total	*100.0*

Table 5 above provides more details about the composition and percentage of each component of solid waste which is generated in Hanoi. As much as 51.9% of the solid waste is organic matter, 16.1% of it is inorganic matter, and 3% plastic.

In Hochiminh city, one of the most important cities in Vietnam besides Hanoi, it is estimated that on the daily basis, there are 5,800-6,200 tonnes of domestic waste generated. Domestic waste is generated as result of the ordinary daily activities. According to an article about the waste situation in Hochiminh city, the sources that contributes the most to the generation of domestic solid waste is households, schools, markets, restaurants, and hotels. Besides that, there is an estimation from DoNRE of 500-700 tonnes of industrial waste, 150-200 tonnes of hazardous waste, 1500-2000 tonnes of construction and demolition waste, and 9-12 tonnes of medical waste generated per day in this city (2). The total volume of solid waste generated in this city is estimated to be about 7-8% per year and the proportion of organic waste is 54-77%, and that of recyclable waste is 8-18%. In Table 6, the amounts of urban solid waste generated per day and per year, together with the increasing rate of urban solid waste generation are given from 2000 till 2015. The composition of urban solid waste as an input for Da Phuoc waste treatment plant, which is one of the main waste treatment facilities in Hochiminh city, is shown on Table 7.

Table 6. Total volume of urban solid waste generated in Hochiminh city throughout the years 2000-2015 (3)

Year	**Volume of urban waste solid generated**		**Increasing rate every year (%)**
	Tonnes/year	**Tonnes/day**	
2000	1,483,963	4,066	39.2
2005	1,746,485	4,785	3.7
2010	2,372,500	6,500	7.4
2015	2,628,000	7,200	8

Table 7. Composition of waste generated in Hochiminh city (3)

Composition	**Rate (%)**
Organic waste	64.5
Plastic	12.4
Coal slag, sand, porcelain	2.2
Paper	8.2
Leather, rubber	0.4
Hazardous	0.1
Fabric	3.9
Metal	0.4
Mud	2.8
Wood	4.6
Glass	0.4
Other	0.1

3. MSW management system in Vietnam

3.1 Governmental institutes of solid waste management

In January 1994, the Environmental Protection Law was firstly introduced and enacted in Vietnam by the Ministry of Justice. After many years, there have been many changes and improvements in the Environmental Protection Law. The newest version of this law came into practice in January 2015. This version introduced some new concepts, for example, green development, climate change, and environmental security. Some changes have been made in order to comply with the International agreement that the

Vietnam government has signed recently. After this change, there are a total of 20 chapters described in the law, while there were only 15 chapters in the previous version in 2005 (4).

According to the Environmental Protection Law, the Ministry of Natural Resources and Environment (MoNRE) is the main ministry that is responsible for implementing, monitoring and assessing practices of the Environmental Protection Law. Besides MoNRE, there are five other ministries involved directly in solid waste management. They are the Ministry of Health, the Ministry of Construction, the Ministry of Planning and Investment (MPI), the Ministry of Transport (MoT), and the Ministry of Industry (MoI). Each of them plays a key role in managing different sections of solid waste (municipal solid waste, industrial solid waste, hazardous waste). The Ministry of Natural Resources and Environment together with the Ministry of Construction, and the Ministry of Planning and Investment take care of municipal solid waste, while, industrial solid waste is handled under MoNRE, MPI, MoT, and MoI. And finally, hazardous waste is handled under MoNRE, MPI, and MoH. The institution arrangement is summarized in Figure 2.

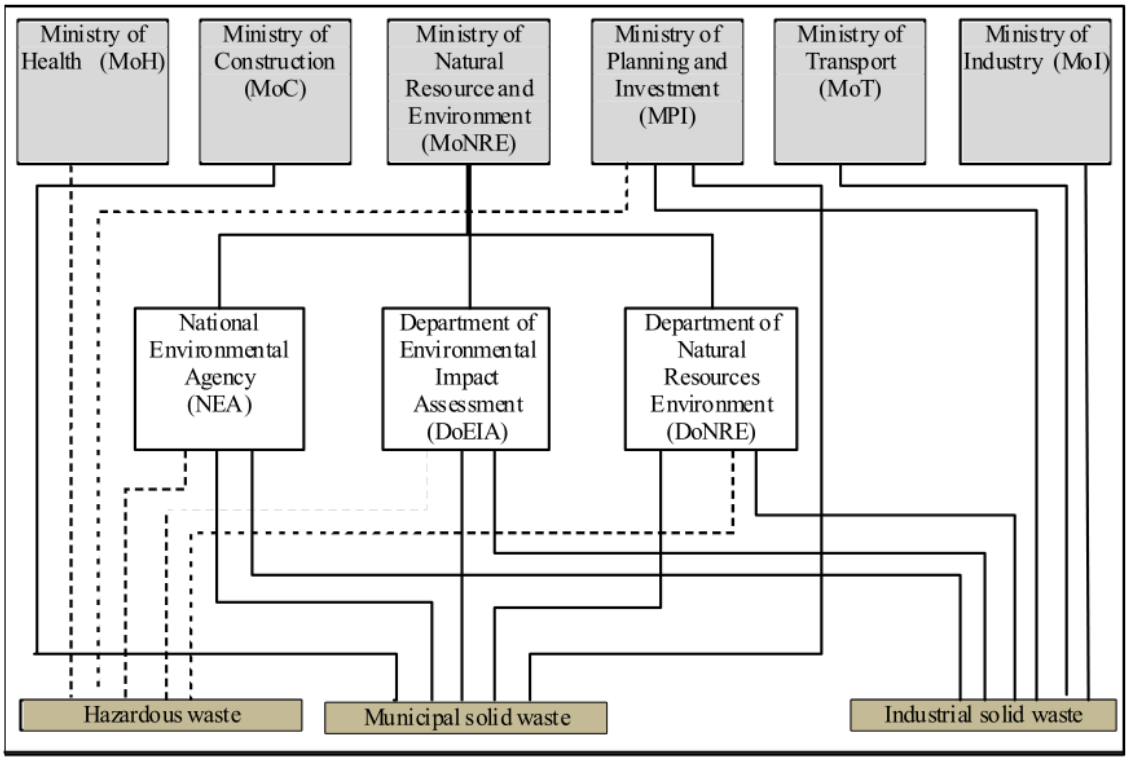

Figure 2. Institution arrangement of solid waste management at national level in Vietnam (5)

Solid waste management at local level is managed by provincial and municipal governments. These parties include the People's Committee (PC), the Department of Natural Resources and Environment (DoNRE), and URENCO.

The People's Committee takes care of state administration at local level. This means PC's responsibilities are to monitor the implementation of environmental management regulations to administrate their local agencies in their works to report to the higher level of management, to give instruction and consultancy for waste management facilities, plants as well as projects related to waste management and treatment, and to be in charge of any investment and subsidization for waste management plans, projects and facilities.

The Department of Natural Resources and Environment is an agency of MoNRE. Thus, it is influenced by MoNRE and receives support, collaboration and guidance from MoNRE. Also, DoNRE is influenced by PC, in which PC provides DoNRE with support in political relations and administration.
Finally, URENCO is an agency of DoNRE and PC. They are the main company that takes care of collecting, transporting, and treating solid waste. Moreover, URENCO also takes responsibility in maintaining hygiene for public places, lighting, and trees along the streets.

3.2 Physical components of municipal solid waste management

3.2.1 Collection and transportation

Solid waste is collected mainly in urban areas only while the practice of solid waste collection in other areas, especially in rural areas is still very limited. In rural areas, even though the government has been trying to increase the rate of waste collecting, the situation has not improved much. According to the report of the National State of Environment 2011-2015 established by MoNRE in 2015, waste collecting rate during the period 2013-2014 in urban areas is 84-85% on the average, and it is 60% in sub-urban areas. However, this rate in the countryside is 40-55%, and in the rural area it is only 10%.

In large cities like Hanoi and Hochiminh citiy, waste collection is done by private companies that have licenses in collecting and treating waste and proper contracts with the local authorities (DoNRE and PC). Some of the companies that have license and contract in collecting and transporting waste are URENCO that operates mainly in Hanoi, Vietnam Waste Solutions Inc. (VWS), and CITENCO that operates mainly in Hochiminh city, and neighbouring provinces including, for example, Binh Duong, Dong Nai, Ba Ria Vung Tau, and Long An. CITENCO is a domestic company that has been licensed for collecting and treating domestic and hazardous solid waste. These licenses are approved and provided by the Vietnam Environment Administration (VEA). Also, CITENCO has achieved a certificate of quality management ISO 9001:2008 and the environmental management ISO 14001:2004 that are certified by the British Standards Institution. The practice of waste collection in those cities is still very simple with no sorting at source. At household level, waste is held in plastic bags or plastic containers and is placed right in front of their houses waiting to be collected. Collection at household level is done by a hand-cart which is carried on foot by waste collecting workers. Once the hand-carts are full, they are carried to a truck and will be transferred to a transferring station and treatment facilities later. Figures 3,4, and 5 below show how municipal solid waste is collected and transported in Hochiminh city and in a countryside area.

Figure 3. Waste bags are waiting to be collected and being collected by carts (6,7).

Figure 4. Waste is being collected by workers onto their cart and then transferred into a truck (8 and 9).

Figure 5. Domestic waste is being collected in a countryside neighbourhood (10).

In the countryside and rural areas, collection is done by small and private cooperation or some small-sized, family sized company. Collecting fees in those areas are agreed between the service-providing organization, local authorities and local people. And the collection stops at transfer points with no further proper treatments.

Figure 6 below describes about the waste management system in Vietnam, from generation and storage into treatment and disposal.

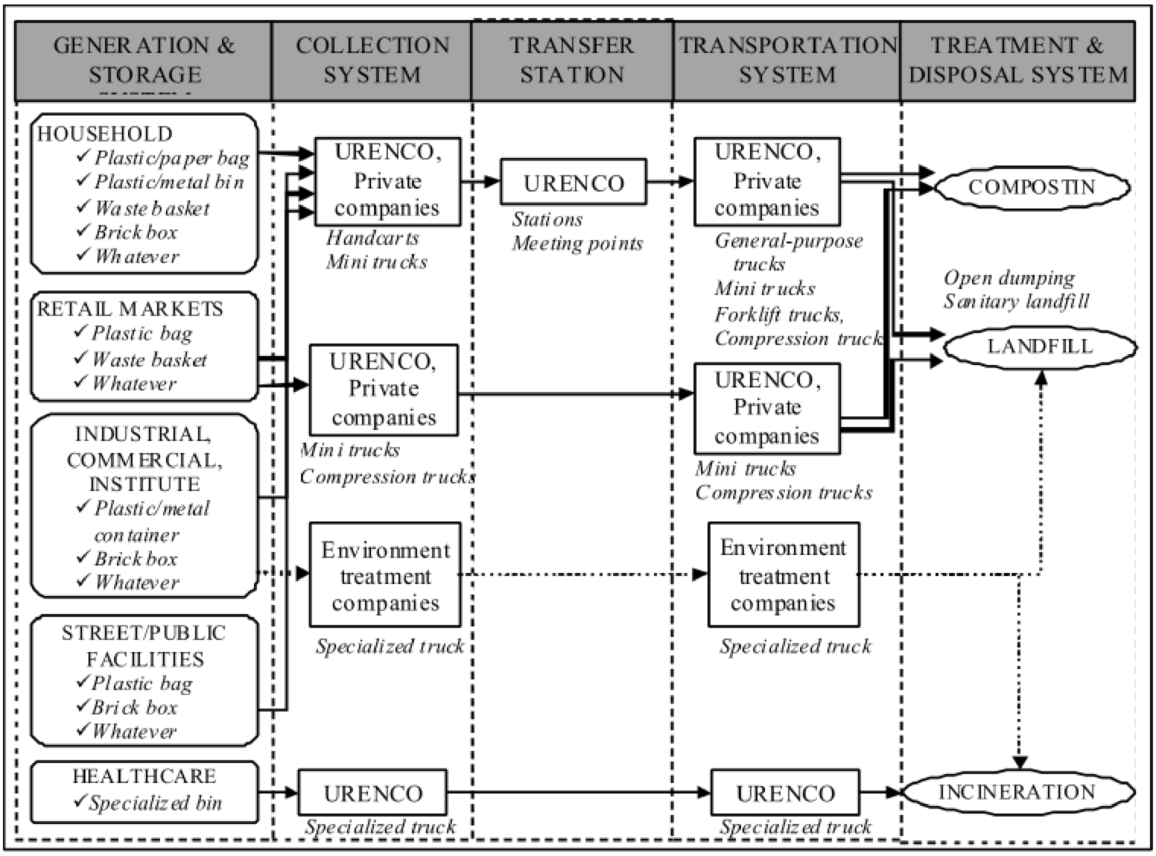

Figure 6. Waste management system in Vietnam (5)

3.2.2 Treatment technology and disposal system

3.2.2.1 Open burning and incineration

Open burning at landfill sites is a common practice in a few cities with the purposes of lowering the total volume of waste at those sites as well as increasing the capacity of the sites. Open burning can also be observed as the main practice of managing domestic solid waste in some countryside areas and in most of the rural areas. Local people in those poor areas burn their solid waste right in their home yards. However, these practices of open burning introduce a large amount of pollutants straight into the atmosphere. As a consequence of this practice, humans are at a higher rate of exposing and suffering serious health problems.

Incinerator facilities are operated to treat hazardous medical waste in some cities. With a limited amount of incinerator facilities, the majority of hazardous wastes from hospitals is dumped into the landfills. Moreover, small-sized incinerator facilities face difficulties in design to meet the standards for the combustion process. Those problems include insufficiently high temperature in the burner, regulation of gas emission (5). It is reported that there are 50 incinerators facilities operating to treat domestic solid waste throughout the country. A majority of those are at small scale whose capacity is less than 500kg/h (11)

Pellet is a compacted source for burning with high calorific value. Making pellets as compacted burning source is also known as a subclass of refuse-derived fuel (RDF) technology. RDF is a type of fuel that is produced from many different types of waste. RDF's main component is combustible components from wastes, such as no recyclable plastics except PVC, paper, and cardboard (12). Refuse paper and plastic fuel (RPF) is a subclass of RDF which mainly utilize paper and plastic waste as the input for making pellets. This project has been carried out by the URENCO company in Hanoi together with Ichikawa Kankyo Engineering (IKE) cooperation in Japan. URENCO stated that their objective is to produce over 12,000 tonnes of pellets (13).

Figure 7. Pellets as the final product from the URENCO waste treatment plant in Hanoi (13).

3.2.2.2 Landfilling

Besides incinerators and open burning, landfilling is one of the most common practices of solid waste managing in Vietnam. It is estimated that about 76-82% of total municipal solid waste ends up in landfills. There are a total of 98 open dumping sites and landfills around the country and only 16 sites have proper practices in treating solid waste, while the rest of the sites are operating in an unhygienic fashion. Furthermore, many open dumping sites and landfills, especially those in large cities, are always overloaded as the total volume of solid waste is increasing remarkably every year but the land is a limited resource (14).

3.2.2.3 Organic waste treatment technology

Recently, there are some other technology of solid waste treatment introduced into Vietnam such as composting and operating a biogas plant which produces energy. It was estimated that in the first quarter of 2014, there were 26 solid waste facilities built as the first step of the solid waste treatment program in the period of 2011-2020. Within those 26 newly built waste treatment facilities, there were 3 incinerating plants, 11 compost-producing plants, 11 plants that both incinerate waste and making composts, and 1 treatment plant that makes pellet (11).

Generally, technology used for organic waste materials includes aerobic and anaerobic digestion (AD). AD is a biological process in which bacteria breaks down organic matter with a little or no oxygen. This is an effectively controlled and enclosed system in comparison to landfills. The compositions of AD products are biogas and digestate. Biogas includes 60 per cent of methane and 40 per cent of carbon dioxide which then can enter further processes to generate electricity and heat or can be used as vehicle fuels. This not only contributes to energy need but also reduce greenhouse gas emission that are methane and carbon dioxide. Digestate is the combination of solid and liquid residue which can be used as soil conditioner to fertilize land. Biochemically, AD process includes four main stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Hydrolysis is done by the activities of bacteria where insoluble organic materials are decomposed to soluble substances. These substances will become source of nutrition for other bacteria to be used later. In acidogenesis, carbon dioxide, hydrogen, ammonia and organic acids will be formed by acidogenic bacteria. During the stage of acetogenesis, those acidogenic bacteria will continue to convert those previously formed compounds further into acetic acid and other compounds such as ammonia, hydrogen and carbon dioxide. Finally, in the methanogenesis stage, the methanogenic archaea will produce the final product, biogas. This final product consists of 60% of methane, 40% of carbon dioxide, and a small amount about 2% of hydrogen sulfide. Before the biogas is good to be used, it needs some further treatment including dewatering, desulfurization, and CO_2 removal.

Aerobic digestion, on the other hand, is the breakdown of biodegradable waste materials with the help of microbes together with the existence of oxygen. The product of this type of digestion is compost which is rich in nutrients. Compost contributes a lot to a healthy environment. Firstly, making compost helps recycle organic matters and conserve landfill space. Moreover, using compost also save water by maintaining soil moisture and preventing water runoff. Soil properties are improved because compost attracts and feeds earthworms and other beneficial soil microorganisms. Finally, the need of chemical fertilizers is reduced which protects the water body from being polluted. The process of composting or in another word, aerobic digestion starts with raw organic materials being broken down. This break down process can occur naturally by activities of earthworms, nematodes, earth insects, etc.; or it can occur in a controlled manner which is done mechanically by machines. Then, those microorganisms found naturally in soil such as soil bacteria, fungi, actinomycetes, or protozoa will start to colonize on those piles of materials and initiate the decomposition process. Decomposition process includes two main phases: active phase and curing phase. During the active phase, temperature of the pile increases rapidly as the metabolism of microbes starts. Within 24 to 72 hours, the temperature of the pile will be between 55-70^{o}C. This quite high temperature helps ton hygienize the raw biodegradable materials by killing pathogens, eliminating weed seeds, and breaking down phytotoxic compounds. Then, thermophilic microbes will take over the decomposition process which goes on several weeks. During this phase, oxygen and hydrogen are required to ensure activities of microbes. Once all easily degradable substances are consumed by the microbes, the pile’s temperature decreases to about 37^{o}C as well as concentration of oxygen. In this phase, mesophilic bacteria will recolonize the pile and it triggers the start of curing phase. The curing phase can take months to complete and it varies depending on the feedstock, composting method and management of the piles. Composting will end when the raw feedstock are no longer decomposed and are biologically and chemically stable.

Anaerobic digestion is recently applied in some waste treatment plants in Vietnam. In Vietnam, the AD process usually takes up to 40-45 days (11). Table 8 below lists some names of solid waste treatment plants that apply aerobic digestion technology in producing composts in Vietnam.

Table 8. Some composting plants in Vietnam (11)

Composting plants	Location	Equipment imported from	Capacity as in design (tonnes/day)
MSW treatment plant Nam Binh Duong	Binh Duong Province	Spain	420
SW treatment plant Cam Xuyen	Ha Tinh Province	Belgium	200
Waste treatment Trang Cat	Hai Phong City	Korea	200
SW treatment Nam Thanh	Ninh Thuan Province	Vietnam	200

4. Identifying challenges in MSW management in Vietnam

4.1 Treatment technology

Treatment technology is still limited in Vietnam as landfilling is still the main method of waste treatment. Besides, open dump sites still exist, especially in less developed areas such as the Highlands and Southern Coastal area. In those less developed areas, it is reported that industrial waste and domestic solid waste are buried in open dump sites. More severely, there are many open dump sites in the Highlands located in alleys and areas that are closed to a water body. This causes risks of water contamination in those areas because leakage from those dump sites will leak directly into the water body and especially into the underground water. Thus, this practice of waste treatment causes serious health problems for the locals living around the dump sites.

An example of the illegal burying of waste is Nicotex Thanh Thai company located in Thanh Hoa Province which illegally buried hundreds of tonnes of chemical waste directly into ground without any proper treatment. It was reported that as an impact of this illegal burying of untreated chemical wastes, a thousand locals living near to this factory were diagnosed with many different health problems including cancer, neurological disorders, and birth defects. Vietnamese have lately become obsessed about their living quality and health being threatened every day by the exposure to polluted water supply. One of the hottest topics recently in Vietnam is “cancer villages” where there are many residents in those villages diagnosed with cancers. In 2014, a report from the Water Resource Programming and Survey Center which works below MoNRE published a list of 37 cancer villages around the country. In the report, the main cause to this serious impact on residents' health was stated to be due to water pollution caused by improper and illegal waste dumping and burying, mainly from industrial waste dumping (15). In Figure 7 below, it can be observed that there is a large amount of solid waste dumped directly onto the river bank of Nhue River in Hanoi. This clearly polluted the river water seriously, and the local residents in Thong Nhat village, which locates close to Nhue River, use water collected from underground wells as their main water supply (16).

Figure 8. Solid waste is dumped directly into the river bank which runs along the Nhue River in Hanoi (11).

According to the report of National State of Environment in 2015, there are still misunderstanding and lack of knowledge in the society about the waste treatment technology. And sorting waste at source is still not a habit in the country, which causes more trouble for further higher treatment technology such as composting, biogas plant and also recycling. There is still a lack of managerial experience in choosing and designing locations for landfill sites, transfer stations, and collection methods. Moreover, there is a lack of proper practices in managing landfills such as compaction of waste before dumping, levelling of waste, final covering, and more importantly, and the lack of leachate collecting system, to prevent leachate from penetrating into the bottom ground. In addition, there is a lack of technology and proper equipment in monitoring and collecting gas emitted from landfills (11). Lately, residents living close to Da Phuoc landfill in Hochiminh city complained about bad odour coming from the landfill. This shows that considerable improvement in managerial skills of the authorities and city planners is still needed.

Besides, open burning and incinerator facilities which are still one of the most common way of managing domestic solid waste and hazardous medical waste releases a large amount of toxic particle such as furans and dioxins into the air. Until now, according to the environmental state report in 2015 (11), Vietnam still lacks of proper technology for analysing and controlling gas emissions from those incinerators.

4.2 Sorting at source and recycling

Sorting at source is not a habit in Vietnam. People are still mixing all their domestic solid waste into one large plastic bag waiting to be collected. This creates a burden in the step of recycling as waste needs to be separated further at the treatment plants. And this results in the increase of workers needed at the plants just to sort different types of waste for later purposes, for example, composting or incinerating.

Moreover, recycling is still mainly done by informal private sectors such as waste collectors, waste pickers, scavengers and some small-scaled recycling business. Also, recycling occurs in various locations, for example at the meeting point where domestic waste is waiting to be collected by waste collecting workers or even at the dump sites. The activities of scavengers picking recyclable waste directly on the dumping sites is very dangerous as their health is at high risk of being exposed to toxic substances and hazardous waste like hospital wastes. Those scavengers, while at work, have no knowledge about protecting themselves.

Recently the authorities in some large cities like Hanoi and Hochiminh city have promoted campaigns encouraging the locals to sort their household waste into different bins at the waiting point, and there are different time schedules for collecting different types of waste. However, this practice of sorting waste at source needs to be spread to other provinces and other cities as well.

5. Study case: Laws and Regulations of waste treatment technology in developed countries

5.1 EU directive in incineration

According to EU directive number 76/2000, article 6, it is required that any incineration plant needs to be designed, built, equipped, and operated in such a manner that ensures the exhausted gas after the last combustion air is injected will be raised to 850^{o}C.

This requirement is measured in the combustion chamber for 2 seconds. Otherwise, for hazardous waste that has more than 1% of halogenated organic materials, this temperature requirement is 1100ºC for at least 2 seconds. This measurement should be carried out near the inner wall of the combustion chamber. In any case that this requirement for exhausted gases' temperature fails, an auxiliary burner needs to be turn on to increase the temperature that the requirement is reached. Therefore, an auxiliary is required for any incineration plants. Furthermore, a way to enhance energy being used efficiently, any heat generated from this incineration process should be recovered. More importantly, infectious medical waste is required to be put into the furnace without being mixed with any other types of waste and should not be handled directly. Emission of exhausted gases as well as discharge of water that was used in cleaning exhausted gases is also required to meet the standard limit values. Those values can be found in the appendices I&II. Finally, as a step to prevent pollutants from the incinerators to enter surrounding environment, storage area is needed. Storage area is designed for holding contaminated rainwater run-off from the plants or for contaminated water which is a result of spillage accident or fire-fighting activities (17).

5.2 EU directive in landfilling

In EU directive number 31/1999, landfill is classified into three types according to its purpose. They are landfills for hazardous waste, non-hazardous waste, and inert waste. In annex I of this directive, there is a detailed description of requirement for landfills. Those are requirements about location, water control and leachate management, soil and water protection, landfill gases control, nuisances and hazards, stability and barriers.

As for requirement of location, distance from the landfill to any residential or recreational areas around it, as well as water bodies and agricultural, urban areas is taken into consideration. Also, risk of natural disasters such as flooding, landslides, geological and hydrogeological conditions are required to be studied as well as prior to the selection of landfill location. Leachate is a liquid that comes from landfill and can penetrate into the ground and thus, can contaminate the underground water bodies. As a prevention of that, proper measures for monitoring precipitations from landfill is a must for the operation of landfill. And contaminated water, leachate from landfill activities need to be collected and treated before being discharged into the nature. Barriers and bottom liners are required to prevent any harm to soil, surface and groundwater nearby. Standards for the permeability and thickness of a mineral layer which acts to prevent pollution from landfill are defined in annex I of this directive as is listed in Table 9.

Table 9. Requirement of mineral bottom layer for landfills (18)

Type of landfill	Permeability (m/s)	Thickness (m)
Hazardous waste	≤ 1.0×10^{-9}	≥ 5
Non-hazardous waste	≤ 1.0×10^{-9}	≥ 1
Inert waste	≤ 1.0×10^{-7}	≥ 1

In addition to that, leachate collection system and sealing of bottom are also required to make sure that there will be no pollution to soil, surface and underground water caused by the operation of landfill. Gas emitted from landfill is another challenge that needs to be controlled and monitored closely during site's operational phase. Mainly, landfill gases include methane, carbon dioxide, oxygen, hydrogen sulphide, hydrogen, etc. Therefore, in EU directives about landfill practices, proper measures to control landfill gas accumulation and emission are required. And that landfill gas is needed to be collected from the sites. Furthermore, collected landfill gases need to be treated and if it cannot be use as a source of energy, it is required to be burned. Further actions are required to reduce any hazards that can be caused by landfilling. These hazards are odours, dust, noise, traffic, traffic of any airborne animals, fires, etc.

In article 12, a program of controlling and monitoring of landfill's operation is described in detailed. That is, during the operation phase of landfills, the operator is required to conduct measurements to ensure the behaviour of landfill is not violating environmental protection. The results of these measurements are required to report back to the authorities at least once per year. These measurements include meteorological data (precipitation volume, temperature, wind's force and direction, evaporation rate and atmospheric humidity); emission data of water, leachate, and landfill gases; ground water's level and its composition; topography of landfill site that is data about landfill body (18).

5.3 Parameters in organic waste treatment

In controlling composting process, it is necessary to know when to the process has come to an end. And the parameters that let us know about this is maturity and stability. *Maturity* is the degree of humification which is the conversion of organic compounds to humic substances. Humic substances are most resistant to microbial breakdown.

Whereas, *stability* can be checked by measuring temperature at the center of the feedstock pile close to the ambient temperature, and oxygen consumption level inside air cavities in the piles remains about 10-15% for several days. At the end of composting process, depending on the purpose of the product as well as its origin, compost product can be sieved further to remove impurities.

In the other treatment of organic waste, anaerobic digestion, the parameters needed to control this process are organic loading rate, pH, temperature, hydraulic retention time (HRT), the carbon to nitrogen ratio (C:N ratio), and particle size. Firstly, organic loading rate is known as the mass of volatile solid (VS) per volume of the reactor and time (unit: kg VS/ m^3 day. Where volatile solid is the organic matter in the feedstock and is usually expressed as percentage of the total solid. A typical good daily loading rate with unstirred technique is less than 2 kg/m^3day, whereas for a stirred reactor is between 4-8 kg/m^3day. The ideal pH range for an anaerobic reactor is between 6.4-7.5 and this pH will slightly vary in different stage of the digestion process. If the pH in the reactor is higher than this range, there is a higher risk of acidification caused by acidogenic bacteria and it is usually because of a high OLR. Acidification results in the inhibition of methanogenic bacteria who is rather sensitive to acidic environment. To remedy this situation, the loading rate should be reduced or lime or sodium hydroxide can be added to increase pH value. Ideal temperature range required for the process can be in two zones, mesophilic or thermophilic zone. The mesophilic zone is 30-40^oC where the thermophilic zone is 45-60^oC. Mesophilic bacteria are more stable and consume less energy; however, it takes more time to degrade organic materials. Whereas, thermophilic bacteria will degrade organic substances more quickly, but they are more sensitive to temperature fluctuation. Hydraulic retention time or HRT is defined as the amount of time that the input materials need to stay in the reactor. It is calculated as the ratio of volume of the reactor divided by volume of daily input. Ideally, HRT should be between 10 to 40 days. Another parameter is C:N ratio. This ratio ideally should be between 16-25. A higher C:N ratio means that there is a limited supply of Nitrogen for bacteria and so this means there is less production of biogas. On the other hand, a lower ratio will cause accumulation of ammonia. And ammonia is an inhibitor of the AD process. The final parameter is particle size of the input materials which ideally should be smaller than 5 cm. A small particle size helps to increase the surface area of the materials and this will allow a faster degradation by microbes in the reactor (19).

6. Proposing action for the development of solid waste management in Vietnam

As mentioned above, there is still a lack of proper method in analysing and monitoring gas emissions from the incinerators in Vietnam. Therefore, there is an urgent need for the government to publish more guidance documents as well as legal documents in the implementation of such equipment and technology needed for controlling the amount of gas emissions from the practice of incinerating waste. Incinerator plants need more investment as well. Because incinerating is one of the good practices in managing ordinary and especially hazardous waste, it is needed to upgrade those small-scaled incinerators. This would help not only to increase the capacity of those facilities but also to reduce the burden of the huge waste volume ending up on landfills.

Furthermore, as a matter of fact that there is still existence of many unofficial, open and unhygienic dump sites, the government as well as local authorities need to promote the upgrading of those sites. Making those unofficial sites into sanitary and official dump sites that operate under close administration of local authorities is another solution for the illegal dumping, which impacts negatively on locals' heath and their living quality, as well as reduces environmental damage. Proper practices such as leachate prevention and landfill gas collectors are also needed to be applied as without these actions, the consequences have already been observed in the form of village cancers around landfill sites. It is necessary for the government to create legal frame according to which practices need to be applied in landfills in order to protect the surrounding environment and residents.

Composting has been becoming more and more popular in Vietnam lately. Thus, there is a need for more practices to stabilize the market of compost fertilizers. In order to make this come true, it is needed to raise public awareness of the good effect of composts on agriculture, and letting the public know that using the compost is one way of minimizing waste generation as the compost is a recycled product. Also, monitoring the quality as well as the quantity of compost production is important to stabilize the compost market and ensure its position on the market.

Last but not least, promoting sorting at source is very important. As already discussed above, the fact that sorting at source is not carried out at a proper rate in Vietnam increases the price of recycled products on the market as the company needs to pay more to the workers to sort the waste at the input step. Those models that have been tried in some part of large cities need to be implemented in other parts of the country. Public campaigns to raise the awareness of recycling and also education in schools for kids are some of the methods that help to change the Vietnamese' habit of separating waste at source.

7. Conclusion

Many aspects of solid waste management were mentioned in this paper. Vietnam has observed changes in the system of waste management since the first Environmental Protection Law was introduced and came into action. The rate of waste collection in large cities has increased remarkably. Together with that, the blooming economy and urbanization trends in the late 2000s have resulted in a significant increase of waste generated every year. However, positive progress in the waste treatment technology is a proof for hope of waste management in Vietnam as it is observed to have more investment from abroad with the help of finance, technology, and legal frames.

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APPENDICES

APPENDIX I – AIR EMISSION LIMIT VALUES FOR INCINERATION PRACTICES (Source: EU Directives 76/2000, Annex V)

(a) **Daily average values**

Total dust	10 mg/m³
Gaseous and vaporous organic substances, expressed as total organic carbon	10 mg/m³
Hydrogen chloride (HCl)	10 mg/m³
Hydrogen fluoride (HF)	1 mg/m³
Sulphur dioxide (SO_2)	50 mg/m³
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2) expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	200 mg/m³ (*)
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity of 6 tonnes per hour or less	400 mg/m³ (*)

(*) Until 1 January 2007 and without prejudice to relevant (Community) legislation the emission limit value for NO_x does not apply to plants only incinerating hazardous waste.

(b) **Half-hourly average values**

	(100 %) A	(97 %) B
Total dust	30 mg/m³	10 mg/m³
Gaseous and vaporous organic substances, expressed as total organic carbon	20 mg/m³	10 mg/m³
Hydrogen chloride (HCl)	60 mg/m³	10 mg/m³
Hydrogen fluoride (HF)	4 mg/m³	2 mg/m³
Sulphur dioxide (SO_2)	200 mg/m³	50 mg/m³
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as nitrogen dixoide for existing incineration plants with a nominal capacity exceeding 6 tonnes per hour or new incineration plants	400 mg/m³ (*)	200 mg/m³ (*)

(*) Until 1 January 2007 and without prejudice to relevant Community legislation the emission limit value for NO_x does not apply to plants only incinerating hazardous waste.

(c) **All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours**

Cadmium and its compounds, expressed as cadmium (Cd)	total 0,05 mg/m³	total 0,1 mg/m³ (*)
Thallium and its compounds, expressed as thallium (Tl)		
Mercury and its compounds, expressed as mercury (Hg)	0,05 mg/m³	0,1 mg/m³ (*)
Antimony and its compounds, expressed as antimony (Sb)	total 0,5 mg/m³	total 1 mg/m³ (*)
Arsenic and its compounds, expressed as arsenic (As)		
Lead and its compounds, expressed as lead (Pb)		
Chromium and its compounds, expressed as chromium (Cr)		
Cobalt and its compounds, expressed as cobalt (Co)		
Copper and its compounds, expressed as copper (Cu)		
Manganese and its compounds, expressed as manganese (Mn)		
Nickel and its compounds, expressed as nickel (Ni)		
Vanadium and its compounds, expressed as vanadium (V)		

(*) Until 1 January 2007 average values for existing plants for which the permit to operate has been granted before 31 December 1996, and which incinerate hazardous waste only.

(d) **Average values shall be measured over a sample period of a minimum of 6 hours and a maximum of 8 hours. The emission limit value refers to the total concentration of dioxins and furans calculated using the concept of toxic equivalence in accordance with Annex I.**

Dioxins and furans	0,1 ng/m³

(e) **The following emission limit values of carbon monoxide (CO) concentrations shall not be exceeded in the combustion gases (excluding the start-up and shut-down phase):**

— 50 milligrams/m³ of combustion gas determined as daily average value;
— 150 milligrams/m³ of combustion gas of at least 95 % of all measurements determined as 10-minute average values or 100 mg/m³ of combustion gas of all measurements determined as half-hourly average values taken in any 24-hour period.

Exemptions may be authorised by the competent authority for incineration plants using fluidised bed technology, provided that the permit foresees an emission limit value for carbon monoxide (CO) of not more than 100 mg/m³ as an hourly average value.

APPENDIX 2 – Emission limit for discharges of water from the cleaning of exhaust gases (Source: EU Directives 76/2000, Annex IV)

Polluting substances	Emission limit values expressed in mass concentrations for unfiltered samples	
1. Total suspended solids as defined by Directive 91/271/EEC	95 % / 30 mg/l	100 % / 45 mg/l
2. Mercury and its compounds, expressed as mercury (Hg)	0,03 mg/l	
3. Cadmium and its compounds, expressed as cadmium (Cd)	0,05 mg/l	
4. Thallium and its compounds, expressed as thallium (Tl)	0,05 mg/l	
5. Arsenic and its compounds, expressed as arsenic (As)	0,15 mg/l	
6. Lead and its compounds, expressed as lead (Pb)	0,2 mg/l	
7. Chromium and its compounds, expressed as chromium (Cr)	0,5 mg/l	
8. Copper and its compounds, expressed as copper (Cu)	0,5 mg/l	
9. Nickel and its compounds, expressed as nickel (Ni)	0,5 mg/l	
10. Zinc and its compounds, expressed as zinc (Zn)	1,5 mg/l	
11. Dioxins and furans, defined as the sum of the individual dioxins and furans evaluated in accordance with Annex I	0,3 mg/l	