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# EVALUATION OF MUNICIPAL WASTE MANAGEMENT OPTIONS BY CIRCULAR PREVENTION TOOLS TO GIVE BETTER WAYS FOR SUSTAINABLE TRANSITIONS – A CASE STUDY OF HANOI

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## Abstract

The transition management approach can help to improve municipal solid waste management in individual cities and city regions. The obsolete technological solutions of waste management cannot support efficient and sustainable urban waste management processes. We would like to present a possible solution to development of the municipal solid waste management system in a high population density megapolis, Hanoi (Vietnam). We examined the development opportunities at three strategic levels (governmental, enterprise and personal levels). We have analyzed the system at strategic, tactical, operational and reflexive levels also, using a transition matrix. Five development aspects and technological directions have been identified, and all of them could be applied at the three decision levels. We came to the conclusion that intervention is needed at all three levels. Based on our results, we have made proposals for the transformation of Hanoi solid waste management structure in the overall organizational structure.

## Keywords

City waste management; circular evaluation, transition management; economy of waste prevention

## 1. Introduction

The purpose of this communication paper is to transform the municipal solid waste management system of Hanoi, Vietnam, with transition management. The novelty of the research is that it examines the transformation possibilities simultaneously at all three decision levels and reviews the development directions in a complex system. It puts forward proposals for transformation at both the technological and the residential (personal) level in order to develop a sustainable and efficient municipal waste management system.

This paper aims to examine the current status of solid waste management systems in Hanoi and to study the criteria system in evaluating and selecting solid waste treatment technologies which are being applied in the developed countries. On that basis, the author will apply these criteria in the specific conditions of Hanoi-the capital of Vietnam to give some recommendations in selecting suitable technologies to the local context. We would like to give a suggestion of circular transition of waste management system by selecting the circular blocks which could be help to transform the system more effectively. We determined the transformable blocks and each developing points of the system. Finally, we would like to give a technological and economical suggestion of municipal solid waste management system transformation and application to Hanoi, Vietnam.

Transition management objectives and strategic levels

The transition management and thinking are structure-based processes. Progress considering and the board generally help the depiction and improvement of practical and persuasive objectives and stories. Long term objectives are matched with momentary employable activities experiencing significant change considering, and executing nearby and worldwide procedures and their associations into the condition winds up conceivable with this methodology. Besides, it offers rules and guidance on collecting either auxiliary structures, or collaboration programs, which can demonstrate productive in achieving territorial or national objectives set as far as supportability (Wittmayer et al., 2016). These objectives are basically either plainly mechanical advancements, green developments, or atmosphere neighborly framework improvement ventures. Thusly, the motor of progress forms is comprised of development programs, however in these cases, change thinking additionally requires another, framework level translation (Kemp et al., 2007). Key advancement speculations have changed essentially in the course of the most recent couple of years, but sadly, the development approaches we as of now use are primarily reliant on the customarily acknowledged development hypothesis - the direct advancement show. In the straight model, the procedure of development creates the final product of another item or procedure, which is essentially an examination result, or a result of the new innovative arrangement. The fundamental direct successive systems (Brooks, 1995) of the advancement procedure are kept up by the improvement of new innovation. The transition management assumes that these exercises should offer explicit characteristics as far as what on-screen characters are sharing simultaneously, what forms they are interlinked with, and what sort of item or on the other hand administration they create, which can make the plan of explicit framework apparatuses and process methodologies conceivable. For instance, we could make reference to evolving partakers (assigning an objective gathering), characterizing the test in the particular progress process, the sort of procedures required for progress, or the utilization of procedure guideline apparatuses (Wittmayer et al., 2016).

Figure 1. presents the main objective levels of transitional thinking and development. On the upper level (Governmental decision level) placed the overall strategic possibilities, because the law background and direct / indirect forms of organizations could control the whole municipal waste management system. The second (and middle) level based on the small and medium enterprises. These companies could organize the technological parts of waste management. They could collect the municipal waste amount by new technical solutions and prepare waste materials to further application or other utilization. The individual level is the most important. Although the two other upper level could control the whole system, the personal thinking is the basis of the total management process. The transition management should focus on the change of personal thinking and attitude. The households could give more effort to the municipal waste management success, because they could collect each type of waste materials separately. Also an important question the acceptance of technological development by individual side.

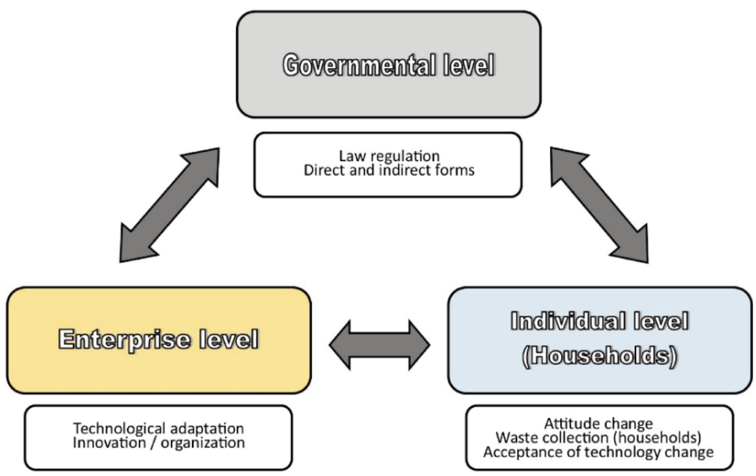


Figure 1. The main levels of transition thinking (Authors' own construction and edition)

The following table (Table 1) presents the levels of circularity and sustainability from value 1 to value 5. The KPI – Key Performance Indicators (which is presented by Table 1) define key system performance metrics based on a sustainable Business Model Canvas results, with five-grade scale. The five-level KPI values are based on expert judgement, it is construed as an objective indicator system. The expert compilation strives to find the most important indicators of the conditions for mitigating environmental externalities. Based on the KPI structure, the transition management should focus on the circular concept also. The higher circulating level of a municipal waste management system results more effective and sustainable overall operation. Therefore the information of Table 1 presents the values and properties of circularity, which should be combined with the sustainability and economic structures. By establishing circular levels, it is possible to transform the system towards the highest

Table 1. The method for transition structure improvement of municipal waste management system with Key Performance Indicators – KPI's (Authors' own edition)level of circularity.

| Values | Circular level | Properties of economic structure |
|---|---|---|
| 1 | Lowest circularity | Disposal of waste |
| 2 | Low circularity | Recovery |
| 3 | Medium circularity | Reusing, recycling |
| 4 | High circularity | Upcycling, down cycling |
| 5 | Highest circularity | Prevention or zero waste (Refuse and reduce) |

**Structural properties of municipal waste management in developing countries**

The solid waste management system is one of the main important system in urban development processes. Municipal solid waste treatment technologies could be transform by many kind of special urban properties. The current status of solid waste management system in Hanoi could not be utilize efficiently, because the system could not follow the changes of population and type of each municipal solid wastes. The habitat of people and the technological process of waste management causes problems, which should be solve by transition of management system.

Solid waste management is also one of the public management aspects that play an essential role in grasping opportunities and minimizing urban and rural difficulties against the negative aspects of increasing urbanization. This is a universal issue affecting every single person in the world. Poorly managed waste has been contaminating the world's oceans, clogging drains and causing the flood, transmitting diseases via breeding of vectors, increasing respiratory issues throughout airborne particles by burning of waste, harming creatures that consume waste unknowingly, and affecting economic development like through reduced tourism [1, 2]. The amount of waste generated is increasing day by day, accounting for a large part of the local budget as well as the government's work in treatment and significantly affects public health. Waste management will function as the sole highest funding thing for all administrations in low-income countries, in which it contains almost 20 percent of municipal budgets, on average. In those countries with middle-income, solid waste management typically accounts for at least 10 percent of municipal funds, while it accounts for roughly 4 percent in high-income nations [1]. The cost of waste management will increase 3-4 times in developing countries from about 20 billion US$ in 2010 to approximately 80 billion US$ in 2025. The rate of cost increase is higher in lower developed countries [3].

Developing countries often have inadequate waste management systems due to lack of financial resources, weak awareness, inefficient management systems, and sometimes improper technology solution applications [4]. Poor collection and disposal of urban solid waste lead deterioration of environmental aesthetics, local flooding, land, air, and water pollution [3, 5]. The consequence of these problems leads to human health hazards, which can only be minimized by implementing cost-effective technical and policy measures [6]. Many technologies have been introduced to overcome the severe consequences of poor waste management and human health risks. According to the hierarchy of waste management (WM), landfilling is the most used and worldwide spread method of municipal solid waste (MSW) disposal [7-11]. Landfills are a potential source of contamination as well as toxic substances, which can find their way into the natural environmental (soil and groundwater) by air (dispersed compounds) as well as by runoff [8, 12-15]. The MSW landfill area also releases the odors consisting of a complex mixture of organic compounds, hydrogen sulfide (H2S) and ammonia (NH3) which are the source of annoyance to nearby urban populations [16, 17]. It is demonstrated that the impact of the landfill goes outside of the sanitary security zone, so which may result in the corrosion of the caliber of drinking water, atmospheric air, sanitary and hygienic condition of agricultural lands on adjacent rural regions [18]. Mechanical-biological Treatment (MBT) for unsorted organic waste is one of the best technologies for the decomposition of organic components from the landfilling site can be done faster [19]. Composting is a method of waste recycling based on the biological degradation of organic matter under aerobic conditions, producing stabilized and sanitized compost products [20]. The composting technologies can constitute a viable alternative for the management of the organic fraction of MSW in developing countries, due to its simplicity, quick, and easy implementation [21]. Of all the recycling methods, composting is recommended due to its environmental and economic benefits [20]. It has many environmental benefits, such as reducing greenhouse gas emissions [22], decreasing leachate quantities once discarded in landfills [23], and improving soil quality when used as a soil amendment [20]. However, when improperly managed and performed, composting may cause various environmental issues including the formation of malodorous or toxic gases [24], bioaerosols [25], and dust [26], resulting in occupational health risks or disturbance to nearby residents [27]. Besides these traditional technologies, waste-to-energy technologies (WTE-T) are promising technologies, especially for developing countries, to turn waste into a useable form of energy [28]. It will play a vital role in sustainable waste management and mitigation of environmental issues [29, 30]. These technologies are generally classified as biological treatment technologies (or Biochemical process like anaerobic digestion technologies [31-36]) and thermal treatment technologies (or Thermochemical process such as pyrolysis [28, 34, 37], gasification [28, 38-42] and incineration [28, 34, 43-45] technologies). Solid waste management is a complex and multi-dimensional issue [46]. Management of MSW deals with many factors such as policy and legal framework, institutional arrangement, appropriate technology, operations management, financial management, public participation and awareness, the action plan for improvement [47, 48]. The key to successful development is the design of waste management systems adapted to local needs and traditions, rather than the selection and transfer of a single procedure or technology from one country or region to another [49].

Each country will decide to choose their strategy for sustainable municipal solid waste management system based on the specific conditions. Of all tools which are applied, life cycle assessment (LCA) by evaluating the environmental performance of municipal solid waste management system will help the decision-maker in selecting the best management strategy with minimum impacts on the environment [50]. From a life-cycle point of view, a comprehensive MSW management system includes all essential operational units from the collection, to shipping, to treatment, to recycling, and disposal. For instance, the landfill directive promoted biodegradable municipal waste (BMW) management systems is applied in Austria, Netherlands; economic instruments including Pay-As-You-Throw (PAYT) and an organic waste tax are applied in some of the EU member states; both BMW system and Landfill Allowance Trading System (LATS) in the United Kingdom (UK); Green Dot system in Germany [51, 52]. In Asian countries, the municipal waste management systems are being oriented to concentrate on sustainability issues; mainly through the incorporation of 3R (reduce, reuse and recycle) technologies [47]. The solutions for these countries are social and technical approaches with social approaches are changing the public behavior by improving the community through training, and encouraging partnerships with decentralized SWM, and the technical approaches are reducing biodegradable SW at the source, converting waste to energy, and using simple technology [53].

The selection and application of such technology depend upon different factors including the country's economic condition, priorities, and types of waste generated [54]. It also is one of the critical considerations for the success of a waste management system for a particular town/city. The technologies to be adopted for MSW management and processing predominantly depend upon MSW quantity, quality, and range of variations [55]. However, the efficiency of a particular technology depends on the criteria for which it is designed and planned. A wrong choice of waste processing technology can cause failure of the entire waste management system leading to lousy economics and environmental cost. There is much research conducted in the technologies applied to process municipal solid waste. However, there is a lack of attention in the study on how to define the criteria for choosing the suitable municipal solid waste technologies in developing countries with the constraints of financial, institutional, technical, and decision-making support system.

Hanoi is a special city and is a center of politics, economy, culture, education, training, science and technology of Vietnam. With the number of people around 8 million [56], the volume of generated municipal solid waste has increased rapidly these years. Until now, there has been limited progress of 3R goals with only two of nine goals have achieved some progress while the other related goals are still far from the desired targets [57].

At present, the municipal solid waste management system in Hanoi is not effective because of the lack of the appropriate financial, technical and human resources, the lack of technical infrastructure for recycling, collection, and transportation [58]. Solid waste transfer and disposal and source separation are not yet implemented throughout the city. Therefore, building a sustainable solid waste management system which is suitable for the local conditions is very important and urgent.

## 2. Materials and Methods

### Transition management of current system

The transition management and circular transformation methods were applicate to solve the technological problem of Hanoi municipal waste management system. We determined the transformable points of current management system and give the possible solution of efficient transformation. Table 1 presents the transformation blocks and parts of management changes.

We accepted the aftereffects of Loorbach (2010), which describe four sorts of separated administration exercises in a societal setting according to the conduct of the performing artists involved. This can lay out whether a brought together mediation identifying with the disguise of externalities is required, or the backhanded main thrusts of market systems can prompt an increasingly reasonable working of waste management.

With these outcomes the supportability estimation of every one of the elements (key, strategic, operational and reflexive) and every one of the structure squares (offer, cost structure and income streams) were appropriately decided. The outcomes picked up demonstrated the overwhelming component and the legislative administration field where cognizant intercession is needed to quicken the disguise of externalities by waste management and process, so as to achieve the most cost-productive and best social transitions towards the supportable execution of bond firms, and from which the most influenced members of this progress can likewise be specified. To translate our outcomes, illustrative web charts were utilized in all the four instances of on-screen characters' conduct.

We would like to present a technological improvement with transitional management to get the maximum circularity and totally waste recyclable system as possible. Value 1 means the linear structure without any circular options. Value 5 means the totally circular system. Our aim could be the medium version, the mostly circular system because the current technological background with linear conditions could not give answers to municipal waste management questions in focus of sustainability and economic effectivity. With these outcomes the maintainability estimation of every variables (strategic, tactical operational and reflexive) and every one of the structure squares (value proposition, cost structure and revenue streams) were legitimately decided. The following figure (Figure 2) presents the transitional matrix with planned changes of current municipal waste management system. This transitional matrix shows the complex structure of circular transition management thinking of solid waste management improvement of Hanoi, Vietnam.

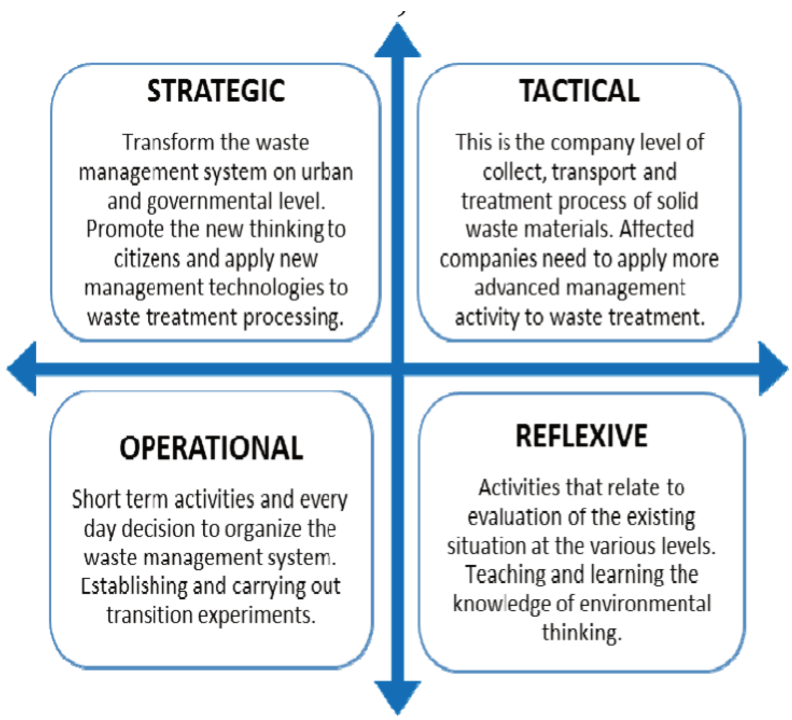


Figure 2. The transitional matrix of municipal solid waste management on each levels
(Based on Osterwalder, 2004; with Authors' own modification)

### Choosing improvement directions of technological background

To be able to select appropriate criteria and technologies, it is essential to have data on the current situation of the local solid waste management. Background data comprise sources of generation, quantity, and composition of solid waste, the current status of treatment technology, financial resources, stakeholder participation, institution framework, and policies/regulations. From these primary data, it is possible to identify the challenges and opportunities of solid waste management systems and from which all solutions can be identified. Solutions implemented for solid waste management include management plans and technological options. Management options include 3Rs (reduce, reuse, and recycling), public-private partnerships, awareness raising, education and training, and economic tools. With the change in the pattern of resource consumption and economic development, this becomes very important for the reduction and reuse of resources. Besides, waste can be converted to other types of resources such as compost, biogas, and energy. The conversion of waste into other energy sources will reduce the amount of solid waste to be disposed into the landfill, which should be the least preferred option in waste management.

Although many solutions have been applied in solid waste management, not all of them may be feasible for adoption. Thus, it is essential to evaluate the appropriateness of each solution based on the set of criteria and local conditions as presented in Table 2. Criteria used for SWM are versatile and dynamic according to situations and circumstances of solid waste in each city. This study applies twelve fundamental management criteria for five operation and utilization techniques. The twelve criteria are technology development, types of solid waste, operating scale, success factors, final products, capital investment, operating cost, land requirement, needed operating skills, possible adverse impacts, and contribution to energy and food security. The five extended SWM operation and utilization techniques include composting, anaerobic digestion, mechanical-biological treatment, landfill, incineration, refuse-derived fuel (RDF) or solid recovered fuel (SRF), pyrolysis, and gasification. After conducting the assessment of the appropriateness of technology, the decision-making process of appropriate solutions is implemented.

### Analyzing the possible points of system improvement

The current technology options have been evaluated based on KPI values. Each technology solution has a value of between 1 and 5, making it clear which option seems to be the best solution for circularity. Adaptation of each technological solution is definitely necessary at the three decision levels examined (government, enterprise and individual / households levels also). The transition management assessment of the applied waste management methods was carried out with reference to the blocks described in the transition matrix

Table 2. The impact and influence of criteria on methods of SWM operation and utilization [19]; with Authors own modifications

| Number of criteria | Part of each segments of transition analyses | Criteria | Composting | Anaerobe digestion | Sanitary landfill | Pyrolysis | Gasification |
|---|---|---|---|---|---|---|---|
| C1 | VP | Solid waste characteristics | 4 | 4 | 4 | 3 | 2 |
| C2 | VP | Waste quantity | 5 | 4 | 3 | 3 | 3 |
| C3 | RS | Compliance with laws | 4 | 3 | 4 | 3 | 2 |
| C4 | RS | Multisector involvement | 4 | 3 | 3 | 2 | 3 |
| C5 | RS | Public acceptability | 4 | 3 | 4 | 3 | 3 |
| C6 | VP | Possible adverse impacts (environment, society, economy) | 5 | 4 | 4 | 4 | 2 |
| C7 | VP | Demand for final products | 4 | 4 | 3 | 4 | 3 |
| C8 | CS | Initial investment | 4 | 3 | 3 | 4 | 3 |
| C9 | CS | Operating cost | 5 | 3 | 3 | 3 | 3 |
| C10 | RS | Time-consuming for the entire process | 4 | 4 | 3 | 4 | 4 |
| C11 | CS | Complexity and required amount of raw materials | 3 | 3 | 3 | 4 | 3 |
| C12 | CS | Wages in each parts of technologies | 4 | 3 | 4 | 3 | 3 |

Notes: Prevention Values of each criteria's: from 1 – linear structure; to 5- fully circularity, based on Table 1. - Values of each circular levels. Abbreviations: VP – Value proposition; RS - Revenue streams; CS – Cost structure

## 3. Results and Discussions

### Systematic approaches of waste management criteria's

Eleven criteria and five technical alternatives [19] to manage solid waste are presented in Table 2. This table describes an overview of solid waste treatment methods, which has been applied in cities worldwide and presents how each criterion relates to each solid waste disposal plan in general. However, to select suitable criteria for each locality, it is necessary to quantify by the score for the criteria. Table 2. is used as support tools for state management agencies in making appropriate decisions on the selection of solid waste treatment options to identify possible (potential) solid waste treatment options for each city or community. These techniques are paired with different criteria that can be used as a benchmark for a solid waste treatment technique. The level of impact is assessed by the score, scale of each criterion range from 1 to 5; on which level of circularity is fit for each methods. Each criterion is attributed to a value based on its score and presented in the table. From the total score of each plan, the local government or waste management units can quickly determine the technical method of treating solid waste by local conditions. Therefore, to ensure the effectiveness and feasibility of a solid waste management system, responsible state management agencies and stakeholders need to coordinate and consider all factors before deciding on the criteria and technical plans for solid waste treatment and score (scale). Table 2 presents the basic guidelines for the selection of suitable solid waste treatment options.

### Results of transition management approach

To accomplish the most elevated usage of municipal waste management, center focuses were controlled by benchmarking of which primary outcomes are appeared at this. Table 3 shows the overview of each circular blocks of transitional management with values of circularity. With these results we could analyze the systematic improvement directions of total waste management process. The table shows that improvements are needed in all three respects (value proposition, cost structure and revenue streams) because the current system does not show partly or fully circularity.

Table 3. Results of system analyze to improvement (Authors' own edition)

| | **Strategic** | **Tactical** | **Operational** | **Reflexive** |
|---|---|---|---|---|
| Value proposition | 3.6 (C2) | 3.8 (C6) | 3.4 (C1) | 3.6 (C7) |
| Cost structure | 3.2 (C3) | 3.8 (C10) | 3.0 (C4) | 3.4 (C5) |
| Revenue streams | 3.4 (C8) | 3.2 (C11) | 3.4 (C9) | 3.4 (C12) |
| **Average of each transition level** | 3.4 | 3.6 | 3.2 | 3.4 |
| ***Average of each of the evaluated blocks*** | | | | |
| Value proposition | 3.6 | | | |
| Cost structure | 3.3 | | | |
| Revenue streams | 3.3 | | | |

Notes: Value 1.0 means the total linear structure, value 5.0 means total circular version. Each columns contains the median value of each transition levels. The abbreviations of each blocks marked from C1 to C12 (according to Table 2 abbreviations)

Table 3 shows the average values of each evaluated blocks also. The highest value shown by the Value proposition. This means focusing on value creation during transition management, as it is possible to achieve quality change in this area. Technological innovation is not necessary for this, only efficiency has to be increased. Value proposition can be achieved by transforming corporate efficiency with centralized management.

***Value proposition:***

The transition thinking (about solid waste management) on four levels means the new value production with structural development. The current waste management system could not treat the whole amount of municipal waste and the rest could not manage with circular loop. The value proposition means a sustainable thinking also and this new idea causes more improvement necessary in waste management system. On strategic level the improvement means a new observe system from waste production until collection and final reuse and recycle. The current value proposition is linear structured system and could not works sustainable and circularly.

***Cost structure:***

The cost structure of the current waste management system could not support the total sustainable and circular development, because works with non-efficiency methods. The low percent of recycled rests of total waste amount and the percent of reusable first raw materials needs a new cost structure. The governmental decisions means a maximum medium circular and sustainable efficiency. The costs of eco-friendly working system and production of reusable and recyclable materials have to be considered, and the costs of education and training of human thinking and habit also. Communication between each segments of new business model, e.g. key partners and costumer segments are also important because their behavior and reactions are also increase the total costs of the system.

***Revenue streams:***

The decision segments of the system should to find a new solutions and opportunities even at the technological level to earn new revenue streams by circular transformation in operational field. This importance also presented by the observed literature and also focuses on their strategic facts. The sales revenue and cash flow also increase in long-term run with awareness of public and firm thinking. In the beginning it can causes monetary and indirect revenue streams.

Development strategies – Suggestion of each tecnological applications

The objective of assessing the appropriateness of solid waste treatment technology is to select the technologies that can be applied in the conditions of Hanoi. This assessment is based on the criteria system, which is used as the tools for the authorities to decide which technology should be adopted appropriately. The selection of criteria will depend on many factors such as natural environment, economy, technology, technology, and society. In Vietnam, the choice of technology also considers the national strategy for integrated solid waste management. In case of Hanoi city, five of the eight solid waste treatment technologies are selected such as (1) Compost; (2) Anaerobic digestion; (3) Sanitary landfill (with biogas collection system) or biological landfill; (4) Incineration (Incinerator); (5) fuel production from waste (RDF) or (SRF). The selection of these five technologies are based on their wide application in many countries around the world as well as in Hanoi. Three remaining technologies (MBT, pyrolysis, and gasification) are not compatible with Hanoi's economic, technical and human resource conditions. Although pyrolysis and gasification are advanced technologies, they are difficult and expensive to operate, while the MBT technology does not give the ultimate treatment solution for treated waste. Five technologies were compared based on 11 criteria as mentioned in Table 4, in which the multi-sector involvement criterion was rejected because it was considered the least important one in the Hanoi's condition. The calculation was performed using scoring system of 1 to 5 scores (5 = most favorable, 4 = favorable, 3 = Medium, 2= less favorable 1 = unfavorable). The point for each criterion is based on the consultation with experts, performance, on-site survey, and results of environmental monitoring. The total final score for each technology can be used as a "Sustainability Index" of technology. If technology has a high score, sustainability is high and vice versa. Based on the current status of solid waste management in Hanoi City, two scenarios assessing the suitability of solid waste treatment technology are given. Results of assessing the appropriateness of solid waste treatment technology presented in Table 4 (Scenario 1) with commingled waste and Table 5 (Scenario 2) with segregated waste.

As shown in Table 4, the total scores of five technologies assessed are not much different. For commingled waste, the technology's sustainability index shows the sanitary landfill with collection of biogas (37 points) as the most suitable technology, followed by incinerator with energy collection (36 points), composting (35 points), RDF or SRF (34 points), and anaerobic digestion (32 points), respectively.

The composition of commingled solid waste in Hanoi also contains a certain amount of household hazardous wastes (HHW) and many non-recycling components. Also, the composition of solid waste amount of Hanoi has a high biodegradable organic fraction (64.8-74.3% of wet weight) and high moisture (55-65%) so that sanitary landfill (with the collection of biogas) is a sustainable technology for solid waste management in Hanoi at present. Amount of non-recycling fraction (about 25% including plastic, diaper, textile, rubber & leather, styrofoam, wood) with high calorific value has increased significantly, and the biodegradable organic fraction has decreased from 2009 to 2015. Due to the lack of available land, incineration technology was ranked second with the possibility of energy recovery. However, the high moisture content of the solid waste and the highest investment and operation costs may limit the utilization of this technology.

The composting technology is ranked the third because the waste is commingled and therefore the separation step has to be carried out before the waste is composted and this step is labor intensive. At present, the quantity of solid waste at two composting plants takes at 35-64%, and the remaining non-compostable (taking 36-65%) are buried at a sanitary landfill or burned by the incinerator. Also, the quality of compost using commingled waste is low because the end product is mixed with scrap glass and plastics making it difficult to consume. The RDF technology ranked fourth. The anaerobic digestion technology has the lowest score due to uncertainties regarding investment and operation costs, low energy prices, damaged reputation due to unsuccessful plants as well as this technology need source-sorted organic. These results are consistent with the set targets for the management of solid waste in Hanoi as according to National strategies on integrated management of solid waste.

Table 4. Assessment of sustainability of treatment technologies for commingled waste (Scenario 1) (Authors' own research and edition)

| **Criteria** | | **Compost production** | **Anaerobic digestion** | **Sanitary landfill with the collection of biogas** | **Incinerator with energy collection** | **RDF or SRF** |
|---|---|---|---|---|---|---|
| Solid waste characteristics | *Separated solid waste at source* | - | - | - | - | - |
| | *Commingled waste* | 2 | 2 | 5 | 3 | 3 |
| Waste quantity | | 3 | 1 | 3 | 3 | 1 |
| Compliance with standard/regulation of National Technology of Vietnam | | 5 | 5 | 5 | 5 | 5 |
| Time-consuming for entire process | | 2 | 3 | 5 | 5 | 3 |
| Complexity and required skills | | 5 | 3 | 4 | 2 | 3 |
| Demand for final products | | 2 | 2 | 2 | 2 | 2 |
| Initial investment | | 4 | 2 | 3 | 1 | 2 |
| Operating cost | | 2 | 2 | 5 | 1 | 2 |
| Land requirement: Large scale | | 2 | 3 | 1 | 4 | 3 |
| Possible adverse impacts | *Odor* | 2 | 2 | 1 | 2 | 2 |
| | *Municipal and industrial wastewater* | 2 | 2 | 1 | 4 | 3 |
| | *Dust and air pollution* | 2 | 3 | 1 | 2 | 3 |
| Public acceptability | | 2 | 2 | 1 | 2 | 2 |
| **Total scores** | | **35** | **32** | **37** | **36** | **34** |

Evaluation: Scoring system: 5 = most favorable, 4 = favorable, 3 = Medium, 2= less favorable 1 = unfavorable.

Table 5. Assessment of sustainability of treatment technologies for separated solid waste (Scenario 2) (Authors' own research and edition)

| **Criteria** | | **Compost production** | **Anaerobic digestion** | **Sanitary landfill with the collection of biogas** | **Incinerator with energy collection** | **RDF or SRF** |
|---|---|---|---|---|---|---|
| Solid waste characteristics | *Separated solid waste at source* | 5 | 5 | 5 | 5 | 5 |
| | *Commingled waste* | - | - | - | - | - |
| Waste quantity | | 5 | 5 | 5 | 4 | 4 |
| Compliance with standard/regulation of National Technology of Vietnam | | 5 | 5 | 5 | 5 | 4 |
| Time-consuming for entire process | | 2 | 3 | 1 | 5 | 4 |
| Complexity and required skills | | 5 | 3 | 4 | 2 | 3 |
| Demand for final products | | 4 | 4 | 1 | 4 | 3 |
| Initial investment | | 5 | 3 | 4 | 2 | 3 |
| Operating cost | | 5 | 3 | 4 | 2 | 3 |
| Land requirement: Large scale | | 2 | 3 | 1 | 4 | 3 |
| Possible adverse impacts | *Odor* | 2 | 2 | 1 | 2 | 2 |
| | *Municipal and industrial wastewater* | 2 | 2 | 1 | 4 | 3 |
| | *Dust and air pollution* | 2 | 4 | 1 | 2 | 3 |
| Public acceptability | | 2 | 3 | 1 | 3 | 3 |
| **Total scores** | | **46** | **45** | **34** | **44** | **43** |

Scoring system: 5 = most favorable, 4 = favorable, 3 = Medium, 2= less favorable 1 = unfavorable.

Table 5 shows that total scores of all technologies in scenario 2 is higher than scenario 1 because solid waste is separated at the source to form clean, biodegradable organic, recyclable, and the remaining fraction. The assessment of treatment technologies for separated solid waste shows that the composting technology (46 points) is the most applicable, followed by anaerobic digestion (45 points), incinerator with energy collection (44 points), RDF or SRF (43 points), and bioreactor landfill or sanitary landfill (34 points), respectively.

The potential demand for organic fertilizers and soil conditioners in the surroundings of Hanoi is very high and exceeds the actual supply. With source separated clean, biodegradable organic fraction, the composting technology is the most suitable because of its simplicity, low cost, and high demand for composting products. The anaerobic digestion can produce green energy and soil conditioner from biodegradable organic fraction, and it is ranked the second after composting technology because of its higher complexity and cost compared to the composting technology. The bioreactor landfill or sanitary landfill with the collection of biogas require a large amount of land, generate leachate and emit an odor, and thus it has the lowest score. Components of remaining solid waste after separation (plastic, diaper, textile, rubber, leather, etc.) with high calorific value can be incinerated with energy collection and thus obtains higher score compared to RDF technology.

***Development goals by transition of each organizing levels (based on the scenarios)***

By assessing the sustainability of solid waste treatment technologies from two scenarios, Scenario 2 have specific advantages such as low operation, high quality of composting product, more efficient land use, lower environmental impacts and higher production of biogas, energy collection in comparison with the Scenario 1 so that scenario 2 will be selected for integrated solid waste management in Hanoi. These results are consistent with the situation of solid waste and the set targets for the management of solid waste in Hanoi. Also, it is clear that one technology would hardly achieve efficiency of solid waste management in Hanoi. The need for a combination of multiple technologies yields an integrated solid waste management system leading to zero waste for sustainable resource utilization in Hanoi. Ideally, the composting technology followed anaerobic digestion technologies is found to be the most sustainable for solid waste in the Hanoi. Incineration with energy collection is essential only for non-recycling solid waste (with high calorific value), and residual solid waste will always be needed for landfills. By separating solid waste at sources (application of Scenario 2), the City will be able to:

– Utilize 70 to 80% of the city's solid waste, among which about 60-70% can be used for producing compost and anaerobic digestion for generating energy. Remaining 10-20% can undergo recycling.
– The decrease in pollution caused by odor and leachate from landfills.
– Raise people's awareness of environmental protection.

To achieve zero waste management, the results of the two exampled scenarios show that waste separation at source is an essential factor that prevents waste from entering landfills. Implementing waste separation allows the collection of a great amount of recyclable waste that can be converted into useful materials. Besides, unmixed waste helps waste collectors save time during collection process substantially, and save cost for Hanoi’s waste management. The segregation of the waste is must for sustainable solid waste management, as the waste can be intercepted for recovery of materials and composting, anaerobic digestion, incineration and the minimal amount go to the sanitary landfill.

## Conclusions

This study investigated the current situation of solid waste management in Hanoi from the collection, transportation, and processing. The rapid urbanization and industrialization in Vietnam caused the increase of waste generation and the variety of composition. Also, inappropriate waste management system in Vietnam has led to various environmental and health issues. To assess and select the appropriateness of solid waste treatment technology that can be applied in the conditions of Hanoi, this research applied benchmarking model with five of the eight solid waste treatment technologies which are widely used in many countries around the world such as (1) Compost; (2) Anaerobic digestion; (3) Sanitary landfill (with biogas collection system) or biological landfill; (4) Incineration (Incinerator); (5) fuel production from waste (RDF) or (SRF) and 11 criteria including (1) Solid waste characteristics; (2) Waste quantity; (3) Compliance with standard/regulation of National Technology of Vietnam; (4) Time-consuming for entire process; (5) Complexity and required skills; (6) Demand for final products; (7) Initial investment; (8) Operating cost; 9) Land requirement; (10)Possible adverse impacts, and (11) Public acceptability. Based on categorizing two scenarios of characteristics of waste such as mixed and separated, this paper resulted that the scenario 1 (commingled waste) has the technology's sustainability index with the sanitary landfill with collection of biogas (37 points) as the most suitable technology, followed by incinerator with energy collection (36 points), composting (35 points), RDF or SRF (34 points), and anaerobic digestion (32 points), respectively. The case for the scenario 2 (separated waste) shows that the composting technology (46 points) is the most applicable, followed by anaerobic digestion (45 points), incinerator with energy collection (44 points), RDF or SRF (43 points), and bioreactor landfill or sanitary landfill (34 points), respectively. It is clear that Hanoi needs to combine multiple technologies yields an integrated solid waste management system leading to zero waste for sustainable resource utilization. The composting technology followed anaerobic digestion technologies and incineration with energy collection are found to be the most sustainable for solid waste in the Hanoi in the condition of segregation of the waste at source, while the last option is the sanitary landfill.

## Suggestions

We would like to make suggestions on which of the twelve development goals (presented by Table 2. in Results chapter) will strengthen prevention, e.g. minimizing the amount of waste and implementing the zero waste strategy. Primarily waste production should be reduced, because if less waste is generated in the system, the waste management can be more efficient. It is important to note that which part of the business models could be the prevention and how they relate to the circular economic concept. It is important to define the prevention levels of circular economy, therefore the development needs at the three transition management levels can be clarified. Based on our suggestion, if prevention is prioritized and development areas are identified (which could strengthen prevention), we can describe how transition management can be interpreted in circular business models. Based on our suggestion, it is necessary to focus on the following target areas in order to strengthen prevention as the key to system development.

–Solid waste characteristics

The heterogeneous composition of municipal waste results the prevention and making possible to operate efficiently the planned waste management system.

–Waste quantity

The increasing amount of waste strengthen the prevention.

–Public acceptability

The prevention increasing the acceptability of the developed municipal waste management system.

–Demand for final products

–Operating cost

–Complexity and required amount of raw materials

**References**


**[1] Kaza, S., et al.**, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. 2018: World Bank Publications.

**[2] Hoornweg, D. and P. Bhada-Tata**, What a waste: a global review of solid waste management. Vol. 15. 2012: World Bank, Washington, DC.

**[3] Hoornweg, D. and P. Bhada-Tata**, What a waste: a global review of solid waste management. 2012.

**[4] Loan, N.T.P.**, Tài liệu hướng dẫn. Lựa chọn công nghệ trong quản lý chất thải rắn bền vững. Nghiên cứu điển hình tại Thành phố Hồ Chí Minh, Việt Nam. 2016.

**[5] Themelis, N.J., et al.**, Energy recovery from New York City municipal solid wastes. 2002. 20(3): p. 223-233.

**[6] Wajeeha Saleem, A.Z., Muneeba Tahir, Fatima Asif, Ghazala Yaqub**, Latest technologies of municipal solid waste management in developed and developing countries: A review International Journal of Advanced Science and Research 2016. 1(10): p. 22-29

**[7] Voběrková, S., et al.**, Effect of inoculation with white-rot fungi and fungal consortium on the composting efficiency of municipal solid waste. 2017. 61: p. 157-164.

**[8] Koda, E., A.** Miszkowska, and A.J.A.S. Sieczka, Levels of organic pollution indicators in groundwater at the old landfill and waste management site. 2017. 7(6): p. 638.

**[9] Jovanov, D., B. Vujić, and G.J.J.o.e.m. Vujić,** Optimization of the monitoring of landfill gas and leachate in closed methanogenic landfills. 2018. 216: p. 32-40.

**[10] Gworek, B., et al.,** Impact of the municipal solid waste Łubna Landfill on environmental pollution by heavy metals. 2016. 8(10): p. 470.

**[11] Vaverková, M.D., et al.,** Municipal solid waste landfill–Vegetation succession in an area transformed by human impact. 2019. 129: p. 109-114.

**[12] Yang, L., et al.,** Photosynthesis of alfalfa (Medicago sativa) in response to landfill leachate contamination. 2017. 186: p. 743-748.

[13] Adamcová, D., et al., Environmental assessment of the effects of a municipal landfill on the content and distribution of heavy metals in Tanacetum vulgare L. 2017. 185: p. 1011-1018.

**[14] Elia, G., et al.,** Numerical modelling of slope–vegetation–atmosphere interaction: an overview. 2017. 50(3): p. 249-270.

**[15] Vaverková, M.D., et al.,** Environmental risk assessment and consequences of municipal solid waste disposal. 2018. 208: p. 569-578.

**[16] Moreno, A., et al.,** Chemical characterization of emissions from a municipal solid waste treatment plant. 2014. 34(11): p. 2393-2399.

**[17] Cheng, Z., et al.**, The identification and health risk assessment of odor emissions from waste landfilling and composting. 2019. 649: p. 1038-1044.

**[18] Makarenko, N. and O.J.A.o.A.S. Budak**, Waste management in Ukraine: Municipal solid waste landfills and their impact on rural areas. 2017. 15(1): p. 80-87.

**[19] Sharp, A. and J.J.I.f.G.E.S.A.h.w.i.o.j. Sang-Arun**, A guide for sustainable urban organic waste management in Thailand: Combining food, energy, and climate co-benefits. 2012.

**[20] Wei, Y., et al.**, Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. 2017. 122: p. 51-65.

**[21] Jara-Samaniego, J., et al.**, Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. 2017. 141: p. 1349-1358.

**[22] (USEPA)**, U.S.E.P.A., Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013. 2015: p. Chapter-7-Waste.

**[23] Adhikari, B.K., et al.,** Effectiveness of three bulking agents for food waste composting. 2009. 29(1): p. 197-203.

**[24] Maulini-Duran, C., et al.,** VOC emissions from the composting of the organic fraction of municipal solid waste using standard and advanced aeration strategies. 2014. 89(4): p. 579-586.

**[25] Wéry, N.J.F.i.C. and I.** Microbiology, Bioaerosols from composting facilities—a review. 2014. 4: p. 42.

**[26] Sykes, P., et al.,** Workers' exposure to dust, endotoxin and β-(1–3) glucan at four large-scale composting facilities. 2011. 31(3): p. 423-430.

**[27] Pearson, C., et al.,** Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: a systematic review of occupational and community studies. 2015. 18(1): p. 43-69.

**[28] Moya, D., et al.,** Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-To-Energy Technologies. 2017. 134: p. 286-295.

**[29] Brunner, P.H. and H.J.W.M. Rechberger,** Waste to energy–key element for sustainable waste management. 2015. 37: p. 3-12.

**[30] Di Matteo, U., et al.,** Energy contribution of OFMSW (Organic Fraction of Municipal Solid Waste) to energy-environmental sustainability in urban areas at small scale. 2017. 10(2): p. 229.

**[31] Baroutian, S. and C. Anyaoku,** Decentralized anaerobic digestion systems for increased utilization of biogas from municipal solid waste. 2018.

**[32] Van Fan, Y., et al.,** Anaerobic digestion of municipal solid waste: energy and carbon emission footprint. 2018. 223: p. 888-897.

**[33] Tyagi, V.K., et al.,** Anaerobic co-digestion of organic fraction of municipal solid waste (OFMSW): Progress and challenges. 2018. 93: p. 380-399.

**[34] Hinchliffe, D., J. Frommann, and E.J.E.G. Gunsilius,** Waste to energy options in municipal solid waste management. 2017.

**[35] Kusch, S.** Understanding and managing the start-up phase in dry anaerobic digestion. in Proceedings in Research Conference in Technical Disciplines, Zilina, Slovak Republic. 2013.

**[36] Kranert, M., et al.,** Anaerobic Digestion of Waste. 2012. 128-129.

**[37] Bosmans, A., et al.,** The crucial role of Waste-to-Energy technologies in enhanced landfill mining: a technology review. 2013. 55: p. 10-23.

**[38] Couto, N.D., V.B. Silva, and A.J.J.o.c.p. Rouboa**, Thermodynamic evaluation of Portuguese municipal solid waste gasification. 2016. 139: p. 622-635.

**[39] Thakare, S. and S.J.E.P. Nandi,** Study on potential of gasification technology for municipal solid waste (MSW) in Pune city. 2016. 90: p. 509-517.

**[40] Mazzoni, L. and I.J.I.J.o.H.E. Janajreh, Plasma** gasification of municipal solid waste with variable content of plastic solid waste for enhanced energy recovery. 2017. 42(30): p. 19446-19457.

**[41] Rajasekhar, M., et al.,** Energy Generation from Municipal Solid Waste by Innovative Technologies–Plasma Gasification. 2015. 10: p. 513-518.

**[42] Arena, U.J.W.m.,** Process and technological aspects of municipal solid waste gasification. A review. 2012. 32(4): p. 625-639.

**[43] Dong, J., et al.,** Comparison of waste-to-energy technologies of gasification and incineration using life cycle assessment: Case studies in Finland, France and China. 2018. 203: p. 287-300.

**[44] Liu, A., et al.,** A review of municipal solid waste environmental standards with a focus on incinerator residues. 2015. 4(2): p. 165-188.

**[45] Sebastian, R.M., et al.,** A technique to quantify incinerability of municipal solid waste. 2019. 140: p. 286-296.

**[46] Di Nola, M.F., M. Escapa, and J.P.J.W.M. Ansah**, Modelling solid waste management solutions: The case of Campania, Italy. 2018. 78: p. 717-729.

**[47] Shekdar, A.V.J.W.m.,** Sustainable solid waste management: an integrated approach for Asian countries. 2009. 29(4): p. 1438-1448.

**[48] Guerrero, L.A., G. Maas, and W.J.W.m**. Hogland, Solid waste management challenges for cities in developing countries. 2013. 33(1): p. 220-232.

**[49] Association, I.I.S.W.,** Waste and climate change, ISWA White Paper. 2009.

**[50] Khandelwal, H., et al.,** Application of life cycle assessment in municipal solid waste management: A worldwide critical review. 2018.

**[51] Pires, A., G. Martinho, and N.-B.J.J.o.e.m. Chang,** Solid waste management in European countries: A review of systems analysis techniques. 2011. 92(4): p. 1033-1050.

**[52] Neumayer, E.J.E.E.,** German packaging waste management: a successful voluntary agreement with less successful environmental effects. 2000. 10(3): p. 152-163.

**[53] Dhokhikah, Y., Y.J.J.o.A.E.** Trihadiningrum, and B. Sciences, Solid waste management in Asian developing countries: challenges and opportunities. 2012. 2(7): p. 329-335.

**[54] Da Zhu, P.U.A., Chris Zurbrügg, Sebastian Anapolsky,** Shyamala Mani, Improving Municipal

Solid Waste Management in India. WBI DEVELOPMENT STUDIES, 2008.
**[55] Gupta, S., et al.,** Nation Challenges for Solid Waste Management. 2017. 9(2).
**[56] GSOVN.,** Area, population and population density by province. Population and Employment. 2016: p. http://www.gso.gov.vn/default_en.aspx?tabid=774.
**[57] Thang, N.T., Country Chapter,** State of the 3Rs in Asia and the Pacific, The Socialist Republic of Vietnam. 2017: p. 37.
**[58] Richardson, D.W.,** Community-based solid waste management systems in Hanoi, Vietnam. 2003, from the Faculty of Forestry, University of Toronto.