Journal of Environmental Health and Sustainable Development

Sustainability Impact Assessment of Waste to Energy Technologies in Iran

Fahimeh Teimouri [1], *Ali Asghar Ebrahimi* [1*], *Mahrokh Jalili* [1], *Hamid Reza Alaghehbandan* [2]

[1] Environmental Science and Technology Research Center, Department of Environmental Health Engineering, School of Public Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran.
[2] Isfahan Scientific and Research Park, Isfahan, Iran.

A R T I C L E I N F O

ORIGINAL ARTICLE

Article History:
Received: 02 August 2019
Accepted: 20 October 2019

Corresponding Author:
Ali Asghar Ebrahimi

Email:
Ebrahimi20007@gmail.com

Tel:
+983531492273

Keywords:
Environmental Impact Assessment,
Municipal Solid Waste,
Waste to Energy (WTE),
Leopold Matrix.

ABSTRACT

Introduction: Current energy sources are coming to end and one of the main priorities of the country's management is the energy recovery from renewable energy. Considerable quantity of municipal solid waste (MSW) is one of the most serious urban pollution sources. Impact assessment matrix is a new and fast tool for Environmental Impact Assessment (EIA).

Materials and Methods: In this regard, renewable energy like waste-to-energy was investigated. Environmental assessment method was performed to evaluate the environmental impacts of common Waste to Energy (WTE) technologies by Wooten and Rau matrix. Most available WTE technologies (anaerobic digestion, sanitary landfill with gas recovery, waste incineration, and gasification) were environmentally assessed and compared.

Results: Results showed that anaerobic digestion could be most environmental friendly WTE technology for production of renewable energy from organic waste and could be considered. Furthermore, executives as green minded managements can improve the quality of waste management by finding new solutions. Other technologies such as landfill by gas recovery and gasification will be ranked second and third in terms of environmental effect.

Conclusion: Results showed that performing anaerobic digestion technology will produce less environmental impact in long term. Then landfilling by gas recovery and gasification technologies will be ranked second and third in terms of environmental effect.

Citation: Teimouri F, Ebrahimi AA, Jalili M, et al. ***Sustainability Impact Assessment of Waste to Energy Technologies in Iran***. J Environ Health Sustain Dev. 2019; 4(4): 885-94.

Introduction

An increase in population increases the human requirements. Energy is one of the most important elements that people depend on them due to their life especially industrial activities. Nowadays, all countries rely on the fossil fuels. However, this source of energy is non-renewable and will not meet all the human needs [1].

To solve this problem, scientists and researchers are thinking about replacing renewable and clean energy with non-renewable energy. Renewable energy has three main achievements including environmental benefits, independence in providing energy, and strengthening the national security [2]. Other advantages are generating reliable electricity at a sustainable cost and producing electricity with minimal environmental pollution that creates opportunities for economic development, especially in underdeveloped and remote rural areas [3]. Most developing countries are interested to use the renewable energy. In many developed countries such as Japan, environmental effects of solid waste have been solved and economical aspects have been estimated [4,5].

Establishment of regulations such as sustainable development, reduction of greenhouse gas emissions from landfilling, and appropriate management of the organic waste have accelerated the use of waste conversion processes into energy [6]. Recent studies in the United States showed that about 37% of Greenhouse Gas Emission (GGE) originated from landfills [7].

The energy recovery potential of solid waste materials is expected to increase from 252,130 GJ/year in 2012 to 525,540 GJ/ton in 2021. In literature, the energy recovery potential of solid recovered fuel production was 2.94 GJ/ton, followed by steam heat generation (2.34 GJ/ton), solid fuel production from sewage sludge (0.77 GJ/ton), biogas production of food waste (0.443 GJ/ton), and landfill gas recovery (0.177 GJ/ton) [8].

Table 1 shows a composition of MSW in some countries throughout the world. As presented, Tehran's organic waste production rate is higher than that of the developed countries [9]. Large amount of the MSW in Iran was formed by residual food and biodegradable material, which plays a significant role in producing biogas from MSW [10].

Table 1: The percentage composition of MSW in different parts of the world [11]

Waste composition by region	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)	Reference
Middle East and North Amfrica	61	14	9	3	3	10	(Daniel and Perinaz, 2012)
Latin American	54	16	12	4	2	12	(Daniel and Perinaz, 2012)
Organization for Economic Co-operation and Development	27	32	11	7	6	17	(Daniel and Perinaz, 2012)
East Asia and the Pacific	62	10	13	3	2	10	(Daniel and Perinaz, 2012)
South Asia	50	4	7	1	1	37	(Daniel and Perinaz, 2012)
Africa	57	9	13	4	4	13	(Daniel and Perinaz, 2012)
Eastern Europe and Central Asia	47	14	8	7	5	19	(Daniel and Perinaz, 2012)
Tehran	**73**	**8**	**5**	**3**	**1**	**10**	**(Nasrallahi-Sarvaghaji, 2016 [12])**

Anaerobic digestion, gasification, Pyrolysis, and landfill are the most WTE technologies used in the world [13]. Recent technologies have some advantages and disadvantages. For example, main problems caused by operation of anaerobic digestion could be related to high costs, complexity of installation, and its operation [14]. Leachate leakage, loss of steady gradient of the burial center, high temperature, odor and gas production, as well as fire and explosion are important concerns from landfill operations [7]. Recent studies have shown that one of the main causes of ozone layer depletion (OLD) is related to the diesel fuel of MSW recycling devices[9].

As it can be seen in Figure 1, transportation (about 40%) and electricity (about 30%) are the highest contributors to form the Global Warming Potential. Figure 1 presents that the world's Total Primary Energy Consumption (TPEC) stands over 150,000,000 GWh in 2015 and rises by 57% in 2050 [15].

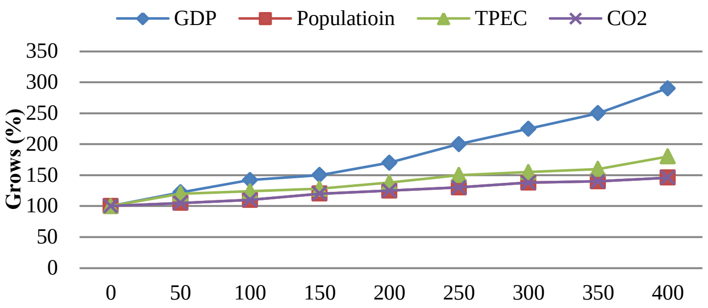

Figure 1: Trends in global gross product (GDP), population. TPEC, and Carbon [15]

In 2015, CO_2 emissions from fossil fuel consumption of 10 countries were about two-thirds of the world's total rate (Figure 2). Later, fuel was related to power plants and transportation sector that was responsible for about 616 million tons of Greenhouse Gases (GHG) emission in Iran [15].

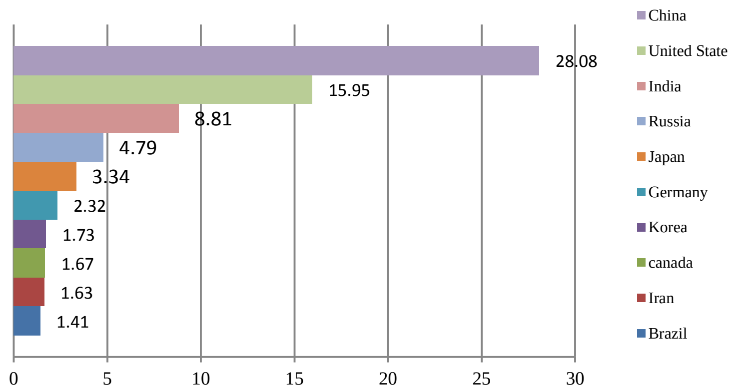

Figure 2: Top 10 CO_2 emitting countries in 2015 [16]

Management of energy with a reduction in environmental pollution plays a key role in performing sustainable development and is impossible without environmental protection [17]. On the other hand, energy is directly correlated to security and development. According to WHO report, the death rates from air pollution are higher than other death types. More than two million people died from air pollution in 2016 [18]. In a 10-year study, 37967 respiratory death cases occurred in Tehran, in which 21,913 (57.73%) cases were male and 16,047(42.27) were female equal to one-twentieth of the total air pollution casualties [19].

Various methods are available for environmental impact assessment (EIA) tools:

The Analytical Hierarchy Process is one of the most comprehensive systems designed for decision making with multiple criteria, since this technique allows for formulating the problem in a hierarchical manner and increases the possibility of different quantitative and qualitative criteria [20]. The life-cycle assessment studies investigate the environmental aspects and potential impacts throughout a product's life from raw material preparation until production, use, and disposal [21]. Strategic Environmental Assessment is a systematic process for evaluating the environmental consequences as a proposed policy [22].

Matrix is a new and fast method for EIA. The main strength of this technique is its flexibility that can fluctuate in size (large and small) in accordance with the type of project. Moreover, in the matrix method, positive and negative signs can be used along with the evaluation numbers to distinguish the unwanted effects. Due to the waste composition in Iran, application of WTE technologies was investigated by EIA matrix method. So, the main goal of this study was to investigate and compare the waste to energy conversion technologies in Iran and to introduce the best technology from the view point of sustainable development.

Materials and Methods

Assessment method

In order to evaluate the WTE conversion methods, various methods are available, but the matrix is one of the main methods for identifying and diagnosing the environmental effects of a project. This method has wide usage and is adapted to the environmental projects [23]. Environmental advantages have been adapted to various sources, such as California waste management studies and Montgomery Watson Consulting Company's management of waste management in Asia [24]. The experts' opinions about some of the criteria for evaluating and weighting can vary according to different criteria, but the difference in viewpoints does not seem to have much effect on the overall ranking. It should be mentioned that the optional ranking has not been important in this evaluation method [25]. In order to detect the proportional rates, most WTE technologies include anaerobic digestion, landfill with gas recovery, gasification, and incineration processes were compared.

The most environmental investigated factors include: emissions of pollutants into the atmosphere (dust, Particulate matters etc.), surface and groundwater contamination, Greenhouse Gas Emissions (GGE), public health considerations, disposal of residual waste, etc. In order to achieve the sustainable development and selection of the superior WTE technology, economical, technical, and environmental criteria were considered and assessed by Wooten and Rau matrix.

Wooten & Rau Impact Assessment Matrix

The Wooten & Rau method (Table 2) is a quantitative evaluation of the project using the algebraic matrix. In this matrix, the basis of analysis (based on the method presented by the multiplication of numbers) is related to the importance of effect on the domain [6].

Typically, development of projects has a positive impact on the economic, social, and cultural environment, while the effects of these projects on the physical and biological environment are negative. In this study, the effects range from severe to weak. The severity of the effects is measured based on the impact of the project on the environment. Projects reduce the environmental perspective, but only predictable effects (environmental, social, cultural, etc.) are only evaluated.

Table 2: Wooten & Rau Impact Assessment Matrix

Scope of effect	Importance of the effect
Multiplication	

Moreover, all effects can be divided into two categories: The first category deals with the construction and maintenance of the infrastructure and the second considers the effects of the project operation. It should be noted that in many cases, the effects of infrastructure operation are unpredictable. In general, the economic and social impacts of the projects are positive. In terms of ranking, they are in a good situation, since the project at this time has reached a stage of economic prosperity.

Moreover, impacts can be divided into two categories of reversible and irreversible. For example, destruction of unique wildlife habitats is an irreversible effect and operation of the soil can also have a reversible effect.

Here, the evaluation of technologies is performed quantitatively using Wooten & Rau matrix, another form of the Leopold matrix.

As seen in Table 2, each cell is divided into three parts. In the left side of each cell, the effect amplitude number with the positive sign (+) means positive and negative (-) sign shows a negative effect. The right part of each cell is assigned to the effect score. For each work, the score is obtained from product of the two numbers related to the "importance of the effect" in the "range of effect" and is placed at the bottom of each cell. After

[DOR: 20.1001.1.24766267.2019.4.4.5.9]
[DOI: 10.18502/jehsd.v4i4.2021]

summing the scores, the positive and negative scores of each column will be calculated in the last row of the table. Finally, the total score of the project will be the sum of the total score of the last row.

Importance of the Effect

Given that the effect scope is for all common effects, the vast majority of existing references recommend the following range in Table 3.

Table 3: Importance of the effect

Importance	Score
No effect	1
Very little effect	2
Little effect	3
Important effect	4
Very important effect	5
Very much effect	6

Scope of the Effect

The existing evaluation matrix was used only at the identification stage and as a framework for those who intended to undertake a preliminary or conclusive assessment. Scope of the micro-activity of each project was considered based on the environmental, economic, and technical parameters for each technology separately. Scopes of effects were described as 1 for low, 2 for medium, and 3 for high effects of the projects.

As mentioned, one of the strengths of this technique is its flexibility that can become large and small in accordance with the project type. Moreover, in the matrix method, positive and negative signs can be used along with the evaluation numbers to distinguish the unwanted effects. By applying this method, the consequences of all project-related activities, such as construction and operations were evaluated [9].

Results

Waste to Energy Environmental Assessment

The main objectives of this study was to assess waste to energy technologies environmentally. Results of the environmental impact assessment of WTE technologies are shown in Table 4.

Table 4: WTE environmental impact assessment by Wooten & Rau matrix

Row	Evaluation criteria	Score	Biological processes		Thermal processes	
			Anaerobic digestion	Landfill by gas recycling	incineration	Gasification/ Pyrolysis
A)	System layout					
1	Simplicity and functionality operation	0-12	8	12	4	4
2	The flexibility of the process	0-12	8	10	4	4
3	Ability to change scale	0-6	6	4	6	6
Total of this section		0-30	22	26	14	14
4	Pretreatment	0-20	12	8	8	8
5	Final treatment	0-10	6	6	6	6
Total of this section		0-30	18	14	14	14
6	environmental effects	0-30	25	15	5	15
7	Energy and byproducts	0-30	20	16	20	24
8	Initial cost	0-12	6	8	4	6
9	Operation and maintenance	0-12	5	6	4	6
10	Background	0-6	6	6	6	3
Total of this section		0-30	17	20	14	15
Total sum		150	102	91	67	82

[DOR: 20.1001.1.24766267.2019.4.4.5.9]

[DOI: 10.18502/jehsd.v4i4.2021]

As shown, due to less environmental hazards, biological processes had a higher score and thermal processes has earned lower scores due to the environmental effects such as emission of toxic gases into the atmosphere [26].

Considering all environmental aspects, anaerobic digestion technology has the highest ecological score (27,102) [27] and the incineration has the lowest score (67), [28]. Gasification technologies and pyrolysis have the same environmental benefits.

Evaluation of the other sustainable assessment criteria

Evaluation criteria are given in Table 5. Environmental assessment was based on the multiplication of numbers related to the effect importance in two construction and operation stages.

According to the type of WTE technology, the relevant scores (Wooten & Rau matrix) are given in Table 6.

Table 5: Sustainable assessment criteria for WTE by Wooten & Rau Matrix (Leopold) [29]

Criterion Stage	The status of environmental pollution			Economic, social and cultural environment					Biological environment					The physical environment				
	Sound	water and soil	Air quality	Monuments and religious places	Health status	Land use	Major economic activities	status and	Ecosystem	Animal habitats	The way of living animals	Wildlife Trail way	vegetation of the region	Shape of the earth	Soil erosion	Earth permeability	Quantity of water resources	The regional climate
Structural phase																		
Operational phase																		

Table 6: Total Environmental Impact Assessment (EIA) score for WTE technologies

Operational Phase Process	Structural	operational	the sum
Waste incineration	-23	-88	-111
Gasification process	-22	-57	-79
Bioreactor	-24	-42	-66
Anaerobic digestion	-16	-23	-39

As shown in Table 6, anaerobic digestion technology has a score equal to -39; the bioreactor and gasification processes are equal to -66 and -79, subsequently. In other words, construction and performance of anaerobic digestion process in the long term have less negative environmental impacts than other methods.

Another factor that contributes to flourishing of the gasification technology is replacing it with incineration technologies in advanced countries. According to our findings, anaerobic digestion is a technology that can be used in advanced countries and is a complete technology to convert solid wastes into energy. Figure 3 shows the results of the environmental assessment carried out by the Wooten & Rau matrix.

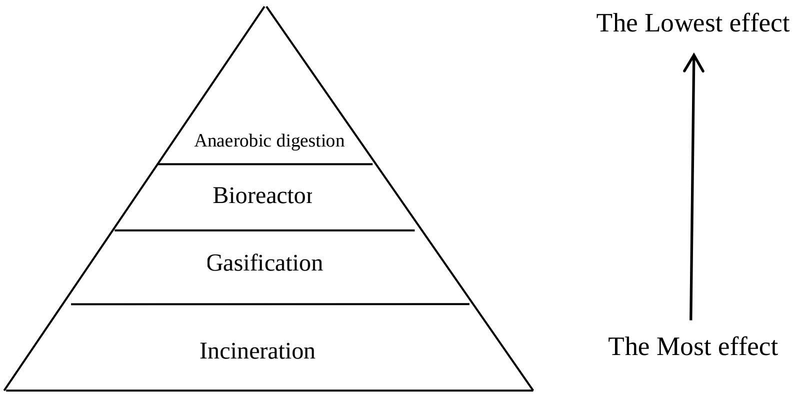

Figure 3: Ranking WTE Technologies by Wooten & Rau Matrix method

Discussion

The range of selected environmental factors was based on a variety of sources such as California waste management studies and Montgomery Watson Consultant on Management of Waste Management in Asia (0-30). In the case that a technology has one or more environmental negative effects, it will receive a low score. An average score is allocated if some of the environmental impacts can be ignored. Biogas production, from an anaerobic digestion, can be used as a fuel in a boiler to generate electricity; so, this parameter is considered as a positive effect and this technology will earn a high score. The landfill process also generates gas, which can be used to generate electricity. The probability of GHG emissions, ground pollution, and surface water are due to the leachate leakage and considered as negative effects. The issue of environmental impacts in landfills is very sensitive. New air pollution control devices can reduce the emission of fine particles to the strict standards, but in some cases, the high cost of these devices has increasingly led to shift the incineration technology. In England, incineration is no longer a suitable method for turning waste into energy. Negative points about incineration method, such as air pollution and high costs make this technology to receive a low score. Gasification technology is positively evaluated, because the amounts of gas emissions are low and residual solids are small and ineffective. The results of present study have shown that the earned scores indicated that digestion technologies had the least environmental impacts and were usable for waste to energy conversion. This technology will suitable for waste producing countries with high organic matter such as Iran.

Also, the electricity produced from burning the biogas is beneficial and supplies ‘green power’ for the local electrical zone [30]. A study by Evangelistivia showed that electricity production by biogas energy can be used in the power plant as a fuel [31]. Another study showed that the best and the most practical scenario could be included in separation of 60% organic matters and anaerobic digestion for biogas production. In this manner, maximization of separating and recycling the recyclable wastes such as PET, HDPE, glass, metals, etc. can be performed. When the alternative scenario is feasible, the global warming and the eutrophication potential will decrease to 166% and 646%, respectively [32]. A new modeling approach to calculate GHG and NH_3 emissions from anaerobic digestion processes was proposed. Post-digestion emissions and their relationship with the anaerobic digestion maintenance were the main factors affecting the net GHG emissions [33]. In another study, a full life cycle inventory was conducted for the combined dry anaerobic digestion and post-composting facility, including the waste received, fuel consumption, energy use, gaseous emissions,

[DOR: 20.1001.1.24766267.2019.4.4.5.9]

[DOI: 10.18502/jehsd.v4i4.2021]

products, energy production, and chemical composition of the compost produced [34].

Landfill by gas recovery (Bioreactor) has been used in developing countries over the past two decades and proper control has partly offset the concerns about atmospheric emissions and leachate production. Today, due to the reduction of land suitable for landfilling and the rapid filling of existing landfills, more emphasis is on the construction of recycling facilities. This action only transfers a small amount of non-recyclable waste to the landfill site [35]. Incineration is a good technology for recycling energy from urban and industrial wastes, which has been used successfully in industrialized countries on a commercial scale and has been a good record. However, the emphasis on controlling atmospheric pollutants in recent years has led to a huge increase in the cost of this technology [36]. Gasification process will get a better ranking if the number of facilities around the world grows.

Conclusions

Most available WTE technologies are compared in this study from the view point of environmental assessment and its effect on sustainable development by Wooten and Rau Matrix method. Results showed that performing anaerobic digestion technology will produce less environmental impact in long term. Subsequently, landfilling by gas recovery and gasification technologies will be ranked second and third in terms of environmental effect.

Furthermore, the results of this study indicated that more attention should be paid to anaerobic digestion process because of a wide range of different criteria. Gasification process will be gradually replaced by incineration technology, because it is more suitable to convert waste into energy. Finally, landfill gas recycling technologies (Bioreactor) can be used in certain areas as short-term and medium-term options.

Acknowledgments

The authors would like to thank the Isfahan Municipality and Rahjooyan Naghshe Jahan Consulting Engineering Company for their helping in collecting of data.

Funding

This research was funded by Rahjooyan Naghshe Jahan Consulting Engineering Company at Isfahan Science and Technology Town.

Conflict of interests

The authors confirm that there is no conflict of interest related to the publication of this article.

References

1. Nicoletti G, Arcuri N, Nicoletti G. Technical and environmental comparison between hydrogen and some fossil fuels. Energy Convers Manag. 2015;(89):205-13.
2. Nizami A, Shahzad K, Rehan M, et al. Developing waste biorefinery in Makkah: a way forward to convert urban waste into renewable energy. Appl Energy. 2017;(186):189-96.
3. Mohammadi A, Omid M. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Appl Energy. 2010;87(1):191-6.
4. Sawayama S, Minowa T, Yokoyama S-Y. Possibility of renewable energy production and CO2 mitigation by thermochemical liquefaction of microalgae. Biomass Bioenergy. 1999; 17(1):33-9.
5. Bhattacharya M, Paramati SR, Ozturk I. The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. Appl Energy. 2016;162:733-41.
6. Ghasemian M, Poursafa P, Amin MM, et al. Environmental impact assessment of the industrial estate development plan with the geographical information system and matrix methods. J Environ Public Health. 2012;2012(2):407162.
7. Boyle W. Energy recovery from sanitary landfills-a review. Microb energy conver. 1977:119-38.

[DOR: 20.1001.1.24766267.2019.4.4.5.9]

[DOI: 10.18502/jehsd.v4i4.2021]

8. Yi S, Jang YC, An AK. Potential for energy recovery and greenhouse gas reduction through waste-to-energy technologies. J Clean Prod. 2018; 176:503-11.
9. Nabavi-Pelesaraei A, Bayat R, Hosseinzadeh-Bandbafha A, et al. Prognostication of energy use and environmental impacts for recycle system of municipal solid waste management. J Clean Prod. 2017; 154:602-13.
10. Damghani AM, Savarypour G, Zand E. Municipal solid waste management in Tehran: Current practices, opportunities and challenges. Waste Manag. 2008;28(5):929-34.
11. East AM, Asia E. Municipal Solid Waste Growing. Gary Gardner. 2012;24(1):1-5.
12. Nasrullah M, Vainikka P, Hannula J, et al. Elemental balance of SRF production process: solid recovered fuel produced from municipal solid waste. Waste Manag Res. 2016;34(1):38-46.
13. Arena U, Mastellone ML, Perugini F. The environmental performance of alternative solid waste management options: a life cycle assessment study. Chem Eng J. 2003;96(1-3):207-22.
14. Mata-Alvarez J, Mace S, Llabres P. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. Bioresour Technol. 2000;74(1):3-16.
15. Hajjari M, Tabatabaei M, Aghbashlo M, et al. A review on the prospects of sustainable biodiesel production: a global scenario with an emphasis on waste-oil biodiesel utilization. Renew Sustain Energy Rev. 2017; 72:445-64.
16. Nejat P, Jomehzadeh F, Taheri MM, et al. A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renew Sustain Energy Rev. 2015;(43):843-62.
17. Watson RT, Boudreau MC, Chen AJ. Information systems and environmentally sustainable development: Energy informatics and new directions for the IS community. MIS quarterly. 2010;34(1):23-38.
18. Vaughan A. China tops WHO list for deadly outdoor air pollution. The Guardian. 2016.
19. Dehghan A, Khanjani N, Bahrampour A, et al. The relation between air pollution and respiratory deaths in Tehran, Iran-using generalized additive models. BMC Pulm Med. 2018; 18(1):49.
20. Singh RP, Nachtnebel HP. Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal. Renew Sustain Energy Rev. 2016;(55):43-58.
21. Yay ASE. Application of life cycle assessment (LCA) for municipal solid waste management: a case study of Sakarya. J Clean Prod. 2015;(94):284-93.
22. Therivel R. Strategic environmental assessment in action. Routledge. 2012;8(2):137-9.
23. Kydd J, Pearce R, Stockbridge M. The economic analysis of commodity systems: Extending the policy analysis matrix to account for environmental effects and transactions costs. Agric Syst. 1997;55(2):323-45.
24. Crites RW, Middlebrooks EJ, Bastian RK. Natural wastewater treatment systems. CRC Press; 2014.
25. Kapepula K-M, Colson G, Sabri K, et al. A multiple criteria analysis for household solid waste management in the urban community of Dakar. Waste Manag. 2007;27(11):1690-705.
26. Fytili D, Zabaniotou A. Utilization of sewage sludge in EU application of old and new methods-a review. Renew Sustain Energy Rev. 2008;12(1):116-40.
27. Arafat HA, Jijakli K, Ahsan A. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. J Clean Prod. 2015;(105):233-40.
28. Duijm NJ, Markert F. Assessment of technologies for disposing explosive waste. J Hazard Mater. 2002;90(2):137-53.
29. Monavari M. Environmental impact assessment model of municipal landfills. First Edition ed: Red Breast Publications; 2002.
30. Haight M. Assessing the environmental burdens of anaerobic digestion in comparison to alternative options for managing the biodegradable fraction of municipal solid wastes. Water Sci Technol. 2005;52(1-2):553-9.

31. Evangelisti S, Lettieri P, Borello D, et al. Life cycle assessment of energy from waste via anaerobic digestion: a UK case study. Waste Manag. 2014;34(1):226-37.
32. Cremiato R, Mastellone ML, Tagliaferri C, et al. Environmental impact of municipal solid waste management using Life Cycle Assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production. Renew Energy. 2018;(124):180-8.
33. Pardo G, Moral R, del Prado A. A modelling framework for the environmental assessment of agricultural waste management strategies: Anaerobic digestion. Sci Total Environ. 2017;(574):806-17.
34. Jensen MB, Møller J, Scheutz C. Assessment of a combined dry anaerobic digestion and post-composting treatment facility for source-separated organic household waste, using material and substance flow analysis and life cycle inventory. Waste Manag. 2017;(66):23-35.
35. Anderson DC, Harold THI. Container for storing and transporting recyclable and non-recyclable waste. Google Patents; 1996.
36. Porter M. America’s green strategy. Scientific American. 1996; 264(4): 33.