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Evaluation of integrated waste management by using of Waste Reduction Model (WARM)- (Case study of Amol-Noor region, Iran)

Seyed Mohammad Hosseini[a*], Naser Mehrdadi[b], Seyed Ali Hosseini[c]

[a] PhD of Environmental engineering-EnviroWise Research Associate Limited, Canterbury, New Zealand

[b] Professor of environmental engineering, Tehran university, Tehran, Iran

[c] PhD of Chemical engineering, Process and Reliability Engineer at BC Hydro, Iran

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Abstract

Lack of proper municipal solid management in the Northern provinces of Iran has led to damages to the natural resources, health, environment, social and economic conditions. Construction of solid waste processing plants such as compost and incineration, ignoring essential elements in waste management, cannot be as a successful strategy to solve the solid waste problems. Integrated management as a suitable and well-proved solution in many developed countries was proposed for Mazandaran province as a more reliable strategy to replace the existing conditions. In this paper, the results of study conducted for Amol and Noor region have been analyzed. Minimizing waste production, maximizing recycling and reuse, processing organic waste through digestion or composting process, producing refusing derived fuel (RDF) and using it in the waste incineration plants or Neka cement plant and finally disposing less than 10% of the waste in landfill is the proposed solution to improve the existing waste conditions. Implementing the proposed integrated management over a period of 20 years will lead to preventing from economic and environmental damages due to the loss of valuable natural resources and the release of various pollutants from landfills which is evaluated to be equivalent of about 28 billion dollars also, saving resources and energy estimated to be about 38 billion dollars. (DOI:https//doi.org/10.52547/JCER.5.3.15)

Keywords: Integrated Waste Management; Mazandaran; WARM.

1. Note

In many developed as well as developing countries, poor management on produced solid waste has caused to serious environmental challenge[1, 2]. However, global environmental and energy concerns make waste management studies necessary even for small towns[3]. The concept of "zero waste management" is a globally approved strategy to solve the waste

* Corresponding author. Tel.: +989123111147; e-mail: envhosseini@gmail.com.

problems. In this strategy, waste is considered a valuable source of materials produced in the natural resources consuming process [18]. The main task of the municipal solid waste management is to minimize the adverse environmental effects of waste generation by minimizing waste production, encouraging the reuse of the usable part of waste and recycling and producing new waste products[2]. Key parameters in waste management are: rules, tax rate, actual available information, available credit, financial transparency, cost-benefit of the project, environmental parameters, project technical conditions and access to the technology, knowledge and expertise [4].

Integrated waste management is one of the most important requirements of the European Union in the field of waste management to let Turkey to join the Union. In order to implement integrated waste management, Turkey needs to implement important measures such as decreasing waste production, increasing recycling of recyclable materials, processing of organic materials with compost or digestion processes, energy recovery by burning material residues and land filling for residual waste (15).

In some of the Southeast Asian countries, in order to create integrated waste management to minimize waste disposal, the following steps have been taken as zero waste achievement topics: improving public behavior, awareness and education, minimizing and prevention of waste generation, waste recycling and compost production, conversion of waste to energy and improving the landfill conditions and post-landfill care [16]. The results of a study on different waste management scenarios in Tehran, Iran, indicated that the least Green House Gases (GHGs) emissions occurs when 50 percent of MSW burn in waste to energy plant, 20 percent recycle and use of sanitary landfill for rest of them[5]. Emission of GHG could be decrease via the diversion of plastic waste by implementation of zero waste strategies [14].

Quantifying the output of each MSW strategy makes it possible to compare them more logically[7]. Thus, the outcomes of each MSW scenarios were quantified that was performed using Waste Reduction Model (WARM), and is recommended by the EPA[8]. WARM model measures emissions in terms of metric tons of carbon dioxide equivalent (MTCO2E) or metric tons of carbon equivalent (MTCE) and energy savings in millions of BTUs. Waste generation data and recycling factors in baseline scenario are one of serious limitations in this kind of studies [14].

Mazandaran province with daily MSW production of about 3000 tons is equipped with 3 recycling and compost production units. Total capacity of these plants is 750 tons per day (TPD). Nowshahr incineration plant with daily capacity of 200 tons of mixed MSW and Sari incineration with 450 TPD capacities are other projects being completed in the province. Noor and Ghaemshahr compost projects with a total capacity of 750 tons per day are in the early stages of completion. Waste management studies in Babolsar and Amol regions are being finalized[9].

The purpose of this paper is to compare the current conditions of MSW management in Noor and Amol regions with the proposed scenario in terms of technical, economic and environmental parameters by WARM. This article is part of the studies conducted for the governorate of Mazandaran with the aim of achieving zero waste, which was conducted during 2020 and 2021.

2. Methodology

This research includes the following steps: 1. Study and analysis the quality of the waste in the area, 2. Defining the possible scenarios based on the existing conditions, 3. Calculating the amount of carbon emissions in each proposed scenario using WARM software, 4. Economic review of the implementation of each scenario and 5. Summarizing the results and proposing the best scenario

2.1. Study area

Amol, as a waste management region of Mazandaran province, Iran, includes the county of Amol with a population of about 402 thousand people and county of Mahmoud Abad with a population of nearly 100 thousand people. The generated waste in this area is estimated around 350 TPD tons per day. Most of this waste is disposed directly in the Amol landfill. In Amol county geographical and environmental constraints to find a suitable place for

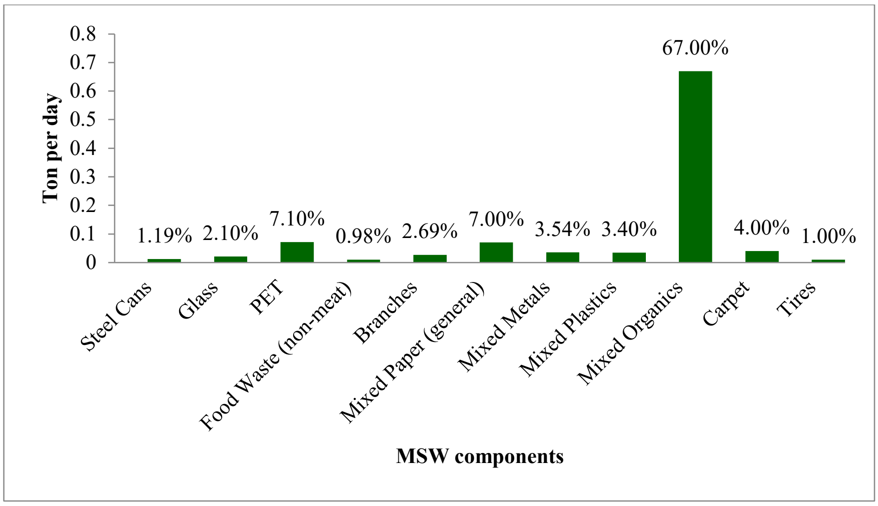

Figure 1. Average composition of MSW in Amol-Noor rejoins

the construction of waste processing facilities is one of the main concerns in MSW management.

MSW generation in Noor county, located 45 km away from Amol, is about 150 TPD. In order to enhance the economic, technical and environmental justification of the projects, it is suggested that Amol and Noor regions with a total capacity of 600 tons per day be managed together [9].

2.2. Waste quality

The results of analysis show that about 70% of the MSW in the area are degradable organic matters, including kitchen waste, twigs and other organic matter. Mixtures of PET and plastic are the second highest fraction in the analysis followed by the mixture of paper and cardboard (Figure 1).

The high percentage of polymer and plastic materials in the MSW stream is significant, indicating the massive use of disposable containers and plastic bag in this area. Therefore, by implementing waste generation reduction projects, source separation and recycling, landfill costs will be reduced and landfill operational life will be increased. Due to the high percentage of the organic matters in the MSW, the use of biological processes such as compost and digestion can be a proper option for processing the organic part of MSW.

2.3. Define different scenarios based on the existing conditions

The results of this study show that the following MSW management scenarios can be presented for the region[9]:

Scenario #	Proposed MSW management strategy
1- Based line waste management	Separation of 1.47% recyclable waste by illegal group and dumping rest of MSW in a non-engineered landfill.
2- Implementation of integrated waste management	waste reduction projects at the sources, utilization of recycling, anaerobic digestion of organic waste and RDF units and implementation of sanitary landfill

Keep going with the current condition is the most available choice, however in terms of technical and economical consideration, using of mix incineration of MSW is completely an unjustifiable and unreliable option. Therefore, in the continuation of this article, only scenarios 1 and 2 will be considered.

2.4. Calculating carbon emissions in each scenario by WARM software

Evaluation indicators that are used to quantify various waste management activities, including waste reduction percent, recycling rate, composting rate, landfilling, incineration and digestion in the form of energy saving and reducing greenhouse gas (GHG) emissions. This software calculates the amount of GHG emissions and the amount of energy saved from recycling for the current waste management conditions and proposed scenarios. Another word, the impact of each proposed scenario on the waste management is calculated and quantified in the form of emissions reduction and energy savings. Thus, according to the results, the efficiency of that strategy on waste management was determined.

The Environmental Defense Fund (EDF) has an initial estimate of the social cost of carbon emissions of $50 per ton, which is expected to be lower than the actual effects of carbon emissions (Harward, 2015). According to the studies conducted by the EPA in 2017, the real costs of carbon emissions are increasing every day because the harmful effects of carbon emissions in the coming years are far more destructive than their effects in previous years, in other words, its impact multiplies over time [13]. But according to the US Congressional Research Service, $25 per ton of carbon emissions is taxed in 2018 for emitting units [17]. According to a study by the US government, $37 is considered too low to compensate for the social cost of carbon emissions, and $220 per ton is a good number[11]. In this project the cost of carbon emission was consider $50 per ton of CO_2.

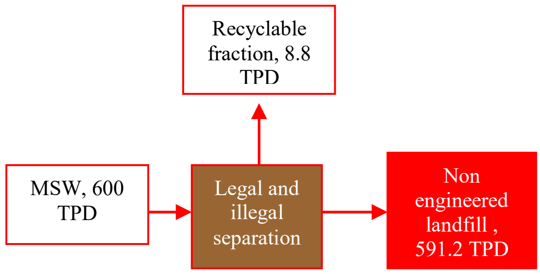

Figure 2. MSW stream for the first scenario

3. Results and discussion

3.1. The first scenario (Baseline waste management)

Table 1.

Input data to WARM for scenario 1

Scenario 1 - Land Filling (Ton per day)						
Material	**Tons Recycled**	**Tons Landfilled**	**Tons Combusted**	**Tons Composted**	**Tons Anaerobically Digested**	**Tons Generated**
Steel Cans	0.4	6.8	0.0	0.0	0.0	7.1
Glass	0.6	12.0	0.0	0.0	0.0	12.6
PET	2.1	40.5	0.0	0.0	0.0	42.6
Food Waste (non-meat)	0.0	5.9	0.0	0.0	0.0	5.9
Branches	0.0	16.1	0.0	0.0	0.0	16.1
Mixed Paper (general)	2.1	39.9	0.0	0.0	0.0	42.0
Mixed Metals	1.1	20.2	0.0	0.0	0.0	21.2
Mixed Plastics	1.0	19.4	0.0	0.0	0.0	20.4
Mixed Organics	0.0	402.0	0.0	0.0	0.0	402.0
Carpet	1.2	22.8	0.0	0.0	0.0	24.0
Tires	0.3	5.7	0.0	0.0	0.0	6.0
Total	**8.8**	**591.2**	**0.0**	**0.0**	**0.0**	**600.0**

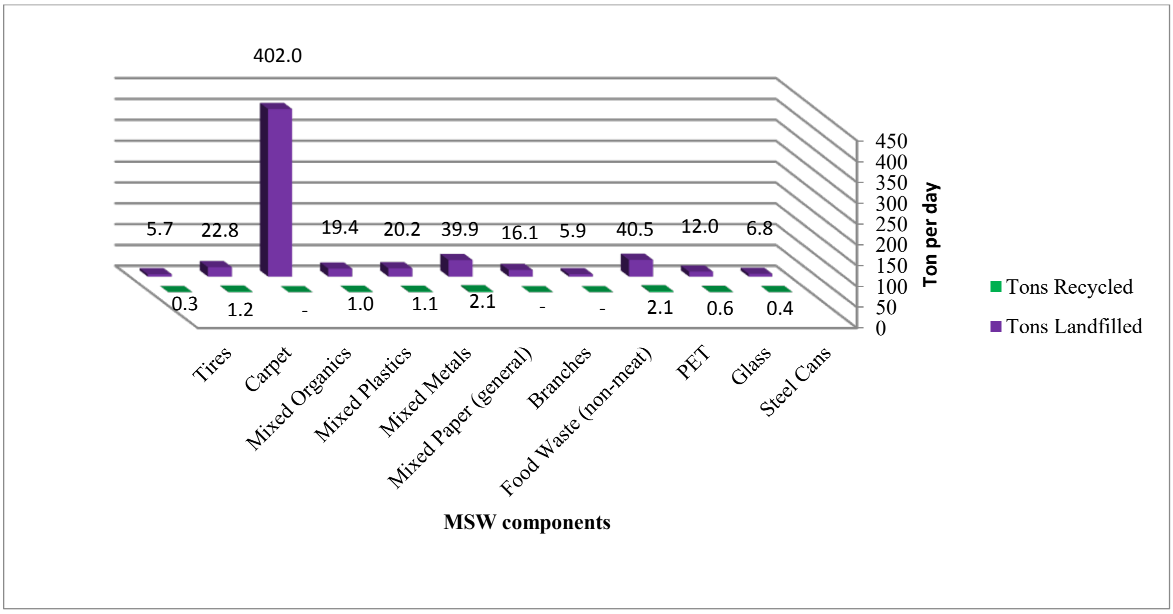

Figure 3. landfilled and recycled materials in scenario 1(baseline MSW management)

Table 2.
GHG Emissions from Baseline Waste Management (Scenario 1)

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Steel Cans	0.36	6.78	0	0	0	(0.50)
Glass	0.63	11.97	0	0	0	0.08
PET	2.13	40.47	0	0	0	(1.51)
Food Waste (non-meat)	0	5.88	0	0	0	8.20
Branches	0	16.14	0	0	0	4.25
Mixed Paper (general)	2.10	39.90	0	0	0	50.19
Mixed Metals	1.06	20.18	0	0	0	(4.18)
Mixed Plastics	1.02	19.38	0	0	0	(0.63)
Mixed Organics	0	402.00	0	0	0	333.24
Carpet	1.20	22.80	0	0	0	(2.34)
Tires	0.30	5.70	0	0	0	0.01
Total	8.8	591.2	0	0	0	386.81

The first scenario deals with current waste management activities. Figure 2 shows the waste generated area in the current conditions.

Based on the ongoing activities in the region, it is estimated that about 5% of recyclable materials, which is equivalent to 8.8 tons per day, is separated by legal and illegal groups. Rest of the waste, over 590 tons per day, is disposed in semi-engineered landfill. The input data to WARM software for Scenario 1 (existing conditions) are presented in Table 1 and Figure 3.

The output results of WARM software based on the amount of greenhouse gas emissions for different activities in baseline waste management are shown as table 2. Daily amount of GHG emissions form current MSW management is 386.81 $MTCO_2E$.

3.2. The second scenario (Alternative scenario)

According to the successful waste management project experiences of countries with a culture similar to Iran, the second scenario based on implementation of integrated waste management is defined as following [9]:

• Implementing a plan to reduce waste generation at the sources [7]

• Construction of transfer stations to cover 100% of the cities and villages of the region

• Site selection for construction of projects according to environmental organization criteria

• Use of biological processes such as anaerobic digestion to process organic waste

• Production of RDF from non-recyclable part with high energy content and transfer to the cement production plant or Sari incinerator plan.

• Update the existing landfill

Accordingly, the waste flow in the second scenario will be as shown in Figure 4.

Regarding to MSW characteristics and our previous filed study results, in scenario 2, around 130 TPD of MSW will be reduced due to reduced waste generation and source separations. Production of 2 to 3 megawatts of electricity, average 2.5 MW, by anaerobic digestion plant, daily production of about 65 tons of high-quality organic fertilizer and daily production of around 50 tons of RDF that can be used in Nowshahr or Sari incineration plants or Neka cement plant, are other outputs of this scenario. Other studies confirm this scenario for achieving to waste to energy and waste minimization [15]. Covert MSW to energy leads to reduces the GHG emissions and other environmental benefits [14]. In this scenario, the amount of landfill is reduced to less than 40 tons per day. Prevention of GHG emission of 395.95 $MTCO_2E$ is another achievement of alternative scenario. Table 3 shows the input data and output results of WARM software, the amount of greenhouse gas emissions for different activities in Scenario 2.

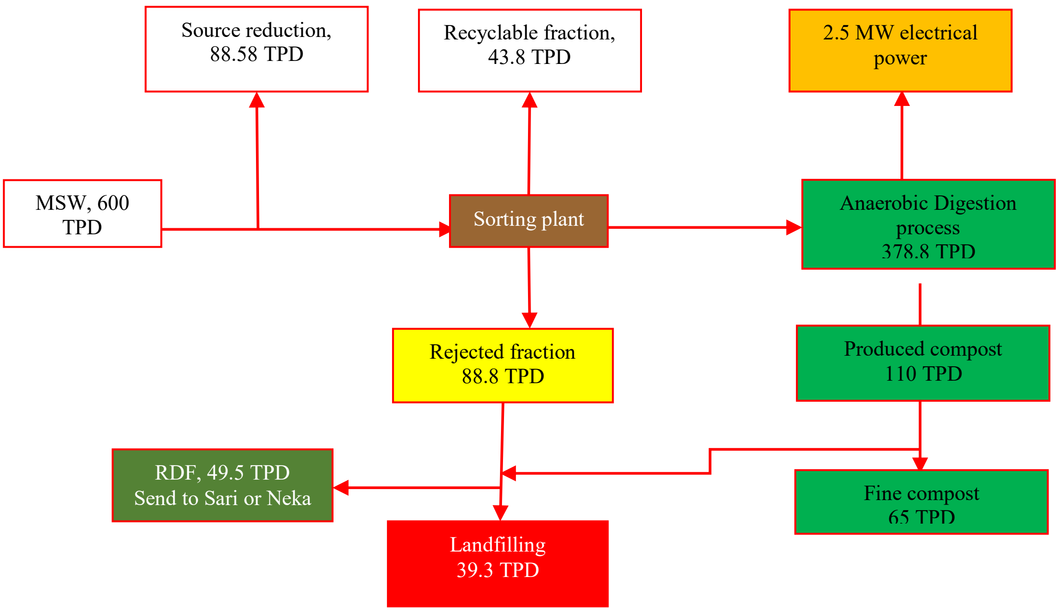

Figure 4. Waste stream in the second scenario for Amol-Noor region

Table 3.
GHG Emissions from scenario 2 (alternative waste management scenario) (TPD)

Material	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons An-aerobically Digested	Total $MTCO_2E$
Steel Cans	3.6	2.1	0.7	0.7	-	-15.92
Glass	6.3	3.8	1.3	1.3	-	-4.29
PET	21.3	12.8	4.3	4.3	-	-55.90
Food Waste (non-meat)	0.6	-	0.6	0.6	4.1	0.09
Branches	-	-	1.6	1.6	12.9	-2.80
Mixed Paper (general)	21.0	8.4	4.2	8.4	-	-156.22
Mixed Metals	10.6	6.4	2.1	2.1	-	-69.08
Mixed Plastics	10.2	6.1	2.0	2.0	-	-23.34
Mixed Organics	-	-	20.1	20.1	361.8	-11.95
Carpet	12.0	2.4	2.4	7.2	-	-43.62
Tires	3.0	1.8	0.0	1.2	-	-12.91
Total	**88.58**	**43.8**	**39.3**	**49.5**	**378.8**	**-395.95**

3.3. Comparison of greenhouse gas emissions

Comparison of greenhouse gas emissions in the scenarios 1 and 2 for Amol-Noor region is given in the following tables.

Table 4.
Quantitative evaluation of waste scenarios in Amol-Noor region

Indicator	Scenario 1	Scenario 2
GHG emission ($MTCO_2E$)	386.81	-395.95
GHGs emissions in metric tons of carbon dioxide equivalent (MTCO2E)		

Negative numbers indicate a reduction in greenhouse gas emissions

Under the current conditions of waste management in Amol-Noor region, more than 386 tons of greenhouse gases are daily released into the air. However, after the implementation of the second scenario, in addition to preventing the emission of greenhouse gases released in scenario one, the emission of more than 395 tons of greenhouse gases will be reduced due to material recycling that prevents the extraction and processing of natural resources. The study that carried out on Malaysian MSW management improved that the carbon emission factor of dumping area of MSW was highest, however it was lowest for recycling of materials [12].

3.4. Economic analysis of scenarios 1 and 2

A comparison of revenues, expenditures and the amount of greenhouse gases produced by implementing scenarios 1 and 2 based on the year of the study (2020) is shown in Table 5. As this table shows, for Amol-Noor region with about 600 TPD of MSW , the required investment for Scenario 1 is about USD 466777 as initial investment and USD 466776.92 annually for sanitary landfill operation, while implementation of Scenario 2 requires an initial investment of more than USD 20546192 (more than 40 times of Scenario 1) and its operating cost is estimated more than USD 1438233 (more than 3 times of Scenario 1).

Many of studies were proved that the most sustainable and short-term solution is recycling of materials[7], so, revenues from material recycling in Scenario 1 can cover the cost of sanitary landfilling, and in Scenario 2, revenues from project implementation can cover the costs of project operation. Of course, in this study, the assumption of financing the construction of the projects is gratuitous by the government. Obviously, if the initial investment of the project is made by the private sector, the investment model will be completely change and parameters such as bank interest, investment profit, etc. must be considered.

Table 5.
Technical and economic study of the proposed scenarios for Amol-Noor regions

Item		Scenario 1	Scenario 2
Execution costs of recycling unit, USD	Recycling Unit	-	830769.23
	Anaerobic digestor	-	15384615.38
	Composting unit	-	3100038.46
	RDF production	-	1230769.23
	Incineration plant	-	-
	landfilling	466776.92	36500
Emissions ($MTCO_2E$)		386.81	-395.95
Products	Recycling (TPD)	8.8	132.38
	Compost (TPD)	-	65
	RDF (TPD)	-	49.5
	Landfilling (TPD)	591.2	39.3
	Electricity (MW)	-	2.5
Annual Income, USD		494153.85	9884607.69
Initial investment, USD		466776.92	20546192.31
Annual Operational cost, USD		466776.92	1438233.46

If the losses of $50 per ton of carbon emissions is considered, based on the investment data presented in Table 5, the total costs and Revenues by implementing scenarios 1 and 2 for a period of 20 years are shown in Table 6.

According to the Table 6, implementation of Scenario 1 in a period of 20 years, causes more than 141 million USD of economic and environmental damages due to the waste of resources and various pollutants emissions from landfills. While implementation of Scenario 2, in a same period leads to saving of about 293 million USD by preserving in resources and energy through implementation of integrated waste management.

Table 6.
Costs and incomes of Amol-Noor proposed scenarios for a period of 20 years

Parameters for 20 years operation	Scenario 1	Scenario 2
Total investment, USD	466776.92	20546192.31
Total Incomes, USD	9883076.923	197692153.8
Operational Costs, USD	9335538.462	28764669.23
Environmental impact costs, USD	141185650	-144521750
Sum, USD	-141104888.46	292903042.3

4. Conclusion

Municipal solid waste issue in the northern provinces of Iran has been a serious concern of national and regional government for many years. Lack of a clear roadmap to solve the MSW problem and also lack of an independent organization to prepare and implement waste management projects, most of the waste problems remained unsolved. Implementing integrated waste management with the aim of minimizing waste production, increasing recycling, organic waste processing by anaerobic digestion, RDF production to reduce the risk and costs of incinerator construction and decreasing waste disposal could be a proper solution to solve the waste problem of the northern provinces of Iran. The most sustainable and short-term solution is recycling of materials. Allocation of sufficient grants by the government to implement integrated waste management can provide sufficient technical, environmental and economic justification for the private sector to enter and solve the problem of waste in different parts of the country.

Acknowledgments

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