



Social sustainability of treatment technologies for bioenergy generation from the municipal solid waste using best worst method

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ABSTRACT

Despite the fundamental role of the social aspect in the implementation of sustainability in the bio-based industries, most of the sustainability assessments research have addressed the environmental and economic dimensions. However, the social dimension has been neglected and it can cause an irreparable outcome in the biotechnology industries.

Following this issue, this study propounds a modified systemic approach for a social sustainability impact assessment of the treatment technologies for converting waste into bioenergy, based on a review on the common social assessment methods.

As it is known, the guideline presented by the United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (2009) due to considering social life cycle assessment has a comprehensive look at the stakeholders. Therefore, in this paper, UNEP method was selected. However, it needs to be modified based on the bio-energy supply chain derived from municipal solid waste. For this purpose, the bioenergy value chain derived from municipal solid waste was designed and combined with UNEP guideline, to complete the level of stakeholder subgroups and the levels of the indicators. The final method of the social assessment system was presented to the board of experts and finalized.

In order to design the measurement part of the social assessment system, because of a multi criteria decision making nature of the social sustainability evaluation of the conversion technologies of municipal solid waste to bio-energies, a recent developed multi-criteria decision making method so-called Best Worst Method (BWM) was used in two stages. The criteria are ranked according to their average weight obtained through Best Worst method. One of the major novelties in this research is the way of application of the best worst technique in the second stage. The model was implemented in the case of Tehran as one of the pioneering Iranian municipalities with high potential to produce bioenergy. The results of this study help decision makers to decide where to concentrate their attention during the implementation stage, and to increase social sustainability in their bioenergy supply chains derived waste.

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Term	Participation Percentage of Authors					
	Zahra Alidoosti	Ahmad Sadeghieh	Kannan Govindan	Mir Saman Pishvae	Ali Mostafae	Abul Kalam Hussain
Conceptual model						
Designing conceptual model	100%	90%	50%	90%	10%	10%
Literature review	100%	90%	87%	95%	10%	
Life cycle Assessment of treatment technologies	100%	50%	20%	80%	10%	30%
The Idea for Using modified social value chain	100%					
Extracting subcategories and indicators	80%	50%	50%	50%	50%	50%
Designing Measurement model						
The Idea for Using BWM for Measurement				100%		
Programming and Using BWM	100%	70%		50%		
Software	100%	70%		70%		
Validation and verification	80%	80%	40%	80%	30%	20%
Writing - Review & Editing	90%	80%	95%	60%	20%	30%
Funding acquisition	100%	100%				
Project administration	70%	100%		50%	40%	
Supervision		100%				

1. Introduction

According to the growth in approach of biotech industry development with noticeable an annual turnover and job creation, it is important to know whether this economic development leads to the equal opportunities and removes social difficulties in the society. For this purpose, to implement sustainability and its evaluation in the bio-based industries, it is necessary to consider the environmental, economic and social aspects together. While, the majority of sustainability assessments are mainly concerned with the economic and environmental aspects and social impacts are rarely investigated.

According to [Rafiaani et al. \(2016\)](#), the nature of social sustainability of bio-based industries is comprised of: how can it be accepted and what size is the domain of acceptance by the society, and what are the advantages of bio-industry to various societies.

There are different definitions for social sustainability because of its ambiguous meaning. [Rafiaani et al. \(2018\)](#) referred to the definition of [Black \(2004\)](#) "how far social worth, social identities, social communications and social establishments can be extended into the future". According to [European commission \(2016\)](#); which was pointed out by [Vanclay et al. \(2015\)](#) and [Rafiaani et al. \(2018\)](#), social sustainable bio-based economy consists of organizing a long-time sustainability plan with ongoing monitoring of social impacts such as food safety, the energy supply reliability, and the security of regions with respecting human rights. According to the definition of the Office of the Deputy Prime Minister in the UK that was referred by [Eizenberg et al. \(2017\)](#), social sustainability in a society was defined in this way: "Sustainable communities are the societies where people want to live and work, now and in the future. They meet the different necessities of present and future inhabitants, are responsible to their environment, and help to a high quality of life. They are secure and inclusive, well planned, made and run, and provide equal opportunities and useful services to everyone".

Based on our review, there is rarely a comprehensive social sustainability definition with balancing other aspects of sustainability, including economic and environmental aspects. In this study, it was attempted to define comprehensive definition of social sustainability to be integrated with the economic and environmental aspects. Therefore, the new definition should include "When the economic development leads to remove social difficulties, create equal opportunities, food and energy security, region development with considering human rights and the others social goals while maintaining environmental priorities, in which means the social sustainability happened" or in the short term "When the economic growth leads to social growth along with maintaining environmental priorities, it means the social sustainability

happened".

According to our reviews, some of the most used guidelines for social sustainability assessment that particularly concentrated on the bio-based and bioenergy sections are the Social Life Cycle Assessment of Products ([UNEP-SETAC, 2009](#)), The Global Bioenergy Partnership (GBEP sustainability indicators for bioenergy, 2011), Global-Bio-Pact (2012), Oak Ridge National Laboratory (ORNL, 2013) and BioSTEP (2016). ([Blom & Solmar, 2009](#); [Hasenheit et al., 2016](#); [Global-Bio-Pact, 2013](#); [Siebert et al., 2016](#); [UNEP-SETAC, 2009](#); [Van Dam et al., 2010](#); [Köppen, 2014](#); [Dale et al., 2015](#); [Efroymsen et al., 2016](#); [Vis et al., 2014](#); [Diaz-Chavez, 2014](#)).

The commonly applied methodologies of all above guidelines is divided into three categories including Social Impact Assessment (SIA), Socio-Economic Impact Assessment (SEIA), and Social Life Cycle Analysis (SLCA). The main difference among the methodologies is related to impact categories and evaluation techniques. SIA and SEIA focus on assessing the social impacts on the community structure as well as considering the protection of cultural ones. In contrast to these two methodologies, SLCA focuses on the impacts on various stakeholders while considering the full life cycle ([Dale et al., 2015](#); [Hosseini et al., 2014](#); [Ibáñez-Forés et al., 2019](#)).

According to this study, there is no worldwide suite social sustainability assessment system which covers all social dimensions and contains a set of indicators that can be applied in the same way in all cases as it really depends on the scope of the study and the priorities of the stakeholders involved in the bio-industry under consideration ([Habibi et al., 2017](#); [Mirdar Harijani et al., 2017](#); [Ahmadi et al., 2017](#); [Fedorova and Pongrácz, 2019](#); [Hasenheit et al., 2016](#); [Dale et al., 2013](#); [van Dam et al., 2013](#); [Köppen, 2014](#)). Since the value of an indicator depends on the quality of the data it contains, the indicator must be carefully selected. By studying these guidelines and indicators, we found that the guidelines presented by the United Nations Environment Program and the Society of Environmental Toxicology and Chemistry (UNEP/SETAC) (2009) method is the most comprehensive in terms of stakeholders, but the level of stakeholder subgroups and levels of indicators need to be completed. The social effects in the social guideline of [UNEP \(2009\)](#) classify in five stakeholder categories that are affected by the life cycle of a product: workers, users, local community, society, and value chain actors. Social outcomes are realized to be very complicated. Moreover, they are completely depending on the geographical place as well as socio-economic circumstances. For simplifying these complexities of social impacts, the value chain of bio-energies derived from municipal solid waste was combined with this guideline. Therefore, it could both reduce the assessment levels in the introduced social assessment guideline and result in extending this guideline.

The goal of this study is to propose a methodology to assess the social sustainability of treatment technology for conversion of municipal solid waste into bioenergy by using the Best-Worst Multi-Criteria Decision Making Method (BWM). By reviewing of the technical feasibility studies and consulting with energy specialists and biotechnologists in the section of industry and academia, the treatment technologies were selected based on their feasibility to the nature of municipal solid waste in the scope of this study. These specialists were selected based on the knowledge of researchers about the bioenergy stakeholders and the consultants in the field of municipal solid waste management and bio-energies. These technologies include: Anaerobic digester for heat and electricity, Anaerobic digester for domestic gas usage, Anaerobic digester for gas fuel, Pyrolysis for electricity, Fermentation for bioethanol, and Landfill with domestic gas.

The Best-Worst Method proposed by [Rezaei \(2015\)](#) applies only the best and the worst criteria for pair-wise comparison and it does not require a complete pairwise comparison. Therefore, compared with the equivalent techniques it requires less data. The method of BWM needs only 2n-3 comparisons and it outcomes more stable results because of its pairwise comparative structure ([Rezaei, 2015, 2016; Sadjadia and Karimi, 2018; Salimi and Rezaei, 2017](#)). Because of these significant reasons, we used this method in our research. The method of BWM has been used for some of the applied problems during the past four years such as supplier management ([Rezaei et al., 2015](#)), risk evaluation ([Torabi et al., 2016](#)), Identifying enablers of technological innovation for Indian enterprises ([Gupta and Barua, 2016](#)), developing a strategy to dominate barriers to energy efficiency in the buildings ([Gupta et al., 2017](#)), assessing the social sustainability of supply chains ([Ahmadi et al., 2017](#)), evaluation of the external forces affecting the sustainability of oil and gas supply chain ([Ahmad et al., 2017](#)), investigation of the key success factors in technological innovation development ([Ghaffari et al., 2017](#)), assessing firms' R&D efficiency ([Salimi and Rezaei, 2018](#)), Risk Prioritization in Mega projects ([Norouzi, and Ghayur Namin, 2019](#)) and assessing the drivers of sustainable procurement ([Kannan, 2021](#)).

Following the mentioned applications, in order to do the assessment of treatment technologies for bioenergy, we applied BWM method to develop two-step innovative approaches for the

presented assessment method based on UNEP guideline. The proposed social sustainability assessment was implemented to a case study in Tehran (Iran) as one of the leaders of Iranian municipalities with high potential of producing bioenergy. Moreover, the validation of the BWM outputs is considered. At the end, along with conclusions, the comments have been pointed out for the further research.

2. Methodology

This study begins with defining the goal and scope of the research. The goal is to evaluate the social score of treatment technologies for municipal solid waste. The scope is the entire stages of the bioenergy supply chains based on selected feasible treatment technologies tailored to municipal solid waste.

In the second step in order to design the conceptual part of the social sustainability assessment system of bio energy treatment technologies based on municipal solid waste (MSW), attempts were made to extend the social life cycle assessment methodology based on the [UNEP/SETAC \(2009\)](#). The social implications in the social guideline of [UNEP \(2009\)](#) are classified in five stakeholder categories that are affected by the life cycle of a product: workers, users, local community, society, and value chain actors. By e grouping into impact categories, it will be possible to identify subcategories, to collect subcategory indicators within groups with the same impacts, to assess further impact assessment and interpret. For extending this guideline, firstly the relevant literature, social sustainability reports and guidelines were reviewed and social subcategories and indicators were extracted (see [Tables 1 and 2](#)).

In order to complete these indicators and subcategories, the social value chain of bio energies was combined with UNEP guideline, in which, it includes three levels so-called upstream, midstream and downstream ([Fedorova and Pongrácz, 2019](#)). In our study, this bio energy value chain was modified based on bioenergy derived municipal solid waste. This social value chain includes activities, basic supply chain and social impacts. By consulting the experts, the social effects of these activities were identified along the entire bio energy value chain (see [Fig. 1](#)). The design of this value chain helped to complete the initial extracted subcategories

Table 1
Social subcategories according to the literature and guidelines.

Subcategories	Guidelines	References
Occupational injury	Global-Bio-Pact(2012), GBEP (2011), BioSTEP (2016), ORNL (2013), UNEP-SETAC(2009), Pre-Sustainability(2018)	Devika et al., 2014; Ibanez-Foresa et al., 2019; Fedorova, 2018; Mota et al., 2015; Govindan et al., 2020
Region development and increase healthy living conditions	GBEP (2011), Global-Bio-Pact(2012), Pre-Sustainability (2018), ORNL (2013), UNEP-SETAC(2009), BioSTEP (2016)	Markevicius et al., 2010; Devika et al., 2014; Bairamzadeh et al. (2015); Yildiz. et al., 2017; Tsao (2017); Govindan et al., 2015; Mota et al., 2015; Ibanez-Foresa et al., 2019; Fedorova and Pongrácz, 2019; Hasenheit et al., 2016; Habibi et al. (2017)
Energy security	GBEP (2011), ORNL (2013)	Fedorova, 2018; Dale et al., 2015; Efroymsen et al., 2016;
External trade	ORNL (2013),	Dale et al., 2015;
Resource conservation	ORNL (2013)	Efroymsen et al., 2016; Dale et al., 2015;
Technology development	UNEP-SETAC(2009)	Efroymsen et al., 2016; Zhang, 2013; Santos et al., 2019;
Relationships between chain members	Global-Bio-Pact(2012), GBEP (2011), BioSTEP (2016), ORNL (2013), UNEP-SETAC(2009)	Fedorova (2018); (Hasenheit et al., 2016); Ibanez-Foresa et al. (2019)
Quality of products and Responsibility towards customer	UNEP-SETAC(2009), BioSTEP (2016)	Mirdar Harijani et al., 2017a,b; Hasenheit et al., 2016; Govindan et al., 2015

Table 2

Social indicators according to the literature and guidelines.

Indicators	Guidelines	References
Occupational injury potential	Global-Bio-Pact(2012), GBEP (2011), BioSTEP (2016), ORNL (2013), UNEP-SETAC(2009), Pre-Sustainability(2018)	Devika et al., 2014; Ibanez-Foresa et al., 2019; Fedorova and Pongrácz, 2019; Mota et al., 2015
Potential to job creation	GBEP (2011), Global-Bio-Pact(2012), Pre-Sustainability (2018), Global-bio-pact(2012), BioSTEP (2016), ORNL (2013),	Tsao (2017); Markevičius et al., 2010; Devika et al., 2014; Bairamzadeh et al. (2015); Yıldız-Geyhan et al., 2017; Tsao (2017); Mota et al., 2015; Fedorova and Pongrácz, 2019
Environmental pollution potential	GBEP (2011), ORNL (2013)	Ibanez-Foresa et al., 2019; Fedorova and Pongrácz, 2019
Waste consumption rate	GBEP (2011), ORNL (2013)	Habibi et al. (2017)
Government policy to facilitate bioenergy production	ORNL (2013)	Fedorova and Pongrácz, 2019; Dale et al., 2015; Efrogmson et al., 2016;
Impact of increasing renewable energy exports	UNEP-SETAC(2009)	Dale et al., 2015; Efrogmson et al. (2016)
Process efficiency	Global-Bio-Pact(2012), GBEP (2011), BioSTEP (2016), ORNL (2013), UNEP-SETAC(2009)	Zhang et al., 2013; Santos et al., 2019
Social acceptance rate		Fedorova and Pongrácz, 2019, Ibáñez-Forésa et al., 2019

and indicators from the literature review, to assure all the social effects have been considered in our conceptual model. Then, it was resulted in reducing the assessment levels in UNEP guideline, with the extension of indicators in the third level (Fig. 2).

In the next step, all five stakeholder categories, subcategories and their indicators are presented to the board of experts including the managers and engineers at Tehran Waste Management Organization(TWMO), Renewable Energy and Energy Efficiency Organization, university teachers and biotechnologists. The purpose and domain of our research are explained during interview with them. In order to standardize the subcategories and indicators, Riddle method was used. At first, the questionnaire that includes conjunction of subcategories and indicators was designed. Then, the experts were asked to identify the degree of importance by interval scale. Thereafter, median and standard deviation were calculated for all the subcategories and indicators. Finally, the total median was estimated and the subcategories and indicators smaller than total median were eliminated. According to their viewpoints, eight subcategories and fourteen indicators are considered as final decision-making hierarchy of social impact assessment at three levels (see Fig. 3).

Some of these subcategories and indicators have been rarely considered in previous studies. As the subcategory, we can refer to "bioenergy quality". Moreover, the indicators consist of "the impact on the decline in non-renewable energy imports", "the amount of fossil energy consumption per unit of bioenergy production", "the added value of fossil energy replaced by bioenergy", "technology complexity", "the content of energy produced per unit of bioenergy generated" and "reduction rate of greenhouse gas compared to the previous situation".

In the fourth step in order to design the measurement part of the social assessment system, since evaluation system the social sustainability of the bio energies is a multi-criteria decision making (MCDM) concept, therefor it should be applied MCDM method to measure it. There are several MCDM techniques that have been used in previous studies for sustainable renewable energy development (Vanclay et al., 2015). Comparing with available methods, Best Worst Method (BWM) needs less data and it does not require a complete pairwise comparison matrix. As well as it generates more stable outcomes because of the nature of its pairwise comparison. It is also realized by the decision-makers as simple and very neighbor to their decision. Because of these reasons, BWM is applied in this study.

In the following lines, it has been briefly explained the stages of

the methodology based on BWM that can be applied to define the weights of the stakeholders, subcategories and criteria (Rezaei, 2015; Rezaei, 2016; Salimi, & Rezaei, 2017):

2.1. Specifying a collection of decision criteria

Decision criteria in the proposed conceptual model in this study are divided in three levels: stakeholders, subcategories and indicators in each subcategory that should be used to arrive at a decision. At the first level, final social score would be a decision. But at the second level, impact on the enhancing social impact of each stakeholder would be a decision. Moreover, the effect on the social impact of subcategory could be a decision in the third level.

2.2. Determining the best and the worst

In this stage generally, the decision-maker/expert(s) identifies the best (e.g. the most important) and the worst criteria (e.g. the least important) in three levels. Firstly, the best (the most important) and the worst (the least important) stakeholders based on their impacts in enhancing social rank are determined. Next step, at the subcategories level, the worst and the best subcategories of each stakeholder are identified based on their impacts in enhancing social rank of each stakeholder. Finally, in the level of criteria in each subcategory, the best and the worst criterion based on their impact in enhancing social rank of each subcategory are specified.

2.3. Specifying the priority of the best criterion over all other decision criteria

In three levels of stakeholders, subcategories and indicators by using a 9-point scale (number between 1 and 9; 1: The degree of importance of B and J is the same; 9: B is much more important than J) the priority of the best stakeholder, subcategory and criterion over all the other stakeholders, subcategories and decision criteria are specified. The resulting Best-to-Others vector would be: $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$, where a_{Bj} indicates the preference of the best criterion B over criterion j. It is clear that $a_{BB} = 1$.

2.4. Specifying the priority of all decision criteria over the worst criterion

Applying a 9-point scale, which results in others-to-worst (OW) vector as follows. $A_W = (a_{1w}, a_{2w}, \dots, a_{nw})^T$, where a_{jw} represents

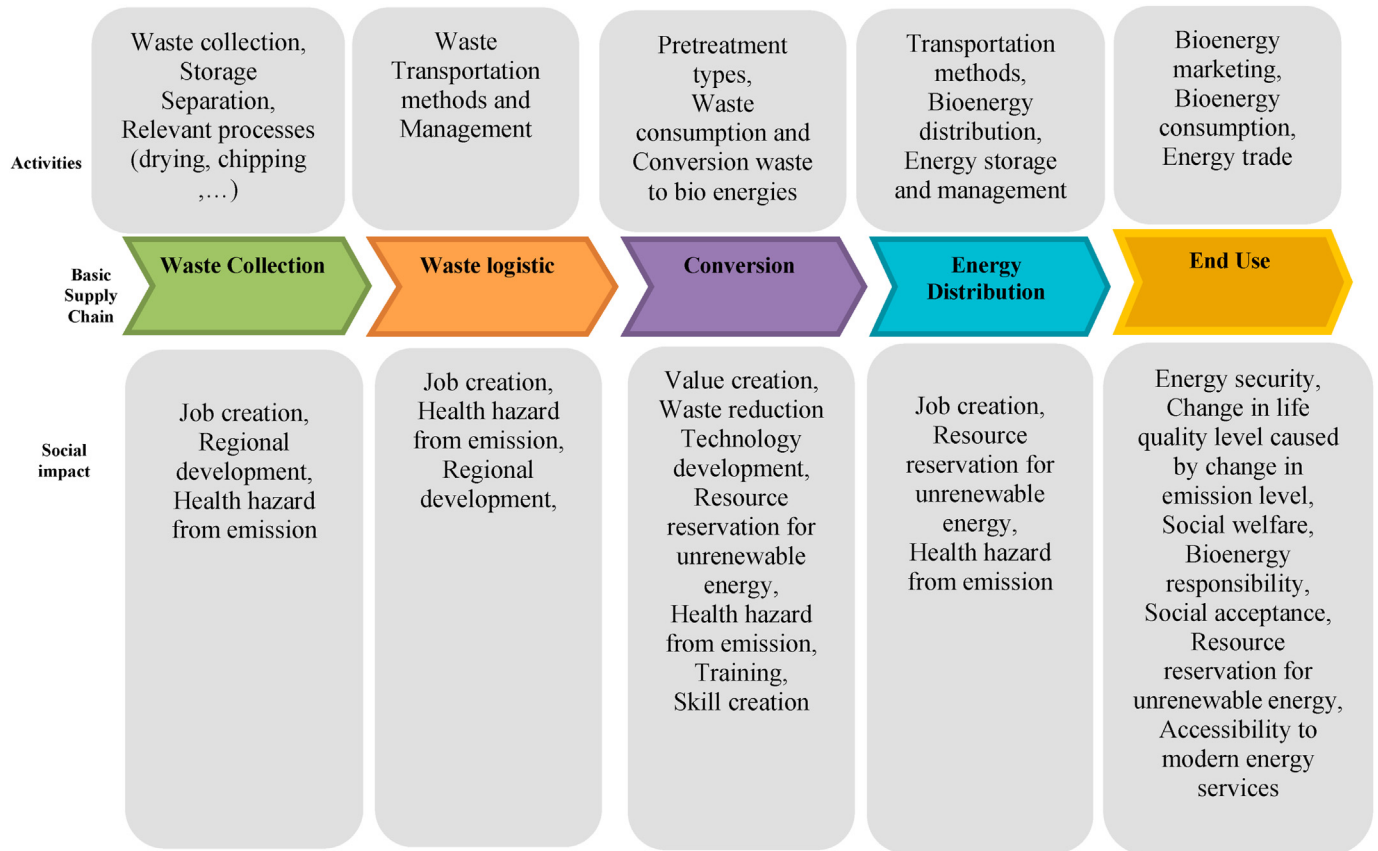


Fig. 1. Value-adding activities and social impacts throughout the bioenergy supply chain derived from waste (improved from Fedorova & Pongrácz, 2019).

the priority of j over w and $a_{ww} = 1$.

$$|w_j - a_{jw}w_w| \leq \xi^L; \text{ for all } j$$

2.5. Finding the optimal weights

The optimal weights ($w_1^*, w_2^*, \dots, w_n^*$) should be defined such that the maximum absolute differences $\{|w_B - a_{Bj}w_j|; |w_j - a_{jw}w_w|\}$; for all j is minimized. Where w_j displays the weight of j ; w_B and w_w represent respectively weight of the best and the worst criteria. Considering the non-negativity and sum condition for the weights, the following problem is resulted:

$$\min \max_j \{|w_B - a_{Bj}w_j|; |w_j - a_{jw}w_w|\}$$

s.t.

$$\sum_j w_j = 1 \quad (1)$$

$$w_j \geq 0; \text{ for all } j$$

Problem (1) is equivalent to the following linear problem:

$$\min \xi^L$$

s.t.

$$|w_B - a_{Bj}w_j| \leq \xi^L$$

for all j

$$\sum_j w_j = 1, w_j \geq 0; \text{ for all } j \quad (2)$$

Solving problem (2), it can be determined that the optimal weights ($w_1^*, w_2^*, \dots, w_n^*$) and the optimal objective function value ξ^{L*} . ξ^{L*} is the consistency index, its values near to zero indicate a high level of consistency of the pairwise comparisons prepared by the decision makers. For MCDM problems with more than one level, we should identify the weights for different levels following the BWM stages, after which we can multiply the weights of different levels by each other to determine the final weights. Applying BWM, the optimal weights of the criteria ($w_1^*, w_2^*, \dots, w_n^*$) are gained.

3. Validation of social sustainability assessment system

In the validation step, the social sustainability rank of waste treatment technologies should be evaluated. One of the major contributions in our study is the way of use of the best worst technique for determining the social score of each treatment technologies. Treatment technologies play the indicator role in the proposed assessment method and each criteria in the third level of this plays a decision role. In the following lines, the stages of the methodology based on BWM has been briefly illustrated that can be used to determine the social sustainability score of treatment technologies:

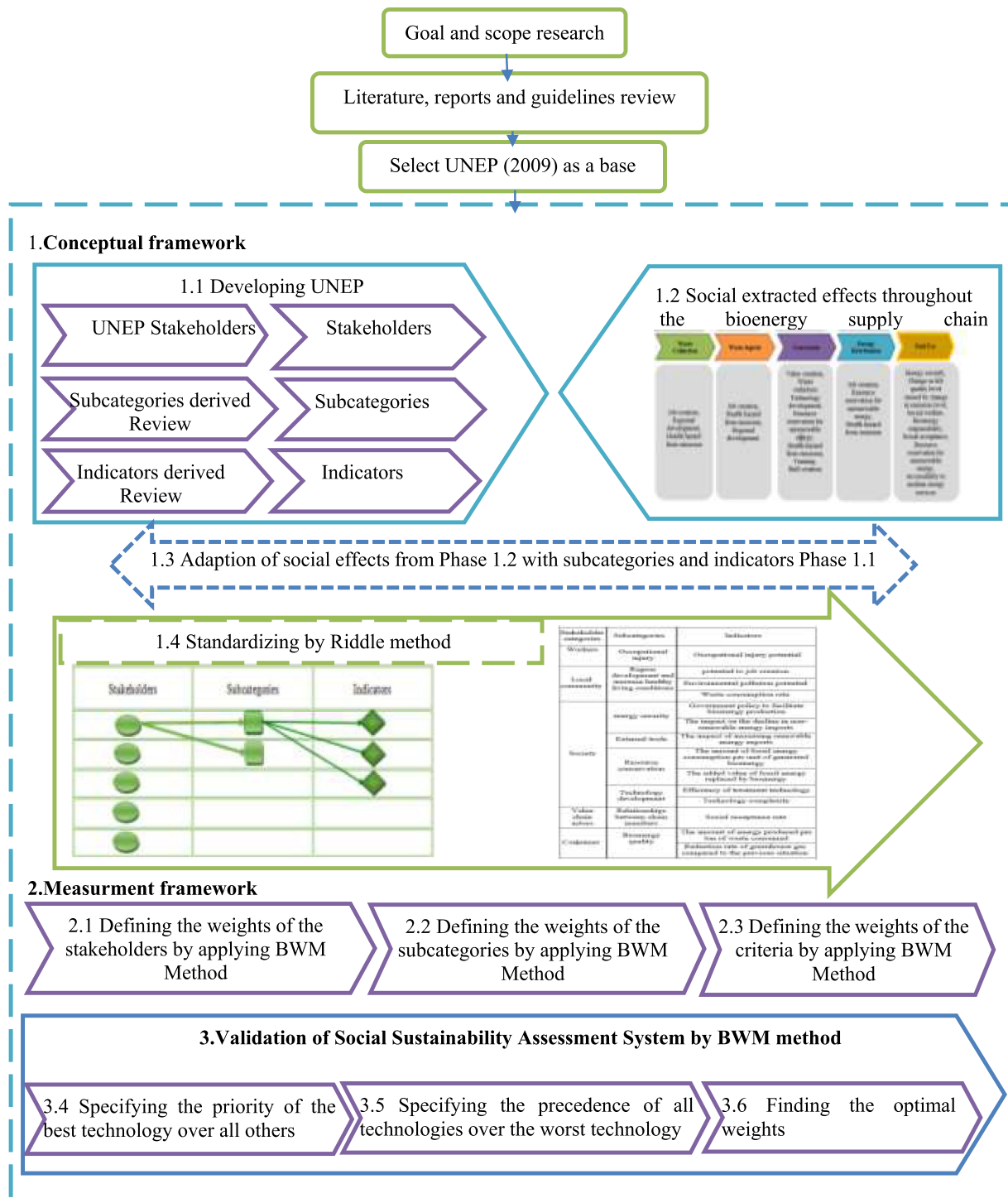


Fig. 2. Framework of social sustainability assessment system.

3.1. Specify a decision and a set of decision criteria

As mentioned above, each of the criteria in the third level of the proposed social sustainability assessment system plays the role of decision, and the treatment technologies play the role of criteria.

3.2. Specifying the best and the worst technology

In this stage the best and the worst treatment technology based

on their impacts on of each criterion in the social sustainability assessment system have been identified.

3.3. Specifying the priority of the best technology over all other technologies

By Applying a 9-point scale the preference of the best treatment technology over all other technologies is specified. The resulting Best-to-Others vector would be: $C_B = (C_{B1}, C_{B2}, \dots, C_{Bn})$, where C_{Bj}

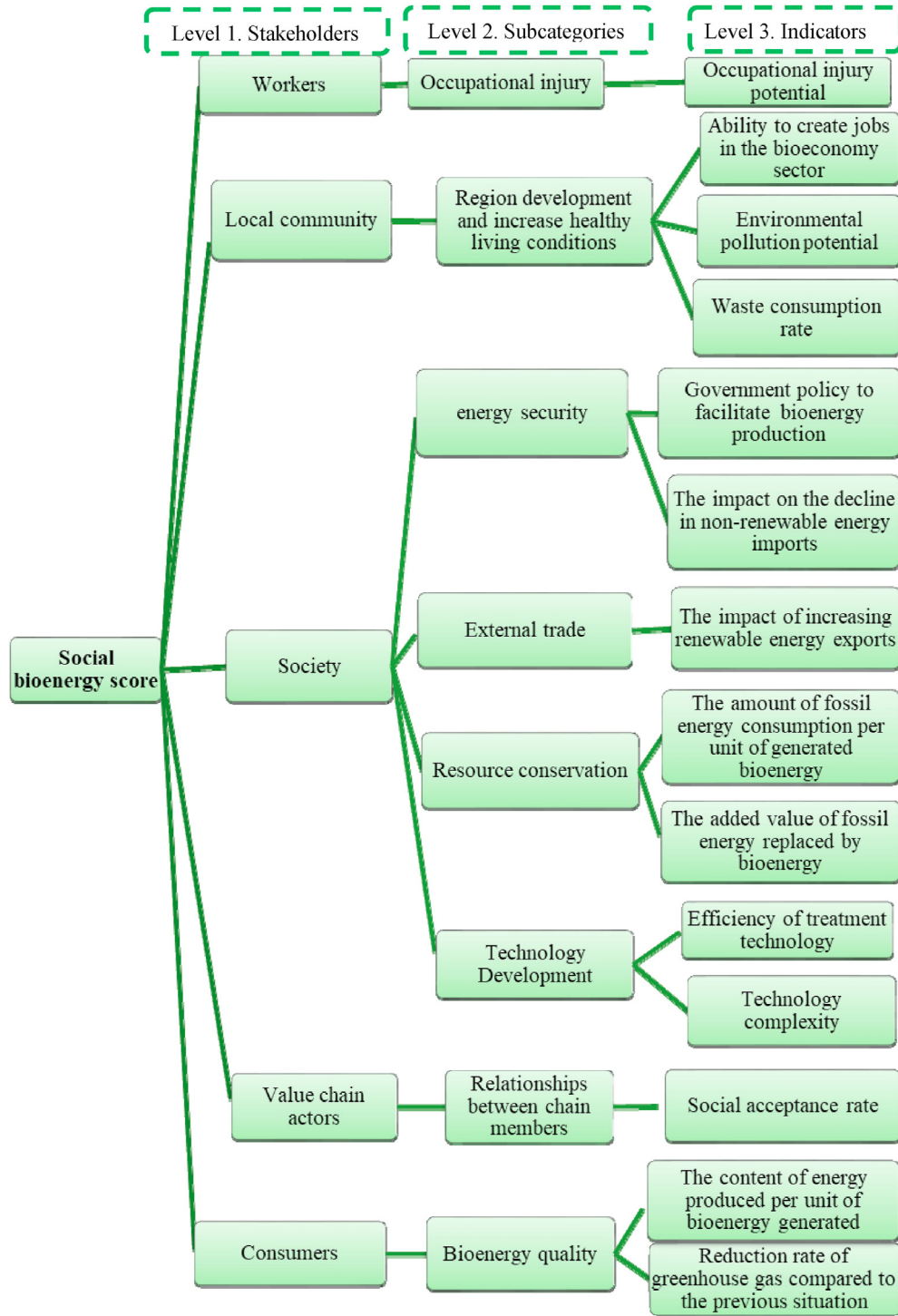


Fig. 3. Decision-making hierarchy of social impact assessment at different levels.

illustrates the priority of the best technology B over technology j. It is clear that $c_{BB} = 1$.

3.4. Specifying the precedence of all other technologies over the worst technology

In this stage, by using a 9-point scale, which concludes in the others-to-worst vector as follows. $C_W = (c_{1w}, c_{2w}, \dots, c_{nw})^T$, where c_{jw} displays the precedence of j over w and $c_{ww} = 1$.

3.5. Finding the optimal weights

The optimal weights $(t_1^*, t_2^*, \dots, t_n^*)$ should be determined such that the maximum absolute differences $\{|t_B - c_{Bj}t_j|; |t_j - c_{jw}t_w|\}$ for all j is minimized. Where t_j represents the technology weight of j; t_B and t_w represent respectively weight of best and worst technology. Regarding the non-negativity and sum condition for the weights, the following problem is concluded:

$$\begin{aligned} \min \max_j \{ & |t_B - c_{Bj}t_j|; |t_j - c_{jw}t_w| \} \\ \text{s.t.} \\ \sum_j t_j &= 1 \end{aligned} \quad (3)$$

$$t_j \geq 0; \text{ for all } j$$

Problem (3) is equivalent to the following linear problem:

$$\begin{aligned} \min \xi^L \\ \text{for all } j \\ |t_j - c_{jw}t_w| \leq \xi^L; \text{ for all } j \\ \sum_j t_j = 1, t_j \geq 0; \text{ for all } j \end{aligned} \quad (4)$$

Solving problem (4), it can determine the optimal weights ($t_1^*, t_2^*, \dots, t_n^*$) and the optimal objective function value. ξ^L is the consistency index, its values near to zero show a high level of consistency of the pairwise comparisons prepared by the decision-makers. For MCDM problems with more than one level, the weights of different levels should be specified by using BWM technique in each level, then for identifying the final weights, it is possible to multiply the weights of different levels by each other.

3.6. Specifying the consistency ratio

In this part, to compare the consistency of the output a consistency ratio needs to be determined. According Rezaei (2015) consistency ratio (CR) is an evaluation of the reliability of the results of a BWM technique.

A comparison is exactly consistent when $a_{Bj} \times a_{jw} = a_{BW}$, for all j , where a_{Bj} , a_{jw} and a_{BW} , are respectively the preference of the best criterion over the criterion j , the precedence of criterion j over the worst criterion, and the precedence of the best criterion over the worst criterion. When for some j not to be completely consistent, it is defined a consistency ratio to display how consistent a comparison is. As mentioned by Rezaei (2015) $a_{ij} \in \{1; \dots; a_{BW}\}$ where the highest possible value of a_{BW} in our study is 9. Consistency decreases when $a_{Bj} \times a_{jw} \neq a_{BW}$ and with the maximum value for a_{Bj} and a_{jw} or equal to a_{BW} the highest inequality occurs, which will conclude in ξ . It is also clear that $w_B/w_j \times w_j/w_w = w_B/w_w$; and given the highest in equality, ξ is a value that should be subtracted from a_{Bj} and a_{jw} and added to a_{BW} , or equivalently:

$$(a_{Bj} - \xi) \times (a_{jw} - \xi) = (a_{BW} + \xi) \quad (5)$$

Problem (5) for the minimum consistency $a_{Bj} = a_{jw} = a_{BW}$, can be equal to the following problem:

$$\xi^2 - (1 + 2a_{BW})\xi + (a_{BW}^2 - a_{BW}) = 0 \quad (6)$$

By using different values of $a_{BW} \in \{1; \dots; 9\}$, the maximum possible ξ as consistency index can be found (see Table 3). Then for comparing the consistency amount of research output, the

Table 3
Consistency index (CI).

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index(max ξ)	0.00	0.44	1	1.63	2.30	3.00	3.73	4.47	5.23

consistency ratio is defined as follows:

$$\text{Consistency Ratio} = \frac{\xi^*}{\text{Consistency Index}} \quad (7)$$

3.7. Case study and treatment technologies

Since 1903, the municipalities in Iran have been responsible for various waste management activities. Due to increased migrations to cities and noticeable urban population growth, waste management activities have been taken more attention, and this, resulted in the establishment of the Waste Management Organization in 1961 as one of its subset organizations in Tehran Municipality. One of the significant tasks of this organization has been collecting and separating recyclable and non-recyclable wastes, establishing processes to recycle and reuse, and managing transportation among different treatment facilities allocated for these processes. The Waste Management Organization of Tehran includes 11 distribution centers.

In this study for implementing assessment system for social score of bioenergy supply chains, Aradkooh in Tehran as a Treatment Site for Municipal Solid Waste and the recipient of Tehran City wastes of 1976 was chosen.

This center is located in the southern part of Tehran in Kahrizak region with an area of approximately 1400 ha. Each day an average rate of 7400 tons of wastes are imported into this center. The wastes are collected from 22 districts of Tehran including city wastes with approximately of 6800 tons/day, hospitals daily wastes and health and treatment centers with the waste of approximately 80 tons/day, companies daily wastes and other wastes with an approximate rate of 580 tons/day.

Some of the wastes imported after being weighed are conveyed to the process and recycle units for the waste processing and compost producing, and others are transported to the landfill. (Tehran Waste Management Organization (TWMO), 2019; Mirdar Harijani et al., 2017; Edalatpour, 2018).

Selecting optimal waste treatment for conversion the waste into energy is the important issue in this center that needs to work on it. In this regards, life cycle assessment of treatment technologies to convert the waste into energy have been studied. The feasible treatment technologies including anaerobic digestion for electricity and heat, anaerobic digestion for gas, anaerobic digestion for gas fuel, pyrolysis, fermentation and landfill with gas recovery were chosen, keeping an eye on Iran conditions and the kind of the compositions of Tehran municipal solid waste.

3.8. Participants and description of measures

To determine the social sustainability score of treatment technologies, we interviewed and presented questionnaire to the board of specialists. The demographic information of them is summarized in Table 4 and Table 5 showing the measures for each decisions from questionnaire. These specialists were selected based on combination of purposeful and snowball sampling. In this method, interviewees were selected based on researcher knowledge about bioenergy stakeholders and consultants. Moreover, after the interview, the expert was asked to suggest other experts among the experts in the field of bioenergy, biotechnology and waste management (Heckathorn, 2011; 2017; Naderifar et al., 2017).

4. Result

This section is started by presenting the weight of stakeholder

Table 4
Demographic information of participants.

No.	Position	Location	Experience area: bioenergy industry/Waste management/ Managing sustainable supply chain	Education
1	Deputy for Processing and Disposal of Waste	Tehran Waste Management Organization	Over 10 years	MSc
2	Bioenergy expert	Tehran Waste Management Organization	5–10 years	MSc
3	General Manager	Renewable Energy and Energy Efficiency Organization	Over 10 years	MSc
4	Consultant for bioenergy Production and Waste management projects, university teacher	Iran university of Science and Technology	Over 10 years	PhD
5	Consultant for bioenergy production and waste management projects, university teacher	Iran University of Science and Technology	5–10 years	PhD
6	Managing Director	Private company	5–10 years	BSc
7	Managing Director	Private company	5–10 years	BSc
8	Consultant for energy production, university teacher	Yazd University	Over 15 years	PhD
9	Consultant for bioenergy production, university teacher	Sharif University of Technology	Over 10 years	PhD
10	Consultant for bioenergy production and sustainable supply chain, university teacher	Amirkabir University	Over 15 years	PhD
11	Consultant for bioenergy production and sustainable supply chain, university teacher	Urmia University	5 years	PhD
12	Processing expert	Tehran Waste Management Organization	5–10 years	BSc
13	Processing expert	Tehran Waste Management Organization	5–10 years	MSc
14	Consultant for bioenergy production, biotechnologist	Isfahan University of Technology	Over 10 years	PhD
15	Biotechnologist	National Institute for Biotechnology Engineering	Over 10 years	PhD
16	Biotechnologist	National Institute for Biotechnology Engineering	Over 10 years	PhD
17	Consultant for sustainable supply chain and bioenergy production, university teacher	Centre for Sustainable Supply Chain Engineering, Denmark	Over 10 years	PhD
18	Researcher	European Bioenergy Research Institute, UK	Over 5 years	PhD
19	Director of training	Renewable Energy and Energy Efficiency Organization	Over 15 years	MSc
20	Managing Director	Private company	5–10 years	PhD

categories, subcategories and indicators by respondents based on BWM, after which the average weight of indicators for each treatment technologies and social score of bioenergy technologies is identified.

4.1. Finding the optimal weights in the social sustainability assessment system

In this step, the optimal weights of the stakeholder categories, subcategories and global weight of indicators are computed by solving the BWM optimization model for each of the responders. Table 6 presents the results of weighting which indicates average consistency rate (C.R) is near to zero, accordingly the comparisons are extremely consistent and reliable.

4.2. Finding the social score of bioenergy treatment technologies

For considering social score of each technology the designed social assessment system was used for those as mentioned above. Table 7 shows the final outcomes of the social score of bioenergy treatment technologies. Moreover, Small numbers for the Consistency rate (C.R.) in Table 6 show homogeneity among respondents.

5. Discussion

The majority of the current literature to measure the social impacts for designing sustainable network of municipal solid waste

rarely focuses on the stakeholders with diverse background and there is no comprehensive framework for measuring multiple social impacts. Therefore, the indicators resulting from the social impacts of technology development, environmental pollution, energy security and so on have rarely been addressed, even in some cases where social impacts have been considered at diverse stakeholders, the comprehensive social life cycle study and systematic approach to extract social indicators has been neglected. Those social impacts that most sustainable network of municipal solid waste focus them would be creation job, visual pollution and so on.

By considering results of total social score of chosen treatment technologies, technology of fermentation and Pyrolysis has stood on the first and the last rank respectively. Moreover, Anaerobic digester for gas, Landfill with gas, Anaerobic digester for gas fuel and Anaerobic digester for heat and electricity has been ranked the second to the fifth respectively. As results show, although the indicator of job creation in the Anaerobic digester for gas fuel is more than Landfill with gas indicator amount of Landfill with gas, but the total social score of them is quietly the opposite. Also the indicator of waste consumption, related to visual pollution, in the technology of Anaerobic digester for heat and electricity and Anaerobic digester for gas is the same rank as well as in the technology of Landfill with gas and pyrolysis is almost the same but the total social score of them are completely different.

Although fermentation has stood on the first rank but indicator scores of Government-friendly policy and social acceptance has

Table 5
Measures to assess social sustainability of treatment technologies.

Decisions/Indicators	Measures	Type	Unit	Actions
Occupational injury potential	The best technology has the lowest potential for worker injury; and vice versa.	Semi-Quantitative	Rate of occurrence per total hours work	1. Literature review
Potential to job creation	The best technology has the highest potential for job; and vice versa.	Quantitative	Employment created per ton of consumed waste	2. Life cycle assessment
Environmental pollution potential	The best technology has the lowest potential for environmental pollution; and vice versa.	Quantitative	Kg emissions per ton of consumed waste	3. International consultation
Waste consumption rate	The best technology has the highest rate of waste consumption per unit of renewable energy; and vice versa.	Qualitative	Percentage of volume reduction of waste per unit of renewable energy	4. World statistics
Government-friendly policy	The best technology has the highest Government-friendly policies; and vice versa.	Qualitative	Presence of friendly policy	5. Collect technical information from previous actions and attach it to the questionnaire
The impact on the decline in non-renewable energy imports	The best technology has the highest impact on the decline in non-renewable energy import; and vice versa.	Qualitative	Positive impact on the decline in non-renewable energy import	6. Questionnaires
The impact of increasing renewable energy exports	The best technology has the highest impact on the increase in renewable energy exports; and vice versa.	Qualitative	Positive impact on the increase in renewable energy exports	7. Interviews
The amount of fossil energy consumption per unit of generated bioenergy	The best technology has the lowest rate of fossil energy consumption as the start- up energy for production of a unit of renewable energy; and vice versa.	Quantitative	Start- up energy consumed per unit of generated bioenergy	
The added value of replaced fossil energy by bioenergy	The best technology lead to bioenergy replaced with the fossil energy with highest added value; and vice versa.	Qualitative	The added value of replaced fossil energy by bioenergy generated	
Efficiency of treatment technology	The best technology has the highest efficiency; and vice versa.	Quantitative	Bioenergy generated per ton of MSW	
Technology complexity	The best technology has the lowest complexity; and vice versa.	Semi-Quantitative	Technology readiness level & skill level required	
Social acceptance rate	The best technology has the highest social acceptance potential; and vice versa.	Qualitative	Positive social acceptance	
The content of energy produced per unit of bioenergy generated	The best technology produce the highest content of energy per unit of bioenergy generated; and vice versa.	Quantitative	Content of energy generated (MJ) per unit of bioenergy generated	
Reduction rate of greenhouse gas compared to the previous situation	The best technology has the highest reduction rate of greenhouse gas compared to the previous nonrenewable energy; and vice versa.	Quantitative	(Kg CO ₂ /Unit of non-renewable energy)per (Kg CO ₂ /Unit of bio-energy)	

Table 6
Weighting social impact system assessment based on BWM.

Stakeholder categories	Weight	Subcategories	Weight	Indicators	Weight	Global weight of indicators	Average C.R
Workers	0.07	Occupational injury	1	Occupational injury potential	1	0.07	0.017
Local community	0.18	Region development and increase healthy living conditions	1	potential to job creation	0.37	0.067	0.039
				Environmental pollution potential	0.39	0.07	0.039
				Waste consumption rate	0.24	0.04	0.039
Society	0.45	energy security	0.36	Government policy to facilitate bioenergy production	0.53	0.086	0.018
				The impact on the decline in non-renewable energy imports	0.47	0.076	0.018
		External trade	0.11	The impact of increasing renewable energy exports	1	0.049	0.018
		Resource conservation	0.28	The amount of fossil energy consumption per unit of generated bioenergy	0.47	0.059	0.018
				The added value of fossil energy replaced by bioenergy	0.53	0.068	0.018
		Technology development	0.25	Efficiency of treatment technology	0.55	0.062	0.018
				Technology complexity	0.45	0.051	0.018
Value chain actors	0.13	Relationships between chain members	1	Social acceptance rate	1	0.13	0.017
Consumer	0.17	Bioenergy quality	1	The content of energy produced per unit of bioenergy generated	0.5	0.085	0.017
				Reduction rate of greenhouse gas compared to the previous situation	0.5	0.085	0.017

stood on the lowest rank amongst other technologies. This means that despite the lowest score of these indicators, positive social impacts of this technology on the society such as decline in non-renewable energy imports, increasing renewable energy exports, noticeable added value of replaced fossil energy by bioenergy would be significant that will lead to the society development. And vice versa, these indicators including Government-friendly policy

and social acceptance in the technology of Pyrolysis have been ranked the highest amongst others but this technology has stood on the last place. These results show that social benefits of treatment technology should be guided to select, develop and implement of each treatment technologies and government policies should be subordinate to social benefit of each technology in the society.

Table 7

Average weight and social score of bioenergy treatment technologies.

Criteria	Anaerobic digester for heat and electricity	Anaerobic digester for gas	Anaerobic digester for gas fuel	Pyrolysis	fermentation	Landfill with gas	Average C.R
	Average weight	Average weight	Average weight	Average weight	Average weight	Average weight	
Occupational injury potential	0.147	0.185	0.215	0.062	0.277	0.144	0.054
Potential to job creation	0.094	0.138	0.138	0.137	0.343	0.150	0.027
Environmental pollution potential	0.244	0.244	0.244	0.102	0.061	0.105	0.009
Waste consumption rate	0.086	0.089	0.101	0.277	0.192	0.255	0.014
Government policy to facilitate bioenergy production	0.183	0.171	0.147	0.183	0.068	0.247	0.014
The impact on the decline in non-renewable energy imports	0.103	0.123	0.140	0.105	0.363	0.164	0.015
The impact of increasing renewable energy exports	0.103	0.186	0.138	0.102	0.307	0.162	0.012
The amount of fossil energy consumption per unit of generated bioenergy	0.216	0.148	0.216	0.052	0.117	0.248	0.021
The added value of replaced fossil energy by bioenergy	0.120	0.152	0.153	0.109	0.322	0.142	0.013
Efficiency of treatment technology	0.130	0.117	0.117	0.364	0.208	0.062	0.033
Technology complexity	0.255	0.177	0.184	0.064	0.105	0.213	0.025
Social acceptance rate	0.136	0.140	0.111	0.265	0.160	0.186	0.022
The content of energy produced per unit of bioenergy generated	0.133	0.219	0.175	0.060	0.275	0.136	0.035
Reduction rate of greenhouse gas compared to the previous situation	0.128	0.304	0.210	0.044	0.105	0.206	0.042
Social Score	0.147	0.174	0.162	0.140	0.203	0.169	0.024
Total Rank	5	2	4	6	1	3	

Since the majority of social sustainability assessment methodology just focus on indicators related to economic impacts such as annual turnover, welfare, and profitability, then the other social impacts such as government-friendly policy, the added value of replaced fossil energy by bioenergy, the impact on the decline in non-renewable energy imports, rate of fossil energy consumption per unit of generated bioenergy and so on have been neglected.

5.1. Limitation

In this research, assessing conversion technologies is done based on comprehensive social indicators. Since some of these chosen technologies were almost in the primary steps of development, data source related to these technologies were limited. Therefore, it was necessary to get international consultation. Moreover, as research scope focuses on the conversion technologies for bio-energies derived from the waste, therefore, some of these indicators is specified to this type of bio-energies and for the others bio-energies with the other sources is needed to revise.

6. Conclusion

This study showed that there is rarely a comprehensive social sustainability assessment system which contains a collection of social indicators that can be used in the same way in all cases. Because, it really depends on the extent of the study and the preferences of the stakeholders involved in the bio industry which are under investigation.

Reviewing the guidelines and indicators that focus on the bio industry, it was found that the guidelines introduced by the United Nations Environment Program and the Society of Environmental Toxicology and Chemistry (UNEP/SETAC) (2009) method is the most comprehensive one in terms of stakeholders. However, the level of stakeholder subgroups and levels of indicators based on the social impacts should be completed. Since the social impacts are realized to be very complex, therefore, the value chain of bio energy derived from municipal solid waste was designed and combined with the [UNEP \(2009\)](#) guideline. By presenting the social

assessment system to the board of experts, it was finalized.

In order to design the measurement part of the social assessment system, because of a multi-criteria decision-making nature of the social sustainability evaluation of the conversion treatment technologies of municipal solid waste into bio energies, a lately developed MCDM method called Best Worst Method (BWM) was used in two stages.

One of the major novelties in this research would be the way of application of the best worst technique for determining the social score of each treatment technologies in the second stage. Each criterion in the third level of this proposed assessment method plays a decision role and treatment technologies play indicators roles and the treatment technologies can be applied to arrive at a decision.

This proposed methodology was applied to the case study of Arad-kooch as a municipal solid waste treatment site for Tehran solid waste. The selected treatment technologies were Anaerobic digester for heat and electricity, Anaerobic digester for gas, Anaerobic digester for gas fuel, Pyrolysis for electricity, fermentation for bioethanol and Landfill with gas for gas domestic.

As the results show, the fermentation and Anaerobic digester for gas have been judged to have higher positive social impacts. The Landfill with gas and Anaerobic digester for gas fuel are next in ranking. According to the results of our study, assessing social impact by limited indicators such as job creation, visual pollution and so on, are quite different than the results of the social evaluation by applying comprehensive assessment model.

The results of assessment clearly indicate the strengths and weaknesses of the social sustainability in each treatment conversion technologies. Thus, decision makers can recognize noticeable points during the implementation phase, to increase social sustainability in their bio-energy supply chains driven by municipal solid waste.

The proposed social sustainability model can be applied to other bio-energy treatment technologies and the other fields in the bio industry. This is recommended as a future work. Moreover, to assess the total sustainability, the economic, environmental and social aspects together should be taken into consideration but this

model is only related to the social impacts. Hence, the next step would be to identify tools that integrate the economic and environmental aspects with the results of this study. Circular economy perspective could be considered as a future direction (Fatimah et al., 2020).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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