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Social sustainability assessment of conversion technologies: Municipal solid waste into bioenergy using Best Worst Method

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Abstract

The majority of sustainability assessments of the bio based industries are primarily focused on the environmental and economic aspects, while social impacts are rarely considered. While overlooking social dimension can have a serious harmful impact across supply chains. To address this issue, this study proposes a modified systemic approach for a social sustainability impact assessment of the technology treatment for converting municipal solid waste to bioenergy based on a review on the common methodologies for assessing social impacts. To show the applicability and efficiency of the proposed framework, a sample of 8 experts were used to evaluate and prioritize social sustainability criteria, using a multi-criteria decision-making method called the ‘best worst method’ (BWM). The criteria are ranked according to their average weight obtained through BWM. The results of this study help bio industry managers, decision-makers and practitioners decide where to focus their attention during the implementation stage, to increase social sustainability in their bioenergy supply chains derived waste and move towards sustainable development.

Keywords: Social sustainability, bioenergy, Best Worst Method (BWM), treatment technology

1-Introduction

Considering the fast-growing approach of biotech industry development with noticeable annual turnover and job creations, it is important to be sure about the sustainability of the industry. Accordingly, sustainability assessment methods that evaluate environmental, economic and social impacts are essential for bio based industries. The nature of social sustainability of bio based industries would be how and how much society accepts that and how different societies benefit from bio-industry (Rafiaani et al., 2016). There are different definition of social sustainability because of its ambiguous meaning. According to Black (2004) that referred by (Rafiaani et al., 2017), social sustainability is “how far social worth, social identities, social communications and social establishments can be developed into the future”.

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According to European commission and Vanclay et al. (Rafiaani et al., 2017, European commission, 2016, Vanclay et al.,2015). Social sustainable bio based economy consist of establishing a long-term sustainability plan with continuous monitoring of social aspects such as food safety, the energy supply reliability, the security of regions with respecting human rights.

According to our reviews some of the most used guidelines for social sustainability assessment that particularly concerned on the bio-based and bio-energy sectors 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), (Hasenheit et al., 2016, Dale et al.,2015, Efroymson et al.,2016, Van Dam et al.,2010, Köppen et al.,2014,Siebert et al.,2016, Blom and Solmar,2009,UNEP-SETAC,2009, Vis et al., 2014).

The commonly applied methodologies of all above guidelines is divided into three categories include 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. In contrast to these two methodologies, SLCA focus on the impacts on various stakeholders while considering the full life cycle (Dale et al.,2015, Hosseinijou et al., 2014, Ibáñez-Forésa et al. ,2019)

According to our 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. 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 must be completed. The steps of this methodology are goal and scope definition, Inventory analysis, Impact assessment and Interpretation (Kumara et al.,2017). During managing an SLCA identifying all stakeholders associated with the bio energy life cycle is a basic matter. Moreover, the inventory analysis contains the development of impact categories, indicators and data collection is one of the most challenging issues (Rafiaani et al., 2017). The objective of the present study is to propose a methodology to assess the social sustainability of technology treatment for conversion of municipal solid waste to bioenergy by using the Best-Worst Multi-Criteria Decision Making Method (BWM). The validation of the BWM results is discussed. Finally, we draw conclusions and make recommendations for further research.

2-Methodology

In order to design conceptual part of the social assessment system to calculate the social sustainability score of energy treatment technology based on municipal solid waste(MSW), it was attempt to combine the developed social life cycle assessment methodology based on the UNEP/SETAC (2009) and value chain of bioenergy supply chain based on MSW. Based on UNEP/SETAC (2009), the four major phases included goal and scope of the study, inventory analysis, impact assessment and interpretation will be presented. The purpose of the classification into impact categories is to support the identification of stakeholders, to classify subcategory indicators within groups that have the same impacts, and to support further impact assessment and interpretation. The stakeholder categories are included workers, local community, society, consumers and value chain actors.

In order to design 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 used MCDM method to measure it. There are several MCDM methods that have been applied in literature for sustainable renewable energy development (Vanclay et al.,2015). In this study, we use a newly developed MCDM method called best worst method (BWM)(Rezaei, 2015, Rezaei, 2016, Salimi and Rezaei, 2017, Ahmadi et al., 2017). Compared to existing methods, BWM requires less data and it does not need a full pairwise comparison matrix, and it produces more

consistent results due to its structured pairwise comparison system, which is the main reason we use it in this study. It is also perceived by the decision-makers as simple and very close to the way they judge and reason while making decision.

Here, we briefly describe the steps of the methodology based on BWM that can be used to determine the weights of the stakeholders, subcategories, criteria and determine the social sustainability score of treatment technologies (Rezaei, 2015, Rezaei, 2016, Salimi and Rezaei, 2017, Ahmadi et al., 2017):

Step1. Determine a set of decision criteria.

According to literature review and investigation of the bio energy value chain based on municipal solid waste, social impacts of bioenergy supply chain based on waste were extracted which may be presented at different levels: subcategories and indicators in each subcategory that should be used to arrive at a decision.

Step2. Determine the best (B) (e.g. the most important) and the worst (W) (e.g. the least important)

In this step generally the decision-maker/expert(s) identifies the best and the worst criteria.

Step3. Specify the preference of the best criterion over all the other decision criteria using a 9-point scale (number between 1 and 9; 1: B is equally important to j; 9: B is extremely more important than j). 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 $a_{BB}=1$.

Step4. Specify the preference of all the decision criteria over the worst criterion (W), using a 9-point scale, which results in the others-to-worst (OW) vector as follows.

$$A_w = (a_{1w}, a_{2w}, \dots, a_{nw})^T \text{ where } a_{jw} \text{ represents the preference of } j \text{ over } w \text{ and } a_{ww}=1.$$

Step5. Find the optimal weights ($w_1^*, w_2^*, \dots, w_n^*$)

The optimal weights should be determined such that the maximum absolute differences $\{|w_B - a_{Bj}w_j|; |w_j - a_{jw}w_w|\}$; for all j is minimized. 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.

$$\sum_j w_j = 1$$

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

(1)

Problem (1) can be equal to the following linear problem:

$$\min \xi^L$$

s.t.

$$|w_B - a_{Bj}w_j| \leq \xi^L, \text{ for all } j$$

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

(2)

$$\sum_j w_j = 1$$

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

Solving problem (2), it can be determined the optimal weights ($w_1^*, w_2^*, \dots, w_n^*$) and the optimal objective function value ξ^{L*} .

ξ^{L*} is the consistency index, it's values close to zero show a high level of consistency of the pairwise comparisons provided by the decision-makers.

For MCDM problems with more than one level, we should identify the weights for different levels following the BWM steps, after which we can multiply the weights of different levels to determine the global weights. Using BWM, the optimal weights of the criteria ($w_1^*, w_2^*, \dots, w_n^*$) are obtained.

Step6. Validation of Social sustainability assessment system

In the validation step, it should be also evaluated waste treatment technologies. We asked the respondents to determine the level of selected treatment technologies based on indicators of proposed social sustainability assessment system (Occupational injury potential, Ability to create jobs, Environmental pollution potential, Waste consumption rate,....., The rate of greenhouse gas reduction compared to the previous situation) on a nine-point Likert-type scale.

3- Results

Firstly, table 1 presents the weighting results of stakeholder categories, subcategories and indicators by respondents based on BWM. In this step, the optimal weights of the criteria are calculated, by solving the BWM optimization model for each of the 8 respondents.

Next, a simple weighted average for each criterion is computed to obtain a single weight vector, as shown in Table 1, which indicates the average consistency ratio (ξ^{L*}) is close to zero, hence the comparisons are highly consistent and reliable.

3-1-Measuring social score of bioenergy supply chains

For implementing assessment system for social score of bioenergy supply chains, Arad kooch in Tehran as a municipal solid waste treatment site for Tehran solid waste is selected. Selecting optimal waste treatment for conversion the waste to energy is the important issue in this site that needs to work on it. In this regards, life cycle assessment of treatment technologies to conversion the waste to energy have been studied. With considering on Iran conditions and the kind of the compositions of Tehran municipal solid waste was selected the treatment technologies so called anaerobic digestion for electricity and heat, pyrolysis, fermentation and landfill with gas recovery. For considering social score of each technology the designed social assessment system was used for those as mentioned above. Table 2 presents the final results of the social score of bioenergy technology treatment. Moreover, Small numbers for the standard deviation (s.d.) in table 2 show homogeneity among respondents.

Table1- Weighting social impact system assessment based on BWM

Stakeholder categories	Weight	Subcategories	Weight	Average consistency ξ^{L*}	Indicators	Weight of indicators	Global weight of indicators
Workers	0.11	Occupational injury	1	0	Occupational injury potential	1	0.11
Local community	0.19	Region development and increase healthy living conditions	1	0.107	potential to job creation	0.32	0.06
					Environmental pollution potential	0.53	0.1
					Waste consumption rate	0.14	0.03
society	0.41	energy security	0.45	0	Government policy to facilitate bioenergy production	0.62	0.11
					The impact on the decline in non-renewable energy imports	0.37	0.07
		External trade	0.11	0	Impact of increasing renewable energy exports	1	0.05
		Resource conservation	0.22	0	The amount of fossil energy consumption per unit of bioenergy production	0.4	0.04
					The added value of fossil energy replaced by bioenergy	0.6	0.05
		Technology development	0.22	0	Process efficiency	0.4	0.04
					Technology complexity	0.6	0.05
Value chain actors	0.19	Relationships between chain members	1	0	Social acceptance rate	1	0.19
consumer	0.10	Bioenergy quality	1	0	The amount of energy produced per ton of waste consumed	0.4	0.04
					The rate of greenhouse gas reduction compared to the previous situation	0.6	0.06

Table2- Average weight and social score of bioenergy technologies

Criteria	Anaerobic digester for heat and electricity		Pyrolysis		fermentation		Landfill with gas	
	Average weight	s.d.	Average weight	s.d.	Average weight	s.d.	Average weight	s.d.
Occupational injury potential	0.12	0.039	0.07	0.032	0.33	0.023	0.18	0.01
potential to job creation	0.09	0.035	0.18	0.025	0.31	0.01	0.18	0.04
Environmental pollution potential	0.24	0.021	0.13	0.018	0.09	0.022	0.05	0.032
Waste consumption	0.09	0.045	0.35	0.012	0.18	0.013	0.18	0.011
Government-friendly policy	0.17	0.011	0.26	0.039	0.09	0.015	0.18	0.025
The impact on the decline in non-renewable energy imports	0.08	0.028	0.12	0.03	0.44	0.016	0.12	0.029
The impact of increasing renewable energy exports	0.1	0.018	0.07	0.014	0.37	0.02	0.13	0.015
The added value of replaced fossil energy by bio-energy	0.07	0.011	0.12	0.022	0.34	0.034	0.18	0.028
Fossil energy consumption per unit of bioenergy production	0.18	0.018	0.06	0.016	0.09	0.012	0.32	0.01
Efficiency of treatment technology	0.18	0.038	0.31	0.05	0.18	0.045	0.08	0.045
Technology complexity	0.22	0.022	0.06	0.029	0.13	0.025	0.13	0.046
Social acceptance	0.14	0.018	0.33	0.025	0.08	0.018	0.21	0.011
Reduction rate of greenhouse gas	0.17	0.011	0.04	0.045	0.1	0.031	0.13	0.039
Energy produced per ton of waste	0.12	0.012	0.07	0.015	0.41	0.022	0.16	0.011
Social Score	0.145		0.174		0.204		0.163	

4-Discussion

The majority of the current literature on social sustainability impact assessment focuses on the creation job, visual pollution and so on. Even in cases where social impacts have been considered at all levels of stakeholders, but the comprehensive social life cycle study and systematic approach to extract social indicators has been neglected. Then the social indicators derived from social impact caused by technology development, environmental pollutions, energy security, resource conservation, external trade and so on have been rarely considered.

By considering results of total social score of bioenergy technologies, although the job creation in the landfill with gas has significant rank amongst technologies but it has a lower score compared fermentation and pyrolysis.

Since the majority of social sustainability assessment methodology just focus on economic impacts such as annual turnover, welfare, profitability then the other social impacts such as government-friendly policy, the added value of replaced fossil energy by bio-energy, the impact on the decline in non-renewable energy imports, fossil energy consumption per unit of bioenergy production were neglected.

By considering social impact of each bioenergy technology on the society was found that fermentation has the highest rank with a weight of 0.091 which means that despite the lack of government-friendly policies for bioethanol production but by setting up this technology, positive social impacts on the society such as decline in non-renewable energy imports, increasing renewable energy exports, noticeable added value of replaced fossil energy by bio-energy would be significant that will lead to society development. Despite first rank in social score of fermentation, social acceptance of fermentation because of low Government-friendly policy would be lowest rank.

5-Conclusion

Our study has shown that there is no worldwide suite social sustainability assessment system which contains a set of social 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. By reviewing the guidelines and indicators that focus on the bio industry 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 must be completed.

Because of a multi-criteria decision making nature of the social sustainability evaluation of the bio energies, therefore it was used a newly developed MCDM method called best worst method (BWM). With Comparing to existing methods, it requires less data and it does not need a full pairwise comparison matrix, and it produces more consistent results due to its structured pairwise comparison system, which is the main reason using it in this study.

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, Pyrolysis, fermentation and Landfill with gas. As can be seen in the results, the Fermentation and Pyrolysis treatment technology have been judged to have higher positive social impacts. The Landfill with gas and Anaerobic digester are the next in the ranking. For future work, the proposed social sustainability model can also be extended to the other bio-energy technologies and the other fields in bio-industry.

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References

- Ahmadi, H. B., Kusi-Sarpong, S., and Rezaei, J., (2017), Assessing the social sustainability of supply chains using Best Worst Method. *Resources, Conservation and Recycling*, 126: 99-106.
- Black, A. W. (2004). The Quest for Sustainable, Healthy Communities. *Australian Journal of Environmental Education*, 20(01), 33–44. <https://doi.org/10.1017/S0814062600002287>
- Blom M, Solmar C. (2009). *How to socially assess biofuels: a case study of the UNEP/ SETAC code of practice for social-economical LCA* – University Publication Master’s thesis in cooperation with the Division of Quality and Environmental Management at Luleå University of Technology, commissioned by Enact;

Dale VH, Efroymsen RA, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, Davis MR, Downing ME, Hilliard RE(2013). *Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures*. *Ecol Indic*;26:87–102

Efroymsen RA, Dale VH, Langholtz MH. Socioeconomic indicators for sustainable design and commercial development of algal biofuel systems. *GCB Bioenergy* 2016. <http://dx.doi.org/10.1111/gcbb.12359>.

European Commission. HORIZON 2020, (2016). *Work Programme 2016 – 2017 Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy*. European Commission Decision C,4614. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-food_en.pdf

Hasenheit M, Gerdes H, Kiresiewa Z, Beekman V. Summary report on the social, economic and environmental impacts of the bioeconomy; (2016). http://bio-step.eu/fileadmin/BioSTEP/Bio_documents/BioSTEP_D2.2_Impacts_of_the_bioeconomy.pdf

Hosseiniyou, S. A., Mansour, S., Akbarpour Shirazi, M. (2014), Social life cycle assessment for material selection: a case study of building materials, *International Journal of Life Cycle Assess*, 19: 620–645.

Ibáñez-Forésa,V., Boveaa, M.D., Coutinho-Nóbregab,C., Medeiros,H.R.D.(2019), Assessing the social performance of municipal solid waste management systems in developing countries: Proposal of indicators and a case study, *Ecological Indicators*,98:164-178.

Köppen S, Fehrenbach H, Markwardt S, Hennecke S. ,(2014), Implementing the GBEP Indicators for Sustainable Bioenergy in Germany. Final Report, ifeu - Institut für Energie- und Umweltforschung gGmbH and IINAS - International Institute for Sustainability Analysis and Strategy GmbH, Heidelberg, Darmstadt, Berlin; October. http://www.iinas.org/tl_files/iinas/downloads/bio/IFEU_IINAS_2014_GBEP_

Kumara,A, Sahb,B., Singhc,A.R. Denga, Hea,X., Kumarb,P., Bansa, R.C.,(2017). *A review of multi criteria decision making (MCDM) towards sustainable renewable energy development*, *Renewable and Sustainable Energy Reviews* ,69: 596-609. <https://doi.org/10.1016/j.rser.2016.11.191>

Rafiaani, P., Kuppens, T., Dael, M. V., Azadi, H., Lebailly, P., & Passel, S. V. (2018). Social sustainability assessments in the biobased economy: Towards a systemic approach. *Renewable and Sustainable Energy Reviews*, 82: 1839–1853, <https://doi.org/10.1016/j.rser.2017.06.118>

Rafiaani, P., Van Passel,S., Lebailly,P., Kuppens, T., Azadi, H.(2016). Social Life Cycle Assessment in Biobased Industries: Identifying Main Indicators and Impacts. Submitted communication, SLCA 2016, Cambridge (USA)

Rezaei, J.,(2015). *Best-worst multi-criteria decision-making method*, *Omega*53: 49-57.

Rezaei, J.,(2016). *Best-worst multi-criteria decision-making method: Some properties and a linear model*, *Omega*64: 126-130.

Salimi,N., Rezaei, J.,(2017). *Evaluating firms' R&D performance using best worst method*, *Evaluation and Program Planning*,66:147-177, <https://doi.org/10.1016/j.evalprogplan.2017.10.002>

Siebert A, Sinéad O’Keeffe AB, Thrän D. (2016). *Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany*. Int J Life Cycle Assess <http://dx.doi.org/10.1007/s11367-0161066-0>.

Vanclay F, Esteves AM, Aucamp I, Franks DM.,(2015). *Social Impact Assessment: Guidance for assessing and managing the social impacts of projects*. International Association for Impact Assessment (IAIA). http://www.iaia.org/uploads/pdf/SIA_Guidance_Document_IAIA.pdf.

Van Dam J, Faaij A, Rutz D, Janssen R. (2010), *Socio-economic impacts of biomass feedstock production*, Global BioPact project. Utrecht: Utrecht University;

Vis M, Dörnbrack A-S, Haye S.,(2014). *Socio-economic impact assessment tools. Socio-Economic Impacts of Bioenergy Production*. Switzerland: Springer International Publishing; pp. 1-16. http://dx.doi.org/10.1007/978-3-319-03829-2_1

UNEP-SETAC. *Guidelines for social Life Cycle Assessment of products*. United Nations Environmental Programme. Belgium: Druk in der weer; 2009. http://www.unep.fr/shared/publications/pdf/dtix1164xpa-guidelines_slca.pdf.