CHEMICAL ENGINEERING TRANSACTIONS
VOL. 62, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216
DOI: 10.3303/CET1762084

Solution Selection of Carbon Emission in Chemical Industry Based on Multi-Criteria Group Decision Making

Aibin Kang

Department of Chemistry & Environmental Engineering, Hebei Chemical and Pharmaceutical College, Shijiazhuang 050026,China
kabcugb@163.com

More and more environmental issues have attracted much attention from people all over the world. In order to copy with these issues, energy conservation and emission reduction as an effective strategy was proposed by the government of China. Hereinto, it should be noted that carbon emission in chemical industry is the one of the most important industries in the above strategy. With the aim of decreasing carbon emission in chemical industry, some appropriate solution should be selected from several alternative solutions. To do it, a group of experts from different departments, fields and organizations are invited to provide their opinions towards to these alternative solutions. Although these opinions may be conflicting, it can be accepted by most experts. Then, VIKOR method is introduced to combine these opinions to generate the final result which is considered as the best solution for reducing carbon emission in chemical industry. Evidently, this solution will help chemical industry decrease or control carbon emissions.

1. Introduction

Chemical industry is a basic industry in economic and social development of China and makes many contributions to the rapid development of economy and society. However, excessive environmental pollution has attracted much attention from people (Gu et al., 2013; Ju et al., 2009). Thick fog and haze shrouds people especially in the big cities. Greenhouse gases make the summer warmer and warmer. Land pollution results in the reduction of workable soil. There are many other environmental issues around us. The environmental pollution caused by chemical industry has been one of the major problems with social concern. At present, there are more than 100,000 chemical products used by each country all over the world (Li et al., 2015). Such a wide variety of chemical products has a common characteristic, that is, about two-thirds of the chemical products can be transformed into usual products and one-third of them will be converted into waste and pollutants damaging environment. More importantly, most of these waste and pollutants are harmful to a certain extent, even have highly toxic substances. For this reason, it is necessary to to reduce the harmful impact of chemical industry on environment.

In these pollutants, we focus on carbon emission which mainly influences greenhouse gases. Note that, in order to copy with environmental issues caused by chemical industry, strategy called energy conservation and emission reduction was proposed by the government in China. Energy conservation and emission reduction can not only reduce the consumption of resources and emissions of pollution but also increase economic benefits and promote technological progress. More importantly, energy conservation and emission reduction is considered as an effective measure to help human being achieve sustainable development in the earth. Hereinto, reduction of carbon emissions is one of the major tasks in this strategy. However, how to effectively achieve this goal is difficult. Many researchers conducted their studies related to energy conservation and emission reduction (Cai, 2013; Chen and Zhi, 2013).

Ju et al. (2009) developed new technology and strategy of energy conservation and emission reduction for chemical industry. Li et al. (2015) applied IPAT formula and LMDI method to analyse the contributions of reducing pollutions of different technologies with the consideration of industrial chemical oxygen and SO2.

In order to effectively facilitate energy conservation and emission reduction, good solutions should be selected from many alternatives to help reduce carbon emissions in chemical industry. It is difficult for an individual

Please cite this article as: Aibin Kang, 2017, Solution selection of carbon emission in chemical industry based on multi-criteria group decision making, Chemical Engineering Transactions, 62, 499-504 DOI:10.3303/CET1762084

expert to express his or her opinions for this selection problem. Therefore, several experts forming a group of experts should be invited to provide their opinions independently. More particularly, these experts may have different background, experience, knowledge and risk attitudes. These factors lead to the solution resulted by combining the opinions of these opinions can be easily accepted by most managers in chemical industry. With the purpose of helping experts provide their opinions, linguistic term set as a popular way is introduced which has been used by many researchers in many fields (Jin et al., 2016). The advantages of linguistic term set are to allow the experts to express their opinions including fuzzy or uncertain information (Liao and Xu, 2013, Liao et al., 2015). In general, for a complex problem, the experts are hard to give exact or precise opinions. After the opinions of experts are obtained, the next step is to aggregate these opinions to generate the final solution. In this paper, we introduce VIKOR method, which was developed for multiple criteria decision making (Ren et al., 2017). It can be used to select the best solution from some conflicting alternatives (Sanayei et al., 2010; Xu, 2008). With the help of the method, we will select the best solution that we need in the problem of selecting solution of reducing carbon emission for chemical industry.
The structure of this paper is shown as follows. Section 2 reviews the basic concepts of carbon emission and analyses the relationship between carbon emission and tourism industry. Section 3 introduces ER algorithm. Section 4 demonstrates a case study. Section 5 summarized this paper.

2. Analysis of chemical industry

In order to select a best solution to help chemical industry reduce carbon emissions, the characteristics of energy consumption in chemical industry are analyzed in this section. Then, literature review about carbon emission of chemical industry is demonstrated to help realize the existing studies.

2.1 Characteristics of chemical industry

Chemical industry is mainstay industry in the development of economy and society and thus will influence the daily life of people. However, it also makes more contributions to energy consumption and greenhouse gases. China is the one of the largest countries producing chemical products all over the world. More importantly, the production of chemical industry in China is not very reasonable, where products with high energy consumption, crude processing, low additional value widely exist. The melting glaciers caused by greenhouse gases are demonstrated in Figure 1.

Figure 1: The melting glaciers caused by greenhouse gases

In general, chemical industry mainly includes basic raw material industry, energy industry which conducts the development and production of chemical products (Xu et al., 2016). Coal chemical industry as a special chemical industry refers to the process of converting coal into gases, liquid, solid fuel and chemical products depending on chemical process. Up to now, chemical industry has been one of industries having the highest energy-consumption (Yuan, 2013). Meanwhile, the amount of pollutants is the largest and toxicity is very high, which will negatively impact on the health of people and the ecological environment.
These activities may put forward higher requirement for energy conservation and emissions of chemical industry. Therefore, it is inevitable to minimize the emission of various pollutants especially carbon emissions so as to achieve the sustainable development of chemical industry. Energy conservation and emission reduction is to save material resources and energy resources, reduce waste and environmental pollution especially noxious substance and noise. Thus, it is very useful measure to achieve sustainability of chemical industry.
That is the main reason why we study how to select solution to reduce carbon emissions in chemical industry in this paper. Then, a typical chemical enterprise is shown in Figure 2.

Figure 2: A typical chemical enterprise

3. Multi-criteria group decision making

In practical solution selection, it is difficult to generate the best solution depending on a single expert. Several experts should be invited to help find the best solution. As such, multiple criteria group decision making method should be introduced rather than multiple criteria decision making method. Experts from different departments, fields or positions may have different knowledge, experience and background. In this section, criteria system is constructed firstly.

3.1 Criteria system for solution selection of carbon emission

After screening corresponding materials and documents and interviewing with some experts, the criteria framework is constructed in Figure 3. This is the basis for the selection problem for reducing carbon emission in chemical industry.

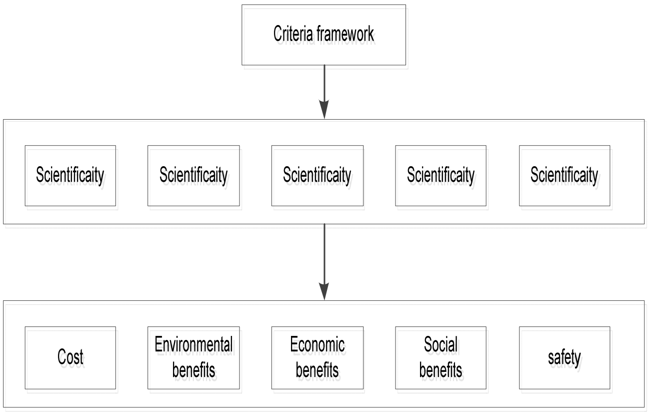

Figure 3: The criteria framework for the problem of selecting solution

3.2 Fuzzy linguistic term set

In 1975, linguistic variable was developed by Zadeh to help characterize uncertainty of preferences of the decision maker. It is derived from a triangle norm (T-norm) operation also called Archimedean T-norm which satisfies some necessary properties such as commutative law, associativity and monotonicity. In general, a T-norm operation is considered to be continuous when it is regarded to be continuous according to a two-place function. In short, two main methods can be used to generate linguistic term sets. The former one is to apply context-free grammar and the latter one is to define a finite term set which is distributed on a constant scale and the order of linguistic terms are pre-defined. In this paper, we focus on the latter one which is regarded to be more popular and widely accepted. Some researchers developed a way to make semantics in linguistic term set can be equal to the corresponding fuzzy membership degrees and non-membership degrees. However, it is difficult for the experts to provide this equivalent relation due to the limited knowledge and experience. Given a finite set LT=$\{lt_1, lt_2, ..., lt_H\}$ which is distributed in increasing order, we can obtain the basic characteristics of linguistic term set below.

(1) Orderliness: if $z>x$, $lt_z>lt_x$;

(2) Negation operation exists: NegO(lt_x) = lt_z, where $z = H + 1 - x$;

(3) Maximum exists: Max(lt_z, lt_x) = lt_z, when lt_z>lt_x;

(4) Minimum exists: Max(lt_z, lt_x) = lt_z, when lt_z<lt_x.

For example, it can be inferred from the above characteristics.

$$LT = \begin{pmatrix} lt_1 : Verybad \quad lt_2 : bad \quad lt_3 : a\ little\ bad \\ lt_4 : Indifferent \\ lt_5 : a\ little\ good \quad lt_6 : \text{good} \quad lt_7 : Verygood \end{pmatrix}$$

Then, the basic operational rule can be further developed as follows in order to aggregate chemical risk decision information.

(1) $lt_b \oplus lt_c = lt_{b+c}$;(2) $lt_b \oplus lt_c = lt_c \oplus lt_b$;

(3) $\delta lt_b = lt_{\delta b}$;(4) $(\delta_1 + \delta_2) lt_b = \delta_1 lt_b \oplus \delta_2 lt_b$;

(5) $\delta(lt_b \oplus lt_c) = \delta lt_c \oplus \delta lt_b$.

3.3 Fuzzy VIKOR

VIKOR (VlseKriterijumska Optimizacijia I Kompromisno Resenje) was developed by Opricovic (2004) has widely applied in multiple criteria decision making and attracted much attention. As mentioned in Introduction, this method is to rank or select from several alternatives in order to find compromise solution which is considered to be feasible in selecting the solution of carbon emission. The procedure of VIKOR is demonstrated as follows.

Step 1: Firstly, the original information should be normalized. Assessments provided by the experts should be transformed into a common format. That is, cost assessments should be transformed into benefit assessments in order to simplicity.

Step 2: The best ideal solution also called positive ideal solution denoted by Pos(M) is defined by the experts. Similarly, the worst solution called negative ideal solution denoted by Neg(M) is also defined by the experts as shown below.

$Pos_j = \max_j \{SS_j \in lt_i\}$ (j = 1, 2, ... J; i = 1, 2, ..., H) and (1)

$$Neg_j = \min_j \{SS_j \in lt_i\} . \quad (2)$$

Step 3: Two important values denoted by S_g and RS_g, g= 1, 2, …, G are calculated by the following equations with the help of step 2:

$$S_g = \sum_{j=1}^{n} w_j\, d\left(SS_{gj}, Pos_j\right) \Big/ d\left(Pos_j, Neg_j\right) \quad (3)$$

$$RS_g = \max_j w_j\, d\left(SS_{gj}, Pos_j\right) \Big/ d\left(Pos_j, Neg_j\right) \quad (4)$$

$$d\left(SS_{gj}, Pos_j\right) = \left|SS_{gj} - Pos_j\right| , \quad (5)$$

where w_j denotes the weight of criterion, satisfying $\sum_{j=1}^{n} w_j$ = 1. It can be used to characterize the relative importance of different criteria.

Step 4: A collective value denoted by Q_g, g= 1, 2, …, G, can be obtained by the following equation to balance the values S_g and RS_g.

$$Q_g = \gamma\left(S_g - S^-\right) / \left(S^+ - S^-\right) + (1-\gamma)(RS_g - RS^-) / (RS^+ - RS^-) \quad (6)$$

where $S^+ = \max_g S_g$, $S^- = \min_g S_g$, $RS^+ = \max_g RS_g$ and $R^- = \min_g RS_g$.

In addition, $\gamma \in [0,1]$ is defined by the experts to represent a weight of the degree of maximum group value or utility, where 1-γ denotes the degree of the individual regret. Then, we can derive that γ is considered as a balance parameter between total utility or satisfaction and single or individual regret. In general, the value of parameter γ is often set as 0.5 which means the degree between group satisfaction and individual regret is indifferent.

Step 5: According the mentioned steps, the values related to S_g, RS_g and Q_g are generated and further the ranking orders will be obtained as $\{SS\}_S$, $\{SS\}_{RS}$, $\{SS\}_Q$. Here, the value Q_g is smaller, the alternative is considered to be better.

Step 6: A final compromise solution will be obtained where alternative ($SS^{(1)}$) denotes the best alternative with the line of the value Q_{min} and can satisfy the following conditions.

Con1. Acceptable advantage should be satisfied.

$$Q(SS^{(\theta)}) - Q(SS^{(1)}) \geq LimV, \tag{7}$$

where $A^{(\theta)}$ is the θ_{th} alternative in the ranking order $\{SS\}_Q$, and $LimV = 1/(G-1)$, G denotes the number of all feasible alternatives.

Con2. Acceptable stability in solution selection should be satisfied:

The alternative $SS^{(1)}$should also be the same best ranking according to the values $S$and RS. Thus, the compromise solution is regarded to be stable in the process of selecting solution of carbon emission. That is, "voting by majority rule" holds in this process.

4. Solution generation of carbon emission

The detailed process of selecting an appropriate solution to the problem of reducing carbon emissions for chemical industry is conducted in this section and is implemented in the Matlab environment to solve the problem.

People pay more attention to the reduction of carbon emissions in chemical industry, which is very important for energy conservation and emission reduction. Now, a public organization in the local government of China faces a problem to select appropriate solution from several alternative solutions which are provided by the academic institution. They are to control the number of raw material including carbon, increase clean energy, set stricter standard of carbon emission, and increase the intensity of punishment, which are denoted by RCE_1, RCE_2, RCE_3 and RCE_4. Four experts are invited from a chemical enterprise, the local government, an university and research laboratory which are denoted by ex_1, ex_2, ex_3 and ex_4. Their weights are determined by the group of experts as (0.2, 0.3, 0.2, 0.2, 0.1). The linguistic term set is provided as $\{lt_1, ..., lt_5\}$ = {Bad, Average, Medium Good, Good, Excellent}. The assessments provided by the experts are shown in Table 1.

Table 1: Assessments provided by the experts

	Criterion$_1$	*Criterion*$_2$	*Criterion*$_3$	*Criterion*$_4$	*Criterion*$_5$
RCE_1	$\{lt_2\}$	$\{lt_5\}$	$\{lt_4\}$	$\{lt_4\}$	$\{lt_2\}$
	$\{lt_4\}$	$\{lt_4\}$	$\{lt_1\}$	$\{lt_4\}$	$\{lt_3\}$
	$\{lt_1\}$	$\{lt_1\}$	$\{lt_3\}$	$\{lt_1\}$	$\{lt_3\}$
	$\{lt_1\}$	$\{lt_2\}$	$\{lt_2\}$	$\{lt_2\}$	$\{lt_4\}$
RCE_2	$\{lt_3\}$	$\{lt_2\}$	$\{lt_4\}$	$\{lt_1\}$	$\{lt_2\}$
	$\{lt_2\}$	$\{lt_2\}$	$\{lt_5\}$	$\{lt_2\}$	$\{lt_3\}$
	$\{lt_3\}$	$\{lt_3\}$	$\{lt_5\}$	$\{lt_2\}$	$\{lt_3\}$
	$\{lt_1\}$	$\{lt_2\}$	$\{lt_1\}$	$\{lt_3\}$	$\{lt_1\}$
RCE_3	$\{lt_4\}$	$\{lt_2\}$	$\{lt_2\}$	$\{lt_3\}$	$\{lt_4\}$
	$\{lt_5\}$	$\{lt_4\}$	$\{lt_3\}$	$\{lt_4\}$	$\{lt_3\}$
	$\{lt_1\}$	$\{lt_5\}$	$\{lt_3\}$	$\{lt_1\}$	$\{lt_4\}$
	$\{lt_3\}$	$\{lt_2\}$	$\{lt_4\}$	$\{lt_5\}$	$\{lt_1\}$
RCE_4	$\{lt_2\}$	$\{lt_3\}$	$\{lt_2\}$	$\{lt_3\}$	$\{lt_3\}$
	$\{lt_2\}$	$\{lt_2\}$	$\{lt_3\}$	$\{lt_2\}$	$\{lt_2\}$
	$\{lt_3\}$	$\{lt_1\}$	$\{lt_2\}$	$\{lt_2\}$	$\{lt_3\}$
	$\{lt_4\}$	$\{lt_1\}$	$\{lt_5\}$	$\{lt_4\}$	$\{lt_3\}$

Based on Section 3, the selection result is obtained and denoted by $RCE_3 \succ RCE_2 \succ RCE_4 \succ RCE_1$.

That means, the solution $RCE_3$is considered as the best one to reduce the carbon emissions of chemical industry. Note that, this result is generated by combining different experts who have large differences. Thus, this result is the optimal solution that we can find.

5. Conclusions

Now, more and more environmental issues have attracted much attention from people all over the world. In order to copy with these issues, energy conservation and emission reduction as an effective strategy was proposed by the government of China. Hereinto, it should be noted that carbon emission in chemical industry is the one of the most important industries in the above strategy. With the aim of decreasing carbon emission in chemical industry, some appropriate solution should be selected from several alternative solutions. To do it, a group of experts from different departments, fields and organizations are invited to provide their opinions towards to these alternative solutions. Although these opinions may be conflicting, it can be accepted by most experts. Then, VIKOR method is introduced to combine these opinions to generate the final result which is considered as the best solution for reducing carbon emission in chemical industry. Finally, this solution will help chemical industry decrease or control carbon emissions.

In the future, we will apply more methods to solve the selection of solution for reducing carbon emissions of chemical industry to compare these methods to find a more appropriate one. Then, the implement of the selected solution will be concerned continuously.

Acknowledgments

Key Project of Science and Technology Research of Hebei Higher Education Institutions (No. ZD2017024)

Reference

Cai M., Andrew F., 2013, Carbon emissions from tourism, a review, China Population, Resources and Environment, 23(11), 1-4.

Chen Z.J., Shi Z., 2013, Design of wireless sensor network node for carbon monoxide monitoring, 1, 35-45, DOI: 10.1007/s11235-013-9675-4

Gu B.H., Tan X.C., Chi H., Wang Y.Y., 2013, A carbon dioxide reduction potential model for chemical industry, Chinese Journal of Management Science, 21(5), 141-148.

Ju F.D., Chen H.P., Yang H.P., Du Q., Wang X.H., Zhang S.H., 2009, Selection of new strategy and technology of energy conservation and emission reduction in chemical industry, Chemical Industry and Engineering Progress, 28, 1-5.

Jin F.F., Ni Z.W., Chen H.Y., Li Y.P., 2016, Approaches to decision making with linguistic preference relations based on additive consistency, Applied Soft Computing, 49, 71-80, DOI: 10.1016/j.asoc.2016.07.045

Li Z.Y., Li Y, Liu R, Wang X.H., Hairti T., 2015, Contribution of engineering technology on pollutant emission reduction in chemical industry, Environmental Science & Technology, 38(2), 200-205.

Liao H.C., Xu Z.S., 2013, A VIKOR-based method for hesitant fuzzy multi-criteria decision making, Fuzzy Optimization and Decision Making, 12, 373-392, DOI: 10.1007/s10700-013-9162-0

Liao H.C., Xu Z.S., Zeng X.J., 2015, Hesitant fuzzy linguistic VIKOR method and its application in qualitative multiple criteria decision making, IEEE Transactions on Fuzzy Systems, 23(5), 1343-1355, DOI: 10.1109/TFUZZ.2014.2360556

Opricovic S., Tzeng G.H., 2004, Compromise solution by MCDM method, A comparative analysis of VIKOR and TOPSIS, European Journal of Operational Research, 156, 445-455, DOI: 10.1016/S0377-2217(03)00020-1 · Source: RePEc

Ren Z.L., Xu Z.S., Wang H., 2017, Dual hesitant fuzzy VIKOR method for mutli-criteria group decision making based on fuzzy measure and new comparison method, Information Sciences, 388-389, 1-16.

Sanayei A., Mousavi S. F., Yazdankhah A., 2010, Group decision making process for supplier selection with VIKOR under fuzzy environment, Expert Systems with Applications, 37, 24-30, DOI: 10.1016/j.eswa.2009.04.063 · Source: DBLP

Xu Z.S., 2008, Group decision making based on multiple types of linguistic preference relations, Information Sciences, 178, 452-467, DOI: 10.1016/j.ins.2007.05.018 · Source: DBLP

Xu W.J., Yun J., Cheng X.J., 2016, Cost analysis on different emission reduction methods of CO_2 from coal to gasoline or gas and chemical products, Coal Chemical Industry, 44(1), 11-14.

Yuan L.W., 2013, Research on energy conservation and emission reduction of coal chemical industry, Chemical Engineering & Equipment, 159-160.