Journal of Cleaner Production 142 (2017) 3883–3889

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Analysis of cardinal grey relational grade and grey entropy on achievement of air pollution reduction by evaluating air quality trend in Japan

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ARTICLE INFO

Article history:
Received 26 October 2015
Received in revised form
9 September 2016
Accepted 14 October 2016
Available online 15 October 2016

Keywords:
Air pollution control
Air quality trend
Cardinal grey relational grade
Grey entropy
Environmental protection

ABSTRACT

The Japanese government has promoted a number of policies regarding air pollution control to regulate the maximum permissible limits of air pollution, including motor vehicles, industrial activities, and firecrackers exhausts, which can be established as a mechanism for monitoring air pollution. Studies of Japan's air pollution have been presented since the 1970's, but only few studies have focused on evaluating air quality trend by grey system, which can be used to calculate the grade of air quality. The study used cardinal grey relational grade and grey entropy to calculate the data of five major Japan's air pollution such as sulfur dioxide (SO_2) carbon monoxide (CO), suspended particulate matter (SPM), Nitrogen dioxide (NO_2), and photochemical oxidants (OX) from 2002 to 2011 for evaluating the air quality trend in Japan. The relation between achievement of air pollution elimination and outcome of air pollution reduction can be determined via evaluating air quality trend. The results of this study can demonstrate the trend of air pollution spread from 2002 to 2011 and also can be used to establish a permissible limit for each type of air pollution. Furthermore, this study can be a reference for further studies on evaluating air quality trend and also on air pollution control and environmental protection, as an ultimate goal.

1. Introduction

A critical issue related to environmental aspects, such as resource consumption, biodiversity loss, extremely severe natural disasters, and climate change, is what global society faces now, and the outcome of a well-developed economic society, including urbanization, population growth, smart and convenient high-tech life, and local pollution is the undoubtedly main reason causing those above environmental crises, supporting global society to shift toward a more well-constructed and multifunctional system (Kanada et al., 2013).

Due to the varied economy progress in the world, there are a variety of environmental pollution occurred. To alleviate the effects which are caused by above environmental pollution, most countries conduct many policies and researches on environmental protection (Scavone, 2006; Moss, 2008; Zeng et al., 2011; Cucek et al., 2012; Kanada et al., 2013; Akihisa, 2015; Kurdve et al., 2015; Duic et al., 2015). Besides, some available researches focused on outcome evaluation of environmental pollution preventions, such as CO_2 emission reduction (Zhou and Zhao, 2016), water pollution prevention (Belayutham et al., 2016), and sewage treatment (Zhang et al., 2015), and those researches tended to reach the ultimate goal of friendly environment for all earth species' living. This research takes an Asian country as the case study, especially on Japan. There are some urgent issues, such as continuing economic growth, local pollution, environmental protection, and global climate change, which must be addressed. As a result, a number of countries are working on conducting environmentally friendly policies that could build up a “City of Continual Development” and figure out these conflicting demands (Chen and Shu, 2012). Therefore, the Japanese government has been promoting a strengthening policy regarding air pollution control to

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http://dx.doi.org/10.1016/j.jclepro.2016.10.072
0959-6526/

regulate any possible pollution sources including motor vehicles, industrial activities, and firecrackers exhausts due to severe problems associated with pollution during the 1950s and 1960s (Nishimura, 1989; Koplan et al., 2005; Tani, 2015).

The Air Pollution Control Law was legislated in 1968 to cope with the problem of air pollution (MOE, 2010a,b,c), where emission control of smoke and soot or particulate matters from plants and maximum permissible limits setting for automobile exhaust is listed in the law's regulations, resulting in pollutants during the 1970s and 1980s decreasing massively. Since these excellent outcomes of pollutant control have been achieved by the Air Pollution Control Law, the Japanese government continues to work actively in formulating international agreements on climate change, such as signing of the Kyoto Protocol, in developing clean energy devices, for example solar energy or hybrid automobiles, and in real-time measures to alleviate greenhouse gases emissions, such as advertising technologies on renewable energy and energy conservation, because of global warming.

After many policies which focused on air pollution elimination were promoted by Japanese government, achievement of environmental protection policies were able to present how degree of air pollution reduction could be conducted via evaluating air quality trend. Grey relational grade and grey entropy are broadly used to analyze data on a variety of fields at available studies (Deng, 1989; Mi and Zhang, 2004; Wu and Zhang, 2004; Chen et al., 2006; Sun et al., 2008; Yang et al., 2010; Hasani et al., 2012; Sun et al., 2014; Golinska et al., 2015; Nelabhotla et al., 2016; Zuo et al., 2016; Li and Zhao, 2016). This study aims to use grey relational grade and grey entropy approach to analyze the relation of achievement of air pollution elimination and air pollution reduction by evaluating air quality trend in Japan.

2. Literature review

2.1. History of Japan's air pollution

Estimating past, present, and future levels of ambient levels of sulfur dioxide (SO_2), sulfate aerosol, and sulfur deposition is related to the evaluation of risks to human health and, changes in radioactive forcing, ecosystems, and resulting changes in climate. This is the primary reason in Asia regarding of the pressing environmental problems of acid deposition, climate change, and urban pollution which are intimately connected to sulfur. Around the periods of 1990, the main energy demand in Asia has risen at a pace twice as fast as the world average. Fossil fuels with coal being as the primary energy source are satisfied with 80% of the energy demand in Asia (Carmichael et al., 2002). Japan is employed as a case study regarding achievement of air pollution reduction in this study. Accompanying booming economic development during the 1950s and 1960s, Japan faced a series of environmental pollution problems (MOEJ, 1969); air pollution caused the number of asthmatic patients to increase in certain areas close to large petrochemical factories. Oxide sulfate (SO_x) was the most serious pollutant which was captured around the neighborhood because of the demand of industrial development during the late nineteenth century and the early twentieth century. Fossil-fuel broadly used in industrial processes in Japan during 19–20th century resulted in rapid economic growth, and nearly half of air pollutant is from fossil-fuel combustion, which is summarized as anthropogenic sources account for more than 70% of SO_2 global emission (Whelpdale et al., 1996; Lu et al., 2010). Moreover, the low efficiency of the installed desulfurization instruments and the lag of the introduction of desulfurization facilities also resulted in the national SO_2 emission rising (Lu et al., 2010). However, developing high standards in environmental protection and policy systems has been considerably conducted by Japanese government to reduce air pollution (MOE, 2010a,b,c). Because of the motivation of environmental protection, many historical analyses at the national-level were conducted on air pollution control. According to these studies, the response actions for SO_2 reduction focused on four principal factors that included industrial structural change, pretreatment (fuel desulfurization) and substitution with low-sulfur alternatives, end-of-pipe (desulfurization) treatment, and production process efficiency (Kanada et al., 2013; MOE, 2010a,b,c; Minamikawa, 1998). Li and Dai proposed a detailed analysis regarding SO_2 reduction mechanisms contributed by decomposing emission data that are divided into five factors and then calculating each factor's variation at different stages via time (Li and Dai, 2000). Li and Dai's studies showed that the principal causes of SO_2 reduction during the early period of 1960–1966 were low sulfur fuel and desulfurization accompanied with other policies' implementation later; for example, fuel substitution, energy savings, and waste air exhaust in the production process then became the most important contributors in the later period of 1974–1996 (Li and Dai, 2000). With the result of those complete policy approaches, the Japanese government's comprehensive policy approach combined with energy-related policies could overcome air pollution problems thoroughly (Nishimura, 1989; Tani, 2015).

2.2. Environmental quality standards in Japan-air quality

For the purpose of air pollution reduction, the Japanese government has implemented the Air Pollution Control Law in 1968 (MOE, 2010a,b,c) to control the national environmental quality. Other comprehensive policy approaches combined with energy-related topics were launched later to mitigate environmental pollution while maintaining the national economic growth. Four issues, water, air, soil, and noise, are the most significant factors in the Japanese environmental quality standards, and the air quality standards for the aim target pollutant, air pollution, are given in Table 1 (MOE, 2010a,b,c).

3. Experimental materials and methods

3.1. Historical air pollutant data at Tokyo Shinjuku

Since the awareness of industrial pollution reduction and environmental protection has grown continuously, the Japanese government has conducted a number of comprehensive policy approaches on environmental pollution reduction. The data of air pollution have been recorded from the 1970s–2011s in the database of the National Institute for Environmental Studies (NIES, 2011), which is available for Japanese government to keep track of air pollution trend. Average value of five pollutants, such as SO_2, carbon monoxide (CO), suspended particulate matter (SPM), Nitrogen dioxide (NO_2), and photochemical oxidants (OX), at Tokyo Shinjuku during 2002–2011 is listed in Table 2, respectively.

3.2. Mathematical model of grey relational grade

The mathematical foundation of grey relational grade can be described as follows.

3.2.1. Factor space

Assume $P(X)$ is one theme and Q is one relationship. If a characteristic possesses key factors, such as countable intention factor, expansion of factor and independence factor for the combination of $\{P(X);\ Q\}$, $\{P(X); Q\}$, then it can be called a factor space.

Table 1
Environmental quality standards of atmosphere in Japan (MOE, 2010a,b,c).

Substance	Environmental conditions
SO_2	The daily average for hourly values shall not exceed 0.04 ppm, and hourly values should not exceed 0.1 ppm.
CO	The daily average for hourly values shall not exceed 10 ppm, and average of hourly values for any consecutive eight hour period should not exceed 20 ppm.
SPM	The daily average for hourly values shall not exceed 0.10 mg/m^3, and hourly values should not exceed 0.20 mg/m^3.
NO_2	The daily average for hourly values should be within the 0.04–0.06 ppm zone or below that zone.
OX	Hourly values should not exceed 0.06 ppm.
Benzene	Annual average should not exceed 0.003 mg/m^3.
Trichloroethylene	Annual average should not exceed 0.2 mg/m^3.
Tetrachloroethylene	Annual average should not exceed 0.2 mg/m^3.
Dichloromethane	Annual average should not exceed 0.15 mg/m^3.
Dioxins (PCDDs, P CDFs and coplanar PCBs)	Annual average should not exceed 0.6 pg-TEQ/m^3.
Fine particulate matter (PM 2.5)	The annual standard for PM 2.5 is less than or equal to 15.0 μg/m^3. The 24-h standard, which means the annual 98th percentile values at designated monitoring sites in an area, is less than or equal to 35 μg/m^3.

3.2.2. Comparison of sequence

Equation (1) is assumed as a sequence of $x_i = (x_1(k), \cdots, x_i(k)) \in X;$,

$$k = 1, 2, 3, \cdots,\ n \in N, i = 0, 1, 2, \cdots,\ m \in I \tag{1}$$

and meet the following three conditions: non-dimensional, scaling, and polarization: Thus, this sequence is comparable.

3.2.3. Four axioms of grey relational measurement

When the space is formed by meeting factor space and comparability, the space is called grey relational space and is demonstrated by $\{P(X); \Gamma\}$, in which $\{P(X)\}$ is the theme and Γ is the measurement tool. $\{P(X); \Gamma\}$ has normality; duality symmetric, wholeness and closeness four axioms. According to the above descriptions, if a function $\gamma(x_i,x_j) \in \Gamma$ can be found to meet all of the above four axioms, $\gamma(x_i,x_j)$ is considered as a grey relational grade.

3.2.4. Grey relational grade

In grey relational space $\{P(X);\ \Gamma\}$, exist the sequences $x_i = (x_1(k), \cdots, x_i(k)) \in X;$, where $k = 1, 2, 3, \cdots,\ n \in N,\ i = 0, 1, 2, \cdots,\ m \in I$, and then Eq. (2) is depicted as follows.

$$\begin{array}{lcl} x_0 & = & (x_0(1), x_0(2), \cdots, x_0(k)) \\ x_1 & = & (x_1(1), x_1(2), \cdots, x_1(k)) \\ x_2 & = & (x_2(1), x_2(2), \cdots, x_2(k)) \\ \vdots & = & \qquad \vdots \\ x_m & = & (x_m(1), x_m(2), \cdots, x_m(k)) \end{array} \tag{2}$$

In grey relational grade, if we take $x_0(k)$ as the reference sequence, and the other sequences are inspected sequences, then it is called “localization grey relational grade”. If each sequence $x_i(k)$ can be the reference sequence, then it is called “globalization grey relational grade”. Fig. 1 shows the pattern of general grey entropy under assumption of monotonic in the range. Nagai's grey relational grade (Deng, 1989; Hasani et al., 2012; You et al., 2012; Golinska et al., 2015; Nelabhotla et al., 2016; Zuo et al., 2016; Li and Zhao, 2016) was employed in this study to analyze the correlation between those air pollution.

Table 2
Average value of five air pollutants at Tokyo Shinjuku.

Year/item	SO_2 (ppm)	OX (ppm)	NO_2 (ppm)	CO (ppm)	SPM (mg/m^3)
2002	0.060	0.020	0.031	0.500	0.034
2003	0.005	0.021	0.027	0.600	0.028
2004	0.005	0.018	0.030	0.500	0.025
2005	0.006	0.019	0.029	0.500	0.027
2006	0.005	0.022	0.028	0.500	0.025
2007	0.001	0.024	0.025	0.500	0.021
2008	0.002	0.026	0.023	0.400	0.021
2009	0.001	0.025	0.022	0.400	0.021
2010	0.001	0.027	0.021	0.400	0.020
2011	0.001	0.024	0.080	0.400	0.019

3.2.5. Localization grey relational grade

The localization grey relational grade can be expressed as Eq. (3), as shown below.

$$\Gamma_{0i} = \Gamma(x_0(k),\ x_i(k)) = \frac{\overline{\Delta}_{\max.} - \overline{\Delta}_{0i}}{\overline{\Delta}_{\max.} - \overline{\Delta}_{\min.}} \tag{3}$$

in which $\overline{\Delta}_{0i} = \|x_{0i}\|_\rho = (\sum_{k=1}^{n} [\Delta_{0i}(k)]^{\ \rho})^{\frac{1}{\rho}}$.where: $k = 1, 2, 3, \cdots, n$, $i = 1, 2, 3, \cdots,\ m,\ j \in I.$

i. x_0 : Reference sequence
ii. x_i : Inspected sequences
iii. $\Delta_{oi} = \|x_0(k) - x_i(k)\|$: The difference between x_0 and x_i norm.
iv. $\Delta_{\min.} = \forall_{j \in i}^{\min.\min.}\ \forall k \|x_0(k) - x_j(k)\|$
v. $\Delta_{\max.} = \forall_{j \in i}^{\max.\max.}\ \forall k \|x_0(k) - x_j(k)\|$

3.2.6. Grey relational ordinal

After the grey relational grade is calculated, according to the value, we can rank the sequence, and this procedure is called grey relational rank. For reference sequences x_0, and inspected sequences are x_i, if $\Gamma(x_0\ ,\ x_i) \geq \Gamma(x_0\ ,\ x_j)$, then we found that under the reference sequence x_0, the grey relational rank of x_i was greater than grey relational rank of x_j.

3.3. Mathematical model of grey entropy

The basic concept and calculation steps of grey entropy and random number are shown as follows.

If a finite set “$\widehat{A}$” is in the whole set, a mapping existsf_i:[0,1]→[0,1], i=1,2,3,...,n, and satisfies three conditions. Three conditions are listed as follows, $f_i(0) = 0$, $f_i(x) = f_i(1-x)$, and$f_i(x)$, and these three conditions are monotonic in the range, $x \in (0,0.5)$. Then, Eq. (4) is derived from the above statements.

$$d(A) = g\left[\sum_{i=1}^{n} c_i f_i\left(\widehat{A}(u_i)\right)\right] \tag{4}$$

where:

i. $g(x)$ is monotonic in the range $[0,a] \rightarrow [0,1]$.

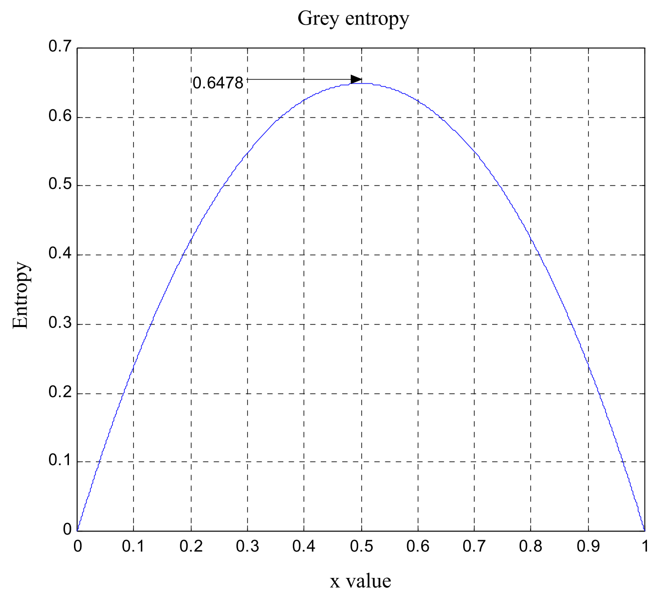

Fig. 1. The pattern of grey entropy under assumption of monotonicity in the range (Wen, 2004; Wen, 2009).

ii. c_i belongs to real and lets Eq. (4) turn to Eq. (5) because of those above conditions.

$$a = \sum_{i=1}^{m} c_i f_i(0.5) \tag{5}$$

Then, $d(A)$ is defined as the entropy of set $\widehat{A}$. According to above mentioned conditions, the new entropy comes from original entropy, which is called grey entropy, as shown in Eq. (6).

$$W\left(\widehat{A}\right) = \frac{1}{0.6478} \sum_{i=1}^{m} W_e(X_i) \tag{6}$$

where:

i. The value of normalization coefficient, 1/0.6478, originates in taking $c_1 = c_2 = c_3 = \ldots = c_m = 1$ into Eq. (5), which is corresponding to the number of factor.
ii. The condition of $W(x)$ satisfies with the follows, $W(x) = [xe^{(1-x)} + (1-x)e^x - 1]$.

The analysis steps of grey entropy are shown below.

3.3.1. Setting the sequences

$$x_i = (x_i(1), x_i(2), x_i(3), \ldots\ldots, x_i(k)) \text{ where}: \ i = 1,2,3,\ldots,m,\ k = 1,2,3,\ldots,n \tag{7}$$

3.3.2. Calculating the total sum of each factor's attribute

$$D_k = \sum_{i=1}^{m} x_k(i) \tag{8}$$

3.3.3. Calculating the normalization coefficient

$$k = \frac{1}{0.6478 \times m} \tag{9}$$

3.3.4. Calculating the entropy of each factor

$$e_k = \frac{1}{0.6478 \times m} \sum_{i=1}^{m} W_e\left(\frac{x_i(k)}{D_k}\right) \tag{10}$$

3.3.5. Calculating the sum of entropy

$$E = \sum_{i=1}^{n} e_k \tag{11}$$

3.3.6. Calculating the relative weighting

$$\lambda_k = \frac{1}{m - E}[1 - e_k] \tag{12}$$

3.3.7. Normalization the weighting: the value of β_k is called the weighting for each factor

$$\beta_k = \frac{\lambda_k}{\sum_{i=1}^{n} \lambda_i} \tag{13}$$

4. Results and discussion

4.1. Results of grey relational grade analysis

The awareness of environmental protection continuously arises around the world because massive pollution have occurred after decades of industry revolution. General environmental pollution involve of waste, wastewater, air, soil pollution, and so on, and air pollution is the principal object in this study. Because of the background of environmental protection, the air pollution reduction has become a critical issue all over the world. Numerous available studies related to environmental protection and environmental pollution reduction have been discussed, not to mention the air pollution reduction. Based on the motivation of environmental protection and environmental pollution reduction, this study employed the analysis of cardinal grey relational grade and grey entropy to evaluate those achievements conducted by Japanese government through analyzing the air pollution trend of Japan. According to previous studies regarding air pollution reduction mentioned in the section of literature review, the air pollution reduction appeared significant improvement after policies of air pollution reduction implemented by Japanese government. However, the degree of air pollution reduction relied on an analysis model to estimate the change of air pollutants' value. With the calculation of analysis model, the result of analysis tests of five air pollutants around 2002 to 2011 was described as follows.

Table 3
The grey relational grade in each year.

Year/item	Grey relational grade	Rank
2002	0.5008	2
2003	1.0000	1
2004	0.5002	5
2005	0.5003	3
2006	0.5003	3
2007	0.5001	6
2008	0.0005	7
2009	0.0004	8
2010	0.0004	8
2011	0.0000	10

Max $\Delta = 4.2935$, Min $\Delta = 4.2040$.

Based on the minimum value principle, the grey relational grade was employed to estimate the relational grade of air quality from year of 2002–2011. According to data of Table 2, the study employed the minimum values of each factor as the standard sequence. Hence, x_0 = (SO_2, OX, NO_2, CO, SPM) = (0.04 ppm, 0.060 ppm, 0.040 ppm, 10 ppm, 0.1 mg/m^3), and the inspected sequences were divided in the below values.

x_1 = year 2002=(0.060, 0.020, 0.031, 0.500, 0.034)
x_2 = year 2003=(0.005, 0.021, 0.027, 0.600, 0.028)
x_3 = year 2004=(0.005, 0.018, 0.030, 0.500, 0.025)
x_4 = year 2005=(0.006, 0.019, 0.029, 0.500, 0.027)
x_5 = year 2006=(0.005, 0.022, 0.028, 0.500, 0.025)
x_6 = year 2007=(0.001, 0.024, 0.025, 0.500, 0.021)
x_7 = year 2008=(0.002, 0.026, 0.023, 0.400, 0.021)
x_8 = year 2009=(0.001, 0.025, 0.022, 0.400, 0.021)
x_9 = year 2010=(0.001, 0.027, 0.021, 0.400, 0.020)
x_{10} = year 2011=(0.001, 0.024, 0.080, 0.400, 0.019)

Grey relational grade of each year is derived from substituting above values into Eq. (3), as shown in Table 3. The relational grade of each year is rank as 2003, 2002, 2005, 2006, 2004, 2007, 2008, 2009, 2010, and 2011 from high to low value of grey relational grade, which depicts the best and worst degree of air qualities are 2003 and 2011, respectively.

4.2. Results of grey entropy

Different from grey relational grade, the grey entropy was used to evaluate the weighting degree of five air pollutants, which was based on the minimum value principle. The results of grey entropy were also originated from Table 2, and the five influence factors were presented as x_1 to x_5.

$SO_2 = x_1$ = (0.06, 0.005, 0.005, 0.006, 0.005, 0.001, 0.002, 0.001, 0.001, 0.001)

OX = x_2 = (0.02, 0.021, 0.018, 0.019, 0.022, 0.024, 0.026, 0.025, 0.027, 0.024)

$NO_2 = x_3$ = (0.031, 0.027, 0.03, 0.029, 0.028, 0.025, 0.023, 0.022, 0.021, 0.08)

CO = x_4 = (0.5, 0.6, 0.5, 0.5, 0.5, 0.5, 0.4, 0.4, 0.4, 0.4)

SPM = x_5 = (0.034, 0.028, 0.025, 0.027, 0.025, 0.021, 0.021, 0.021, 0.02, 0.019)

Through the calculation steps of formula in grey entropy by Kansei Engineering Toolbox as depicted in Fig. 2, the result of calculation is shown in Fig. 3, and the middle values of processing are listed in Table 4 and Table 5. The values of relative weighting lambda for SO_2, SPM, NO_2, CO, and OX were 0.3548, 0.1576, 0.1713, 0.1577, and 0.1586, respectively, which depicted the effects of air pollutants ranged as SO_2 > NO_2 > SPM > CO > OX. The most critical index on air pollutant is SO_2 after the calculation of grey entropy, which is corresponded to the previous statement of literature review. Nearly half of air pollutant is from fossil-fuel combustion, because the necessary demand of industrial development in Japan cause fossil-fuel broadly used in industrial processes.

5. Conclusions

After many contributions by Japanese government on air pollution reduction, air pollution have controlled below the values

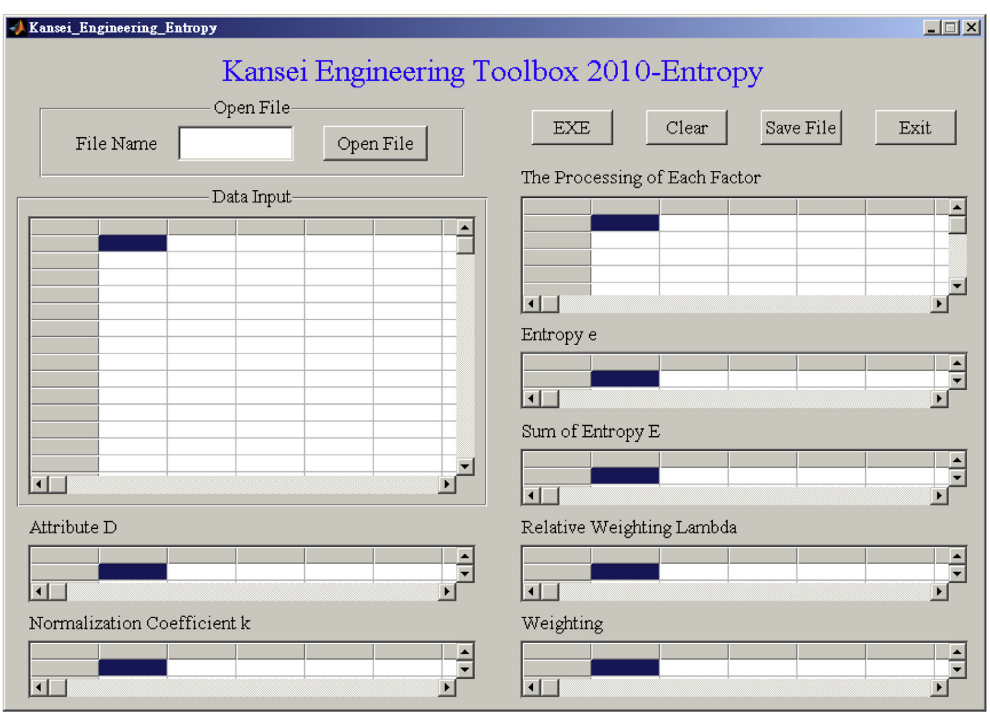

Fig. 2. The model scheme of Kansei Engineering Toolbox 2010-Entorpy.

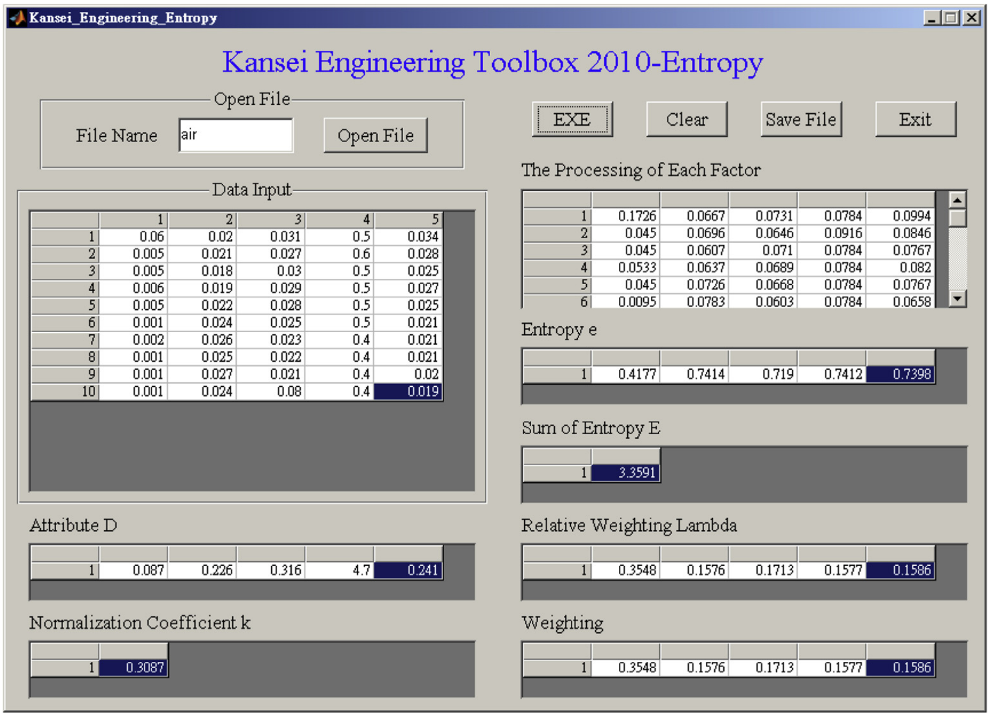

Fig. 3. Image of weighting analysis by Kansei Engineering ToolBox.

Table 4
Values of attribute *D* calculated by importing data of five air pollutants by using grey entropy.

x_1	x_2	x_3	x_4	x_5
0.060	0.020	0.031	0.500	0.034
0.005	0.021	0.027	0.600	0.028
0.005	0.018	0.030	0.500	0.025
0.006	0.019	0.029	0.500	0.027
0.005	0.022	0.028	0.500	0.025
0.001	0.024	0.025	0.500	0.021
0.002	0.026	0.023	0.400	0.021
0.001	0.025	0.022	0.400	0.021
0.001	0.027	0.021	0.400	0.020
0.001	0.024	0.080	0.400	0.019
Attribute *D* =				
0.087	0.226	0.316	4.700	0.241

Normalization coefficient k = 0.3087.

Table 5
Values of the processing of each factor after weighting analysis by using grey entropy.

The processing of each factor				
0.1726	0.0667	0.0731	0.0784	0.0994
0.045	0.0696	0.0646	0.0916	0.0846
0.045	0.0607	0.071	0.0784	0.0767
0.0533	0.0637	0.0689	0.0784	0.082
0.045	0.0726	0.0668	0.0784	0.0767
0.0095	0.0783	0.0603	0.0784	0.0658
0.0188	0.0839	0.0559	0.0644	0.0658
0.0095	0.0811	0.0537	0.0644	0.0658
0.0095	0.0866	0.0515	0.0644	0.063
0.0095	0.0783	0.1532	0.0644	0.0601
entropy E =				
0.4177	0.7414	0.7190	0.7412	0.7398
relative weighting lambda =				
0.3548	0.1576	0.1713	0.1577	0.1586
rank = 1 > 3 > 5 > 4 > 2				

of air quality standard. Although those five air pollutants are all lower than theirs corresponding values of air quality standard, the effect of those five air pollutants can be calculated by grey relational grade to obtain the rank of air quality during the year of 2002–2011. After the calculation, the result demonstrates that the best rank of air quality is year of 2003 and the worst rank is year of 2011, and the air quality is getting worse since year of 2008. Through analysis of grey relational grade, the result presents a consequence that the emission of air pollutants is excess to the value of air pollution reduction. The reason for the getting worse air quality may assume the usage of fossil-fuel by anthropogenic activities is not balanced with the contributions of air pollution reduction by Japanese government.

From the different aspect of grey relational grade, the calculation of grey entropy results in the most critical index on air pollutant of SO_2, which is corresponded to the previous statements of literature review. Fossil-fuel is broadly used in industrial processes in Japan because of the demand of industrial development during the late nineteenth century and the early twentieth century. Nearly half of air pollutant is from fossil-fuel combustion, and these air pollutants are caused by anthropogenic activities. As a result, the air pollutant of SO_2 dramatically caused air quality worse.

Acknowledgments

The authors indeed appreciate for Prof. Kun-Li Wen's instruction on grey relational grade theory.

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