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Chinese life cycle impact assessment factors

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Abstract: The methodological basis and procedures for determination of Chinese normalization references and weighting factors according to the EDIP-method is described. According to Chinese industrial development intensity and population density, China was divided into three regions and the normalization references for each region were calculated on the basis of an inventory of all of the region's environmental emissions in 1990. The normalization reference was determined as the total environmental impact potential for the area in question in 1990($EP(j)_{90}$) divided by the population. The weighting factor was determined as the normalization reference ($ER(j)_{90}$) divided by society's target contribution in the year 2000 based on Chinese political reduction plans, $ER(j)_{T2000}$. This paper presents and discuss results obtained for eight different environmental impact categories relevant for China: global warming, stratospheric ozone depletion, acidification, nutrient enrichment, photochemical ozone formation and generation of bulk waste, hazardous waste and slag and ashes.

Key words: life cycle; impact assessment factors; China

Introduction

Life cycle assessment (LCA) is an environmental management tool that is used to examine and evaluate the environmental impacts associated with the existence of products(Jensen, 1998; Weidema, 1997; Wenzel, 1997). The focus of LCA is on the entire life cycle of the product, i.e. from the extraction of the raw materials through the production of materials and components and the manufacture, transportation and use of the product to the final disposal and possible recycling of the product.

For life cycle assessment to be able to support decisions with respect to product solutions, the data obtained in the inventory must be interpreted to show which of the environmental exchanges are significant, and how great their contributions are compared to each other, so as to help to examine and evaluate the environmental impacts.

In the EDIP method (Environmental Design for Industrial Products; Wenzel, 1997) the interpretation of the inventory is done by three steps: (1) characterization——how much do the emissions contribute to the various types of environmental impacts? (2) normalization——how great are the potentials for impacts on the environment relative to the impacts from the society's activities as a whole? (3) weighting——which of the environmental impacts are the most important?

In the characterization step, it is determined how much the emissions associated with the product contribute to the various types of environmental impacts(e.g. global warming, acidification etc.). All emissions that contribute to global warming are for example expressed in CO_2-equivalents. The characterization is based on properties of the emitted species, and characterization factors available in the literature are globally valid (Wenzel, 1997).

$$EP(j) = Q_i \cdot EF(j)_i, \tag{1}$$

where, $EP(j)$ is the environmental impact potential for impact category j, Q_i is the amount of emitted substance, i and $EF(j)_i$ is an equivalency factor for compound i's contribution to environmental impact category j.

In the normalization step, contributions from the product to each type of environmental impact is divided by the expected lifetime of the product and the yearly contribution to each impact from an average person in one year.

$$NP(j) = EP(j)/(T \cdot ER(j)). \tag{2}$$

Where, $NP(j)$ is the normalized environmental impact potential for impact category j, T is the expected lifetime of the product in years, $ER(j)$ is the normalization reference for impact category j and thus, as a result of the normalization, all environmental impacts from the product are expressed as a fraction of an average person yearly contribution to the impact, and the unit is milliperson equivalents, *mPE*.

Some environmental impacts may be considered more important than others may, and the purpose of the weighting step is to weight the results obtained in the normalization step in accordance with the users concern with the studied environmental impacts. The rating of concern with environmental impacts is of course subjective, an several

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individual sets of weighting factors can be established, based on different means.

$$WP(j) = WF(j) \cdot NP(j). \quad (3)$$

Where, $WP(j)$ is the weighted environmental potential for impact category j and $WF(j)$ a weighting factor for environmental impacts category j.

Politically determined environmental targets have been selected as basis for weighting by the EDIP method, and year 2000 has been chosen as the common target year. The result of the weighting is a "weighted environmental impact potential", with the unit milliperson equivalents, targeted, $mPET_{2000}$.

The normalization references and weighting factor are specific for countries or regions of large countries, and the purpose of the present paper is: (1) to present the methodological background for determination of Chinese normalization references and weighting factors and (2) to present and discuss some results obtained for eight different environmental impact categories for relevant for China. The details have been reported by Nielsen and Yang(Nielsen, 1999).

1 Method

1.1 Normalization references

The normalization reference $ER(j)_{90}$ for impact category j based on emissions in 1990 can be determined by following equation:

$$ER(j)_{90} = EP(j)_{90}/Pop_{90}. \quad (4)$$

Where, $EP(j)_{90}$ is determined by characterization of the total mass of emissions for the area in question in 1990. ($Q(j)_{i,90}$) contributing to the specific impact category (j) through multiplication by an equivalency factors $EF(j)_i$ specific for each emitted substance(i).

$$EP(j)_{90} = \sum EP(j)_{i,90} = \sum (Q(j)_{i,90} \cdot EF(j)_i). \quad (5)$$

For the global environmental impacts(global warming and stratospheric ozone formation), the normalization references are globally valid and extracted directly from literature(Wenzel, 1997; Table 1). For the regional and local impacts, the normalization references are calculated based on Chinese data. Since China is a large country with varying population density and degree of industrialisation, specific references have been determined for the eastern, central and western region of the country as well as for the whole country.

1.2 Weighting factors

The general Chinese targets for environmental emissions have been selected as basis for weighting in this study, and year 2000 has been chosen as the target year. The weighting factor $WF(j)$ for the environmental impact category(j) is thus defined as the normalization reference($ER(j)_{90}$) divided by society's target contribution in the year 2000 based on political reduction plans, $ER(j)_{T2000}$.

$$WF(j) = ER(j)_{90}/ER(j)_{T2000}. \quad (6)$$

The 2000 target reduction plans for all impact categories in China are generally concerned with single substances or groups of substances and not with the environmental impacts as such. Due to relatively low level of industrialisation in China and the significant growth in all sectors in recent years, the Chinese targets aiming at limiting the growth of pollution(growth plans) are considered as useful indicators of the Chinese environmental concern. The determination of weighting factors has been based on general Chinese reduction targets and the present factors are valid for the whole country.

2 Determination of Chinese normalization references

The Chinese normalization references have been established by (1) making an inventory of the whole country's environmental emissions in 1990; (2) calculating the environmental impacts to which the emissions can lead and (3) division with the population in the area in question. The following three sections present and discuss the background data for acidification, nutrient enrichment and photochemical ozone formation, and the final results are summarized in Table 1. The complete record of data and calculations for all impact environmental impact categories has been reported by Nielsen and Yang(Nielsen, 1999).

2.1 Acidification

Substances such as SO_x, NO_x, NH_3, H_3PO_4, HF, H_2S, HCl and organic acids all contribute to acidification of the environment. In the Chinese inventory the main contributions of SO_x, NO_x and NH_3 are addressed.

Data for SO_x emissions are extracted from Wang *et al*.(Wang, 1996), which are based on mass balances for fuel combustion and industrial process in specific provinces and industrial sectors (not considering the SO_2 emission control). Compared with the official data reported openly(CEY, 1995), SO_2 emission calculated in this study is 17% higher, but it is close to some other scholar's estimates(Akimoto, 1994).

NO_x emission data are also extracted from Wang *et al*. (Wang, 1996) and the same industrial sectors as for SO_x are included as sources in the estimations. The emission factors for NO_2-emissions for specific sectors, provinces and fuels constitute the main source of uncertainty for the final result. Currently, in China there is no control of NO_x-emission. Therefore, the present estimate provides only an order of magnitude.

Table 1 Chinese normalization references and weighting factors for environmental impact potentials(Nielsen, 1999)

Impact category	Normalization reference, ER_{90} (3)				Normalization reference unit	Weighting factor $WF^{(4)}_{T2000}$
	East	Central	West	China		China
Global warming(1)	------8700(5)-----------				$kgCO_2$-eq/(person.a)	0.83
Ozone depletion(1)	------0.20(5)-----------				kgCFC11-eq/(person.a)	2.7
Acidification(2)	35	33	41	36	kg SO_2-eq/(person.a)	0.73
Nutrient enrichment(2)	57	60	67	61	$kgNO_3$-eq/(person.a)	0.73
Photochemical ozone formation(2)	0.76	0.63	0.48	0.65	kgC_2H_4-eq/(person.a)	0.51
Bulk waste(2)	291	247	186	251	kgbulk waste/(person.a)	0.62
Hazardous waste(2)	22	17	15	18	kghazard. waste/(person.a)	0.45
Slag and ashes(2)	18	21	16	18	kgslag and ashes/(person.a)	0.61

Notes: (1) reference region: world; (2) reference region: east China, central China, west China or China in total; (3) reference year: 1990; (4) target year: 2000; (5) source: Wenzel *et al.*, 1997

Another important source for acidification in China is NH_3, which contributes to about 40% of total acidification potential. The estimates of emissions are cited from the literature(Wang, 1997), in which the main sources of NH_3 are livestock, N-fertilizer production and application, human feces and urine.

In general, the estimates of SO_x-emissions(the most important contributor to the acidification) are believed to be quite accurate while the estimates of NO_x and NH_3 emissions are associated with more uncertainty. In total, the present normalization references for acidification are overall believed to provide a reasonable order of magnitude(Table 1).

2.2 Nutrient enrichment

The main sources of nutrient enrichment are N and P emitted to water and NO_x and NH_3 emitted into the atmosphere. There are no official data or research data available for aquatic emissions of N and P, and the total amounts of N and P emitted into water from industry and domestic sewage are estimated roughly by mass balance considerations.

The emissions of N into the sea in year 1990 are roughly estimated to 140000t total N/a (Ye, 1992). So far there is no additional information for total N emitted into other waters such as lakes and rivers. Only a rough estimation is made based on the ratio of wastewater emitted into the sea and other waters(1:29)(CEY, 1995). As a result, the total amount of N emitted into water in China in 1990 is assessed to 4200000t total N/a in 1990.

There is no information available in the literature about aquatic emissions of P in China, and just a rough estimation saying that total P constitute about 5% of the total N is made, based on Danish data(Hauschild, 1998). The result is 210 kt/a for the entire country. Since there are no specific emission data for the provinces, an allocation based on the population is adopted to distribute the totals on the three regions.

According to the present estimation of nutrient enrichment potentials, the aquatic emissions of N contribute to about 30% of the total environmental impact whereas the waterborne P only contributes with about 10%. So total N emission has a great effect on the uncertainty of normalization reference for nutrient enrichment, while P has only limited influence. Generally, the normalization reference for nutrient enrichment is quite uncertain and detailed studies of N and P emissions are needed to reduce the uncertainty of the normalization references at this point.

2.3 Photochemical ozone formation

Non methane volatile organic compounds(NMVOC), CO and CH_4 are considered as the main contributors to photochemical ozone formation in China. The main sources of NMVOCs and CO are energy production(electricity and heat), road transportation, solvent use and oil refining and distribution. The last three sources are not taken into consideration in this study, due to lack of data. The main source of CH_4 emissions is agriculture(growth of rice, breed of animals etc.), coal mining, city activities and composting(Wang, 1996). Agriculture is responsible for about 70% of the total CH_4 emissions in China and only this source is included in this study.

Some of the most important contributions to photochemical ozone formation, CO and NMVOC have been estimated based on emission factors for road transportation and industrial combustion. Although emission factors are associated with uncertainty, it is believed that the present estimates of emissions are providing a reasonable order of magnitude for the included sectors. However, certain sources of methane emissions have been ignored in this study (e.g. mining activities and natural gas outlet) and important sectors such as oil refining, solvent use and agriculture have also been ignored. Thus, in total, the present normalization reference is supposedly a bit on the low side.

3 Determination of Chinese weighting factors

The Chinese weighting factors have been determined by relating Chinese environmental impacts in 1990(see previous section) to expected environmental impacts in 2000, based on the Chinese government's environmental plans. Following three sections present and discuss the background data for acidification, nutrient enrichment and photochemical ozone formation while the results are summarized in Table 1. The details for all impact categories can be found in Nielsen and Yang(Nielsen, 1999).

3.1 Acidification

The Chinese emissions of acidifying compounds in 1990 are extracted from the normalization reference study. SO_2 target emission in 2000 is cited from the governmental environmental plan (China SEPA, 1996). The governmental requirement is that the total SO_2 emissions is kept within 24600 kt in 2000, an increase of 37% compared to the 1990 emissions. There are no specific reduction plans for NO_x and NH_4. The growth rate(37%) is therefore used to calculate the NO_x and ammonia emission in 2000. This provides a reasonable judgment for the future acidification limitation strategy.

As can be seen from Table 1, the weighting factor is smaller than one. That means that acidification will remain a severe problem in the near future, but the growth rate of acidification will be probably reduced.

3.2 Nutrient enrichment

The main contributions to nutrient enrichment in China are the industrial and domestic emissions of N and P with wastewater and the atmospheric emissions of nitrous oxides and NH_4.

There are no specific reduction plans for N and P, and therefore the governmental reduction plan for total wastewater volume in general is taken as the best estimate. In 2000, the total wastewater discharge should only increase by 35.7% relative to that in 1990. So all contributors are assigned the same growth rate to get the target emissions in 2000. Nitrous oxides and NH_3 emission are expected to increase by 37% in 2000.

The weighting factor for nutrient enrichment is smaller than 1 and almost the same as that for acidification.

3.3 Photochemical ozone formation

The level of photochemical ozone formation in China is widely determined by road transportation, industrial combustion processes and emissions of CH_4 from agriculture. According to China's energy saving and tailor gas control scenario(China SEPA, 1996) the road transportation is going to be increased between 1990 and 2000 and the reduction target for emissions is estimated to − 140%. That means that the emissions of compounds, which contribute to photo-chemical ozone formation will increase by an absolute volume although the growth rate is going to be reduced compared to the current growth rate. The total industrial combustion is also reduced by − 32% based on the national total gases waste control plan(China SEPA, 1996). The rice fields area in China will supposedly be kept at current scale(1990) for a long time. Thus, the CH_4 emission are assumed to be unchanged in 2000.

The weighting factor for POCP is around 0.5. That means that according to governmental development plans the total emission of POCP in 2000 will be two times the 1990 level, because China has plans for great growth of transportation and industry.

4 Results and discussion

The normalization references and weighting factors for eight environmental impact categories determined for the three regions of China and for the entire China are summarized in Table 1.

The normalization references show how much an average person contribute to each kind of environmental impact. The global environmental impacts are based on averages of the global population, whereas the regional and local environmental impacts are based on averages of the Chinese population in the actual regions or in the entire country. It is interesting to note that east China (which is the most industrialized region in China) is not at a higher level with respect to normalization references than the other regions. The reason is that this region has a higher population density than the other regions(Nielsen, 1999).

The weighting factors indicate how important various environmental impacts area considered in China. A weighting factor of one indicates that status in 1990 will be maintained in year 2000 according to the national plants. Weighting factors smaller than 1 indicate how much the environmental impact will grow between 1990 and 2000 whereas weighing factors larger than 1 indicate how much the environmental impact will be reduced between 1990 and 2000. It is interesting to note that ozone depletion is the only environmental impact, which is intended to be reduced in the coming years. All other environmental impacts will be increased more or less according to the national plans.

It has been the aim of the present study to establish normalization references and weighting factors for use in LCA studies products produced and used in China. However, due to China's enormous size and due to lack environmental data in certain areas it has been very difficult to make a complete inventory of the contributions to various types of environmental impacts. Thus, the present normalization references and weighting factors should only be considered as rough estimates, which are useful now, but have to be improved with more data in the future.

The weighting factors presented in this paper are based on target emissions in 2000 which is actually not "the future" when this paper comes out. The reason is that this study was initiated in the beginning of 1997 and it was expected to be finished within a quite short period of time. However, the data collection and set up of calculation methods was more time consuming than expected at first, and the final result is unfortunately a little bit old when it is finally presented. Nevertheless, it is the authors opinion that the present impact assessment factors are valuable for a number of years anyway, and that an updated version can be determined more easily based on the results presented here.

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