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Design of chemical enterprise carbon reduction scheme based on carbon handprint method

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ABSTRACT

Product environmental impact analysis by carbon footprint is a highly recognized research method to quantitatively evaluate carbon emission intensity of industrial products. In addition to the traditional carbon footprint method, researchers have recently proposed a carbon handprint method. This method is driven by the concept of describing the positive impact of products on climate. However, the handprint method has not been applied to industrial scenarios. The guidance of this method for industrial enterprises' emission reduction plans is not clear. The essence of handprint is to reduce the footprint. This paper proposes an enhanced evaluation method of product carbon handprint. We compare footprint and handprint methods by considering the improvement of production process. We consider both the reduction of footprint in the sense of life-cycle analysis and the positive impact of reducing the footprint of downstream customers. A plasticizer production enterprise in Zhejiang province is taken as an example. This paper establishes four carbon emission reduction methods of such enterprises and makes a quantitative comparison between footprint and handprint. The comparison results show that the input raw materials account for a high proportion of carbon emissions in both methods. However, in the scope of handprint, plasticizer manufacturers could produce modified plasticizers to generate carbon handprint and reduce GHG emissions for downstream customers. The reduction effect of plasticizer on carbon handprint of polyvinyl chloride customers reached 0.983 tCO_2-eq/t, twice as much as the reduction of carbon footprint in the manufacturer. Our work shows that handprint method is a more systematic method.

Keywords: carbon handprint, carbon footprint, life cycle assessment, chemical system, emission reduction

NONMENCLATURE

Abbreviations	
LCA	Life Cycle Assessment
GHG	Greenhouse Gas
PVC	Polyvinyl chloride
Symbols	
H	Carbon handprint
E	Emission
W	Annual output
R	Recovery of CO_2
δ	Raw material emission coefficient
ε_i	Raw material addition ratio

1. BACKGROUND

In the national carbon emission data, industrial enterprises account for the most significant proportion of carbon emissions, so "carbon reduction" has become a challenge that industrial enterprises must face. China's total greenhouse gas(GHG) emissions have surpassed the United States to become the world's largest, but 23% of its emissions are indirectly caused by our efforts to meet the needs of advanced countries[1].Achieving peak carbon in the industry is the key to carbon neutrality. Take Zhejiang Province as an example, in 2020, the industrial carbon emissions accounted for 61% of the whole society, and the carbon emissions of the seven high-carbon industries of chemical, petrochemical, steel, building materials, paper making, chemical fiber, and textile accounted for 70% of the total emissions. Carbon footprint mainly refers to the total amount GHG of various activities. Based on existing studies, it covers all

GHG. Or the total amount of direct and indirect carbon emissions of activity entities (including individuals, organizations, departments, etc.) in the process of an activity. The calculation result of carbon footprint is the sum of GHG emissions in the whole life cycle of the product, expressed in terms of carbon dioxide equivalent (CO_2e) and expressed in tCO_2e/ t[1, 2]. Calculation of carbon footprint is an important way to evaluate the environmental impact of products or activities. At present, there are two main methods in carbon footprint research: one is the "bottom-up" model, based on process analysis. The other is the "top-down" model based on input-output analysis. Both methods are based on the basic principle of life cycle assessment(LCA)[3]. Shen et al.[4] applied LCA method to quantitatively calculate the carbon emissions of cement in its life cycle. The results showed that the greenhouse effect coefficient of Portland cement and mixed cement was 1.45t and 1.21t. The burning process of clinker accounted for about 0.9 tCO_2-eq/t.

The carbon footprint analysis method analyzes the whole process of carbon emissions. It takes the GHG emissions related to individual or enterprise activities into account, so as to deeply analyze the nature of carbon emissions and develop a scientific and reasonable carbon emission reduction plan from the source[5]. Product carbon footprint analysis based on LCA is a highly recognized research method to deal with climate change and solve the quantitative evaluation of carbon emission intensity. This method evaluates the impact of the product or service system on environment in the whole life cycle. It finds the improvement direction and considers the social and economic development and the sustainable development of environment. In recent years, China's research institutions and efficient life cycle carbon footprint assessment process has been studied[6-10], but most of the research conducted in-depth discussion on the carbon emissions during usage. There is currently a lack of scientific guidance on positive impact assessment of products or services to demonstrate the environmental benefits of activities.

UNESCO first proposed the concept of carbon handprint in 2007 to shift the focus from reducing the negative impact to increasing their positive impact. This new environmental metric can promote positive effects on the environment for marketing and communication purposes and make product development more climate-friendly. It can improve the competitiveness of enterprises. From the perspective of carbon handprint, there is no upper limit to the environmental benefits realized. Beckmann et al.[11] proposed reducing one's carbon emissions (e.g., at the production stage) as a way of producing carbon handprint, which could be considered to overlap with reducing one's footprint. Carbon footprint evaluation is a static evaluation centering on the negative environmental impact of products or services, which lacks guiding significance for sustainable development. There are many types of research on carbon footprint evaluation theory but few applications. Introducing carbon handprint can connect enterprises and drive the practical application of carbon evaluation. Therefore, in this paper, plasticizer products as an example. We pay more attention to the process of change combined with LCA and carbon handprint theory. More systematic research on product’s environmental impact will provide a scientific basis for the product assessment system of China's industrial enterprises.

Our starting point is by introducing the concept of carbon handprint, based on the real implications of the product or service to determine its whole life cycle of a comprehensive environmental value, unlike some scholars to make a clear distinction between carbon handprint and carbon footprint to avoid overlapping, we believe that the carbon footprint and carbon handprint is unable to cuts, carbon handprint evaluation is based on the calculation of carbon footprint compared to baseline. By analyzing a practical chemical plasticizer product case, it is of systematic significance to analyze the difference of many carbon reduction schemes in chemical enterprises from two different perspectives for energy saving and emission reduction.

2. METHODOLOGY

2.1 Carbon footprint method

At present, enterprises usually use the coefficient method for carbon emission verification, among which the typical representative is the GHG Accounting System (GHG Protocol) and ISO 14000 series. We use coefficient method to select the most appropriate emission factors based on activity data and references and finally calculate the total emissions of the whole life cycle. For example, for the emission factor of solid waste treatment, we found the data in China and Japan's solid waste treatment literature, compared it with other data of the same type, and selected it after confirming that it was reasonable.

The calculation process of carbon footprint is as follows[12]:1) Determine the accounting boundary;2) Identify emission source N;3) Identify data requirements - activity level data and emission factors;4) Calculate the emissions of emission source N;5) Report the summary of carbon emissions.

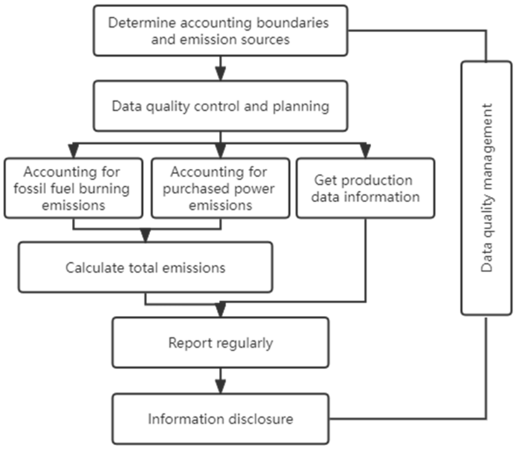

Fig.1. Flow chart of carbon footprint

During the mapping process, companies need to identify the activities of carbon inventory. The GHG Protocol divides emissions into three scopes and instructs enterprises to sort out their activities by scopes to assess their emissions within each scope.

Table 1. Carbon baseline inventory scope list

Scopes	Define	Activity list
Scope1	Direct emissions	Own boiler
	GHG emissions directly from the burning of fuels	Own furnace (none)
		Own vehicle (construction, loading, unloading, feeding)
		Chemical production
		The new carbon sink
Scope2	Indirect emissions	Purchased electricity
	GHG of electricity, heat, and cooling purchased	Outsourcing thermal
		Outsourcing steam
		Purchased cooling (none)
Scope3	Other indirect emissions	Purchased raw materials, goods, and services
	In addition to scope 1 and 2, indirect emissions of operation, include upstream and downstream emissions	Fuel-related activities
		Upstream transportation and distribution
		Waste during operation
		Domestic emissions (none)
		Processing and Use of Sold Goods (None)
		Franchising and investing

The enterprise carbon footprint inventory can clarify the GHG emissions of the product life cycle, help enterprises identify the production links with high energy consumption and high carbon emissions, and take improvement measures for the relations with high emission reduction potential, so as to realize energy saving and reduce costs.

The carbon footprint calculation formula is:

$$E_{GHG} = E_{fuel} + E_{tran} + E_{pro} + E_{dis} - R \quad (1)$$

$$E_{pro} = E_{mat} + E_{ele} + E_{heat} + E_{dir} \quad (2)$$

2.2 Carbon handprint method

The calculation process of carbon handprint is as follows: 1)Define customers and carbon handprint generation sources; 2) Define a baseline. On the one hand, the carbon footprint of the new production scheme is compared with that of the original scheme. On the other hand, the customer's use of the product needs to be compared with other products. Still, because the customer has many kinds of products to choose from, so we can not develop a single product for comparison, so we choose the average consumption and performance of industrial-grade commercially available products, with statistical data as the benchmark; 3) Define functional units. For in-factory production and customers, the unit quality plasticizer is used as a functional unit; 4) Define system boundaries. Use LCA, from cradle to grave; 5) Result statistics. By calculating the difference between the internal carbon handprint and the baseline after the optimization scheme and the difference between the carbon handprint and the baseline, the carbon handprint of the product itself and the carbon handprint of different industries are obtained statistically.

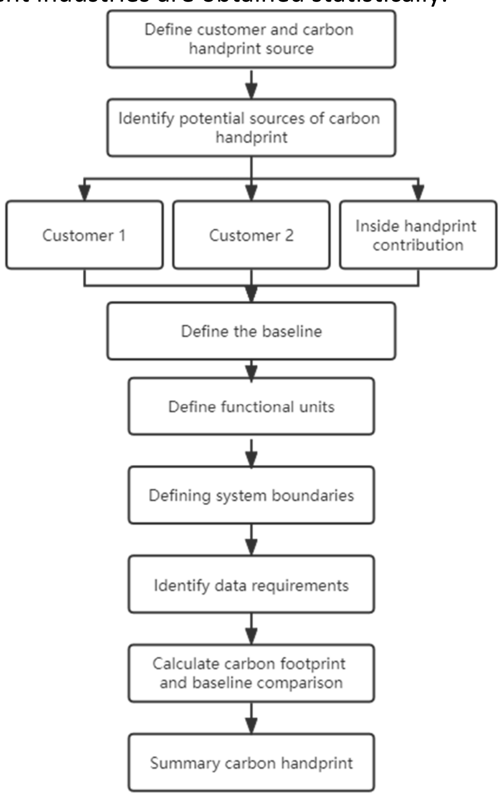

Fig.2. Flow chart of carbon handprint

The carbon handprint calculation formula is:

$$H = (E'_{GHG} - E_{GHG}) + H_{out} \quad (3)$$
$$H_{out} = \sum_{i=1}^{M}(W_i \cdot \varepsilon_i \cdot (\delta_1 - \delta_0)) \quad (4)$$

3. CASE INTRODUCTION

3.1 Case handprint description

The chemical company was mainly engaged in the production of plasticizer, due to the close distance water, restricted by the state environmental protection requirements, the development is a large limitation, now according to the regulatory scheme of Zhejiang province chemical industry product upgrades, improve the environmental benefits of the product. The following diagram shows the chemical plant boundary and flow diagram:

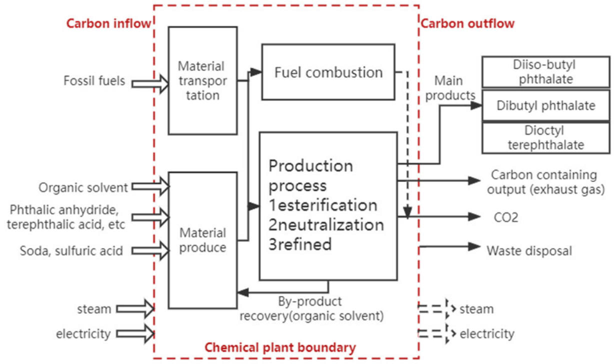

Fig.3. Chemical plant boundary and flow diagram

The plasticizer products produced by this chemical plant have many carbon handprint contributing sources. Plasticizers can increase the plasticity of the polymer system, used in concrete, gypsum, energetic materials, food packaging, etc. The potential customers are mainly in the construction industry and packaging industry, customers are determined according to the function and use of products. The type of customer is the plastic manufacturer that decides to replace the plasticizer used.

The purpose of the plastic production industry is to use plasticizers to complete the production and manufacture of products, producing carbon handprint. In the construction industry, it is mainly used as an additive to improve the performance of its products, producing carbon handprint. The production process of plasticizer through raw material recovery, energy-saving and consumption reduction, optimization of the process, producing carbon handprint

New plasticizers can produce carbon handprint by plastically reducing the number of packaging materials, prolonging the engineering life of concrete, or reducing GHG emissions during use and waste treatment. Because plasticizers are plastic additives, they do not have recyclable properties and cannot be recycled to produce carbon handprint. The recycling of raw materials can produce carbon handprint from the use of raw materials. The use of required raw materials contained in the waste of other industrial manufacturers can also produce carbon handprint. Potential carbon handprint contributors include improving energy efficiency, reducing material use, using environmentally friendly materials, developing product recyclability, reducing waste, extending product life, and improving product availability.

3.2 Data sources and explanation

The life cycle process system boundary of plasticizer production includes raw material production, raw material transportation, production process engineering (esterification reaction, neutralization reaction, refining process), waste treatment.

Explanation of main emission factors: mainly include diesel emission factor, purchased power emission factor, purchased steam emission factor, plasticizer production process emission factor, and transportation emission factor. The emission factors adopt the default value specified by IPCC, and the activity level data comes from field measurement. The emission factors of some production process materials and emission treatment processes are supplemented by literature search. *Enterprise GHG emission accounting method and reporting guide* and *China CO2 emission account 1997-2015*.

Table 2. Plasticizer production process emission factors[13-16]

Material	Emission factor δ_0	Note
Isobutyl alcohol N-butyl alcohol	3.473	Recovery 24.60%
Octanol	6.976	Recovery 21.35%
Phthalic anhydride	2.086	
Terephthalic acid	2.27	δ_1 1.2691
Soda ash	0.411	
Sulfuric acid	2.235	
Activated carbon	11	
Diatomite (industrial grade)	0.045	
Net purchase of electricity	6.1E-4	
Net purchase of steam	0.3	
Wastewater treatment	9.2E-4	
Waste gas treatment	1.246	
Solid waste disposal	0.32	

4. RESULTS AND DISCUSSION

4.1 Results

Carbon handprint is for product positive environmental impact quantitative evaluation index, based on the baseline of carbon interrogating method, using emission factor to calculate the carbon footprint of the difference before and after, it is concluded that four carbon handprint, optimizing production plan and calculate the performance after the upgrade products, were applied to two different plastic manufacturing and construction industry when the carbon handprint industry customers.

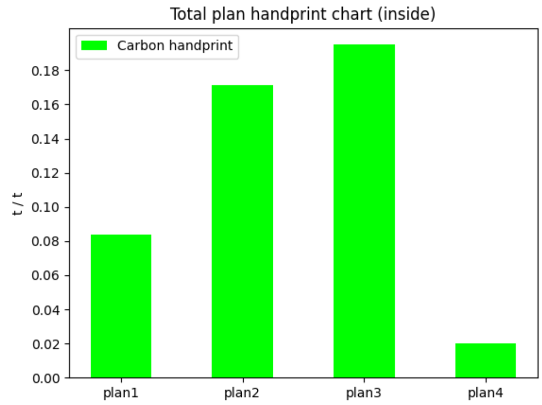

Fig.4. Inside carbon handprint schemes comparison diagram

In carbon handprint calculation, the four internal schemes are respectively optimizing the organic solvent recovery process (5% increase in recovery rate), adopting new p-dibenzoic acid raw material, replacing the backup coal-fired boiler with the biomass boiler, and optimizing the heat transfer efficiency of the heat transfer network to increase by 10%. The optimized recovery process can produce 0.08tCO2-eq/t carbon handprint. The carbon handprint of 0.171tCO2-eq/t can be produced by using the new material. The recovery of biomass boiler can produce 0.195tCO2-eq/t carbon handprint; Only 0.02tCO2-eq/t carbon handprint can be produced by optimizing the heat transfer network.

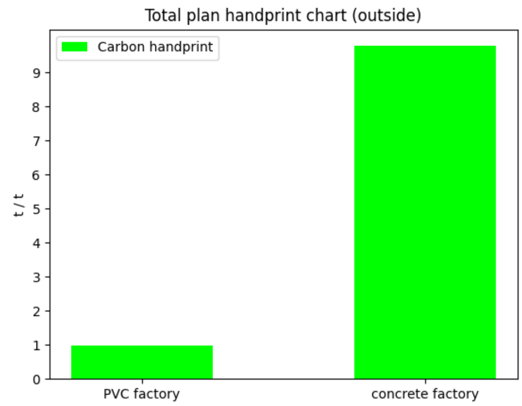

Fig.5. Comparison of outside carbon handprint schemes

Calculating the carbon handprint produced by plasticizer for different customers, the plasticizer with improved performance was used for quantitative calculation. When the performance was increased by 10%, the plasticizer addition ratio was reduced from 20% to 18% in the polyvinyl chloride(PVC) production process, and 0.983tCO2-eq/t carbon handprint could be produced. When the plasticizer addition ratio is reduced from 1% to 0.9% in concrete production, 9.778tCO2-eq/t carbon handprint can be produced.

4.2 Discussion

The carbon verification results of the case show that the carbon emission of input raw materials accounts for 86.31% of the total carbon emission of plasticizer in the whole life cycle, followed by the energy consumption of product production and the carbon emission of the reaction process (13.31%), the carbon emission of material transportation (0.21%) and waste treatment (0.17%). Suppose the data of raw material carbon emissions are excluded, and the specific production process is analyzed. In that case, the energy consumption and reaction process occupies the absolute majority (97.22%), while the carbon emissions of raw material transportation (1.54%) and waste treatment (1.25%) account for little. Therefore, raw material transportation and waste treatment process can be ignored in carbon handprint calculation of emission reduction scheme. For internal carbon handprint, the carbon footprint reduced by raw material selection upstream should be attributed to the carbon handprint of the raw material producer, so the improvement of internal carbon handprint should focus on reducing the emissions of the reaction process in the production process and improving energy efficiency and reducing energy consumption. Optimization of recycling process can produce carbon handprint by reducing raw materials. In terms of external carbon handprint, the positive environmental benefits generated by products applied to customers in different industries are obviously different, which needs to be calculated separately, and different industries should formulate standards for evaluation.

In terms of emission reduction scheme design, as the carbon emission of steam accounts for a very high proportion of production energy, it is suggested to improve the control device to electric control device, improve the utilization efficiency of steam, replace the current standby coal-fired boiler with biomass boiler and add waste heat boiler to improve the utilization rate of heat energy.

5. CONCLUSIONS

This paper takes the actual chemical plant products as the research object, and based on the carbon baseline, the LCA of plasticizer production and application is investigated. We compiled a data sheet for the accounting factors of product raw materials, sorted out the carbon verification process of the entire industry chain, used the carbon footprint verification model to calculate the carbon footprint of plasticizers, and compared the carbon footprints of four emission reduction schemes and two types of customers. According to the analysis of the comparative results, a more reasonable emission reduction scheme is proposed for production energy consumption, which has reference significance for the low-carbon planning and design of chemical plants.

The calculation results of the case show that the carbon footprint of plasticizers used in the production of PVC and concrete is 0.983tCO2-eq/t and 9.778tCO2-eq/t. Therefore, the impact of product carbon footprint evaluation in different industries is quite different. To evaluate the LCA environmental benefits of products with handprint, it is necessary to formulate industry standards for different typical industries. At the same time, reasonably unify and convert different industries.

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REFERENCE

[1] WIEDMANN T. Development of an Embedded Carbon Emissions Indicator - Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System [J]. Accounts of Chemical Research, 2008, 6(1): 32-40.

[2] Huang Wenxiu. Development of carbon footprint evaluation and carbon labeling system of domestic and foreign products [J]. Daily Electrical Appliances, 2012, (4): 4.

[3] Deng Nansheng. Life Cycle Assessment [M]. Life Cycle Assessment, 2003.

[4] Shen Weiguo, Cai Zhi, Liu Zhimin, et al. Talking about low carbon dioxide emission technology in cement concrete industry [J]. New Century Cement Herald, 2008, (4): 6.

[5] WEBER C L, MATTHEWS H S. Quantifying the global and distributional aspects of American household carbon footprint [J]. Ecological Economics, 2008, 66(2): 379-91.

[6] Ding Ning, Gao Feng, Wang Zhihong, et al. Comparison of energy consumption and GHG emissions in primary and secondary aluminum production [J]. Chinese Journal of Nonferrous Metals, 2012, 22(10): 8.

[7] Gu Daojin, Zhu Yingxin, Gu Lijing. Life cycle assessment of environmental impacts of buildings in China [J]. Journal of Tsinghua University(Natural Science Edition), 2006, 46(012): 1953-6.

[8] Li Man, Wang Zhen, Sun Dezhi. Study on Life Cycle Assessment of Polyethylene Production [J]. Environmental Science and Technology, 2009, 32(5): 5.

[9] Li Xiaodong, Wang Shuai, Kong Xiangqin, et al. Life cycle environmental impact assessment of ready-mixed concrete [J]. Chinese Journal of Civil Engineering, 2011, 44(1): 7.

[10] Awaking, Zhang Xu, Sun Yongqiang. Detailed List Analysis of Steel Structure Residential Building Parts Life Cycle [J]. Journal of Tongji University (Natural Science), 2011, 39(12).

[11] BECKMANN J P, EBERLE U, EISENHAUER P, et al. Der Handabdruck: Ein Ansatz zur Messung positiver Nachhaltigkeitswirkungen von Produkten. Stand und Ausblick [J]. 2017.

[12] Tian Tao, Jiang Ye, Li Yuan. Research status and application prospect of product carbon footprint evaluation in petrochemical industry [J]. Petroleum and Petrochemical Green and Low Carbon, 2021, 6(1): 7.

[13] LU, SUN, ZHAOLING, et al. Carbon footprint assessment for the waste management sector: A comparative analysis of China and Japan [J]. Frontiers in Energy, 2018.

[14] SHAN Y, GUAN D, ZHENG H, et al. China CO2 emission accounts 1997–2015 [J]. Scientific Data, 2018, 5: 170201.

[15] Jiang Li, Chu Jiangwei. Life cycle GHG emissions of corn butanol [J]. Journal of Beijing University of Technology, 2015, 41(10): 5.

[16] Lu Jiayuan. Analysis of carbon footprint and emission reduction potential of China's sewage treatment industry [D]; University of Science and Technology of China.