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Water Footprint Sustainability Analysis: A Case of the Chlor-alkali/Polyvinyl Chloride Sector in China

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Water resource conservation and management have been major concerns for industrial sectors. It has been recognized that water availability may be a limiting constraint to the development of water intensive industries, e.g. chlor-alkali sector. The water footprint is a measure of freshwater appropriation underlying a certain production pattern. Three components are the blue, green, and grey water footprint. They have all been applied specifically to trace direct and indirect water use and pollution over production chains as well. Water footprint benchmarks for water-intensive commodities reflect local water scarcity, and some agreement about equitable sharing of the limited available global water resources among different communities and nations. This work will interlink the water footprint of the product and the corresponding production process with water scarcity at the regional level. A framework for water footprint sustainability analysis is proposed. It assesses the sustainability of industrial products by combining with water scarcity index and water footprint at the regional level.

1. Introduction

Water resource covers 70 % of the earth surface, but the potable water accounts for a small part. Besides water shortage is more serious in China. In China, the ratio of water resources is only 8 % of the world's water resources, and water resources per capita is only 220 m^3, equivalent to a quarter of the world average. The chlor-alkali/polyvinyl chloride (PVC) is one of the basic chemical industries in China. Its products are widely used in various fields. It is estimated that the annual consumption of PVC in 2050 will be close to 16 Mt (Zhou et al., 2013). In the chlor-alkali/polyvinyl chloride sector enormous amounts of energy and water is consumed. Hence, it is of significance to consider the water consumption of the chlor-alkali/polyvinyl chloride from the point of view of life cycle.

Water footprint proposed by Hoekstra et al. (2012) had been applied to analysing water consumption at different levels (a country, a region, an industry, and an product). Čuček et al. (2012) utilized footprints as defined indicators to measure sustainability of humans, nations, processes, products or activities. Fang et al. (2014) came up with the idea of footprint family, which combined the ecological, energy, carbon, and water footprints to assess environmental impacts. At the national level, Zhao et al. (2002) used input-output model to investigate national water footprint of China. Besides, at the regional level, Okadera et al. (2015) evaluated the water footprint of the energy supply of Liaoning Province, using the input-out method. And at the industrial level, Herath et al. (2011) assessed the water footprint of hydroelectricity in New Zealand. Wei and Shi (2015) analysed the water footprints of the coal-oil industries at five largest coal bases in China. Using an iron factory in Eastern China as an example, Gu et al. (2015) calculated its water footprint of the iron and steel industry. At the product level, Chapagain and Orr (2009) linked global consumption to analysis potatoes products water footprint, in Spanish.

In this work, a framework for water footprint sustainability analysis is proposed. It assessed the sustainability of industrial product by combining with water scarcity index at the regional level. It aims to interlink the water footprint of the product and production process with water scarcity and availability at the regional level.

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2. Water footprint of the chemical product

Water footprint of the chemical product includes direct and indirect water consuming during the production process. Besides, the water footprint includes not only water footprint of production process, but also water footprint of supply chain. In the practical accounting, only the blue water and grey water footprints are considered. Figure 1 is the water footprint of chemical products production process. The equations of each footprint are as following.

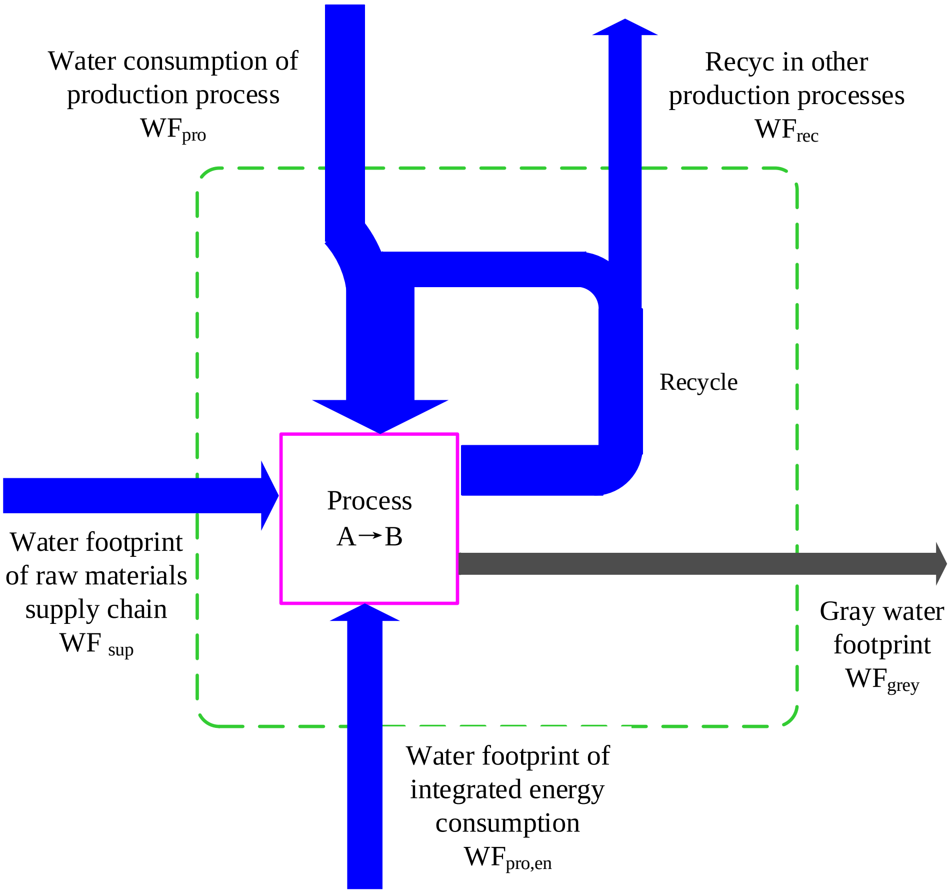


Figure 1: Water footprint of chemical production process

Equation of the blue water footprint (WF_B):

$$WF_B = WF_{sup} + WF_{pro} + WF_{pro,en} - WF_{rec} \tag{1}$$

WF_B: Blue water footprint; WF_{sup}: Water footprint of raw materials supply chain; WF_{pro}: Water consumption of production process; $WF_{pro,en}$: Water footprint of integrated energy consumption ; WF_{rec}: water footprint of recycling.
Equation of the grey water footprint (WF_{grey}):

$$WF_{pro,gray} = \frac{L}{c_{max} - c_{nat}} = \frac{V_{effl} \times \left(c_{effl} - c_{nat}\right)}{c_{max} - c_{nat}} \tag{2}$$

C_{max}: pollutants concentration of the standards (mg/L); C_{nat}: pollutants concentration of the receiving water (mg/L); C_{effl}: pollutants concentration of the effluent (mg/L); V_{effl}: the volume of the effluent (time/volume); L: the discharge rate of the effluent (t/s).

Equation of industrial chain products ($WF_{c,p}$):

$$WF_{c,p} = WF_{sup} + WF_B + WF_{gray} \tag{3}$$

WFsup: Water footprint of raw materials supply chain; WF_B: Blue water footprint; WF_{gary}: Grey water footprint.

3. Water footprint sustainability assessment

3.1 Assessment procedure

The regional water footprint sustainability should be assessed firstly, to know the water footprint sustainability of the production process and products. Figure 2 is the procedure of water footprint sustainability assessment for the product.

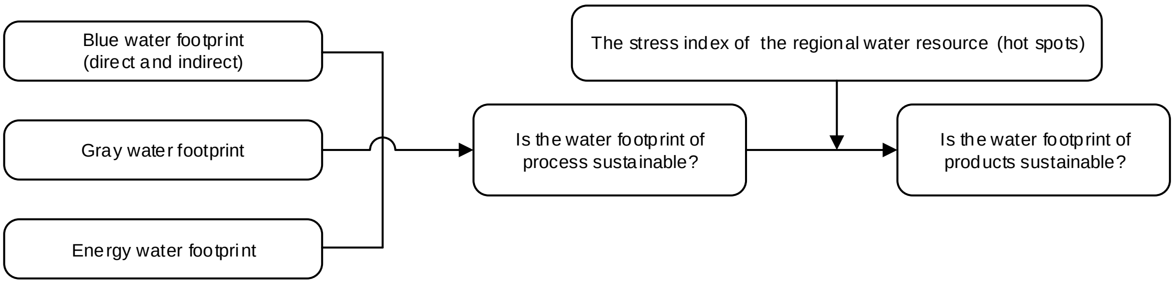


Figure 2: Water footprint sustainability assessment

3.2 Assessment criteria

From the view of geographical aspect, substandard water and injustice or inefficient of the water resources allocation are regarded to water footprint unsustainable. Form the view of other process, there are two assessment criteria. One is when all the water footprints are sustainable; the process treats as the sustainable process. The other is the water footprint of the process is sustainable. From the view of products, water footprint sustainability of products depends on the production process. However, because the process is more complex, the water footprint of each product is made of many sections. Therefore, water footprint sustainability of each sector should reference to the two criteria.

(1) Whether the river basin where the process is going on is the hot spots?

(2) Whether the water footprint of the process is sustainable?

3.3 Water scarcity index

Water scarcity index (WSI) is the indicator, which reflects the lack of water resources in different regions. Firstly, Falkenmark and Widstrand (1992) used the per capita water resources to measure the scarcity of water resources and defined it as a water pressure index. Furthermore, considering social adaptability and taking the Human Development Index of the United Nations Development Program as the weight coefficient of the WSI, Ohlsson (2000) got the social water resource pressure index.

At present, there are two indicators of universal macroeconomic measures to measure water resources: one is the per capita water resources in the region, and the other is the degree of exploitation and utilization of water resources. Generally, the WSI is higher, the more serious shortage of water resources in the area. Figure 3 is the WSI of China at the provincial level at 2015.

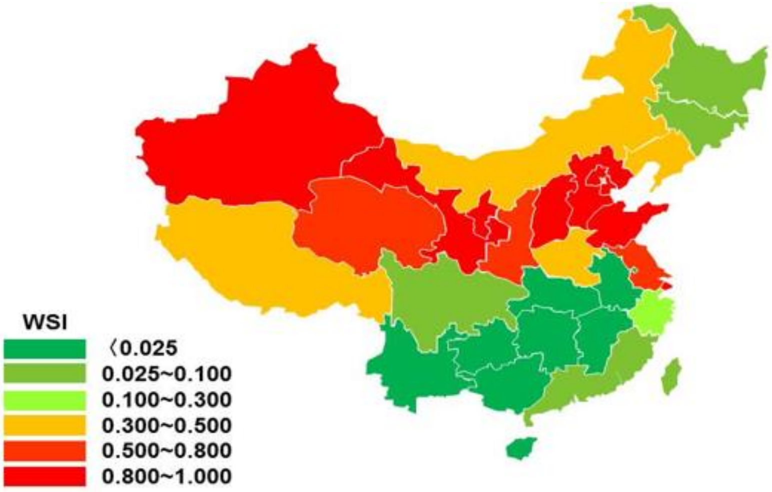


Figure 3: WSI of China at the province level

4. Water footprint sustainability analysis of Xinjiang province

Xinjiang province is one of the driest provinces in the northwest of China. Because of the two deserts, Taklimakan Desert and Gurbantunggut Desert, Xinjiang province faces more serious water shortage. At present, Xinjiang province has 88.2 billion m^3 water resources, including 79.4 billion m^3 surface water and 8.8 billion m^3 underground water.

4.1 Water scarcity analysis of the river basin

In the special watershed, generally annual precipitation is used to obtain the regional water supply. Then, utilize the data of local water supply to analysis condition of water consumption. Because of lacking a direct method to calculate the amount of the underground water, most usually let annual precipitation to replace available water resource.

According to the scarcity of local rainfall, classification is as flowing.

Large: annual precipitation < 75 cm
Moderate: annual precipitation on 75 ~ 150 cm
Small: annual precipitation >150 cm

Figure 4 is Water scarcity index and classification. In Xinjiang, annual average natural precipitation is only 155 mm. Based on the rain scarcity grading of Figure 4, Xinjiang area is in the high rain scarcity level. Also, the water scarcity index of Xinjiang is 0.8-1.0 showing in Figure 3, which suggests most water consumption is unsustainable. This is because normally when WSI is more than 0.4, it means the area is severely shortage of water; and WSI is higher, the more serious shortage of water resources.

Either from the perspective of the annual precipitation, or from water resources pressure index, Xinjiang province has serious imbalance between the supply and demand of water resources. Especially in recent years, more high water consumption industries gradually shift to the west, increasing the burden of the local water supply, and make water footprint of the area more unsustainable. Thus, Xinjiang province belongs to the hot area.

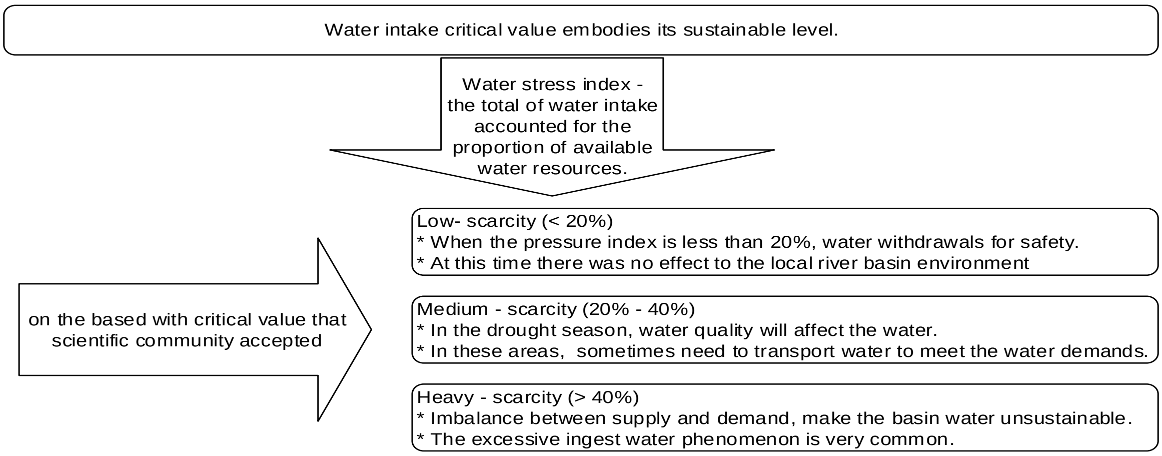


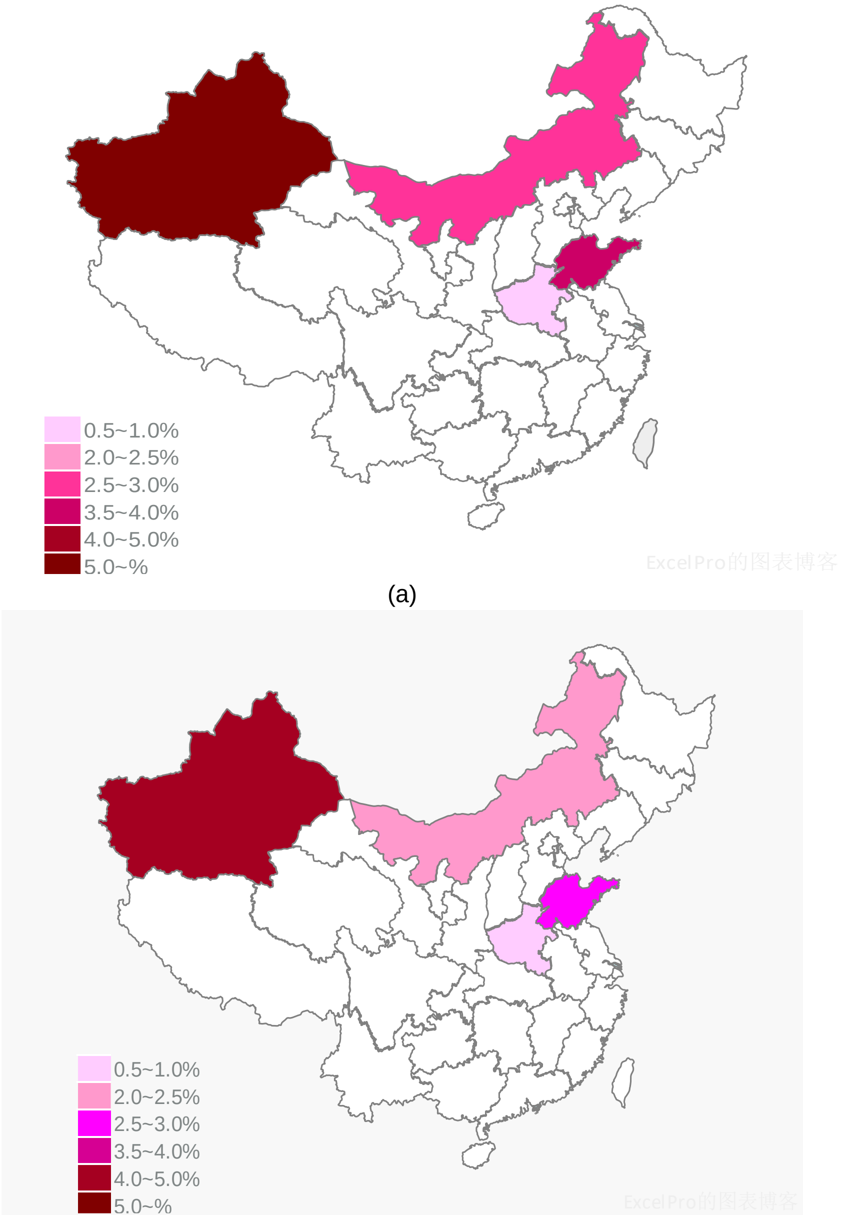
Figure 4: Water scarcity index and classification (Taikan and Shinjiro 2006)

4.2 Water footprints of chlor-alkali products in Xinjiang province

According to the data from National Bureau of Statistics, in 2012, the yield of 100 % caustic soda and PVC are 14.64 Mt and 19.27 Mt in Xinjiang province. The yield of PVC accounted for 14.73 % of national total output. Table 1 is the water footprints of main chlor-alkali production in Xinjiang province. As Table1 showed, the product water footprint at advanced level is less than at the current level. In order to reach the advanced level, the new technologies and optimized supply chains must be taken. Some technologies are selected from the Guide of efficient water consumption in emphasis industry (MIIT, 2013). Figures 5a and b are water consumption severity of four provinces ((Xinjiang, Inner Mongolia, Henan, and Shandong) at current level and at advanced level.

Table 1: Water footprints for chlor-alkali products of Xinjiang province at current and advanced level

Level	100% caustic soda (10^4·t)	PVC (10^4·t)	Water footprint (10^4·t)	Total industrial water (10^8·t)	Proportion (%)
Current	146.39	194.72	0.7358	12.38	5.943
Advanced	146.39	194.72	0.5926	12.38	4.787



(a)

(b)

Figure 5: Water consumption scarcity at (a) current level and (b) advanced level for Xinjiang, Inner Mongolia, Henan, and Shandong

5. Conclusion

In the work, the water footprint assessment model is used, which combining with water scarcity index at the regional level, to assess the sustainability of industrial product in Xinjiang province. The results show that the water footprint of Xinjiang province is unsustainable. At present, most chlor-alkali industries have the mature process flows. In order to get the advanced level, the supply chain water footprint and grey water footprint should be reduced. The future work will consider process integration and other approaches to reduce the water footprint.

Acknowledgments

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