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Review and recommendations on a water pollution control framework for the pulp and paper sector in China

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Abstract

The pulp and paper sector has been a significant source of water pollution in China for many years. The Chinese government has made great efforts on water pollution control for the pulp and paper sector. While actively participating in various international treaties and conventions related to environmental management and pollution control in this sector, China has created a comprehensive environmental management framework, including several environmental policies, regulations and standards. This study reviews the current environmental framework for the management and control of water pollutants generated by the pulp and paper industry in China, with reference to relevant experiences. Apart from assessing the achievements that China has made, this study proposes some recommendations to further enhance water pollution control capacity and facilitate effective legal enforcement. Approaches such as improvements to environmental standards and permit systems, technical upgrading, cleaner production strategy, environmental monitoring improvements, integration of financing channels for environmental improvement, and enhancement of social responsibilities of enterprises are addressed.

Keywords: Environmental framework; Pulp and paper; Standard; Technical upgrading; Water pollution control

1. Introduction

During the past couple of decades, China has experienced rapid economic growth. With the increases in population and the business markets, the consumption of paper products has also increased (Szabo *et al*., 2009). Consequently, pulp and paper production has been increasing year by year.

The massive pulp and paper yield has led to intensive energy consumption and great amounts of pollutant discharge (Gu, 2009). China's pulp and paper sector has been recognized as the most highly polluting industrial sector. It is expected that over 3 billion tons of wastewater and over 1 million

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tons of COD_{cr} (dichromate chemical oxygen demand) will be annually discharged from the pulp and paper industry (Luo, 2011). In 2009, the pulp and paper sector discharged 18.8, 28.9 and 11.2% of China's national industrial wastewater, COD_{cr}, and NH_3-N emission loadings respectively (NBS & MEP, 2010). Due to the unsuitable raw material structure, relatively small scale, backward production processes, lack of equipment and recycling techniques, and various other problems, China's paper industry has been suffering heavy environmental pollution for many years (Cao, 2007). Studies have shown that the major sources of water pollutant generation are from spent bleaching liquor, black liquor from pulp cooking, and wastewater generated from brown pulp washing, screening and paper machines (Chen *et al*., 2012). Among these, dioxin and AOX (adsorbable organic halogens) generated from chlorine bleaching have attracted a lot of attention around the world (Pokhrel & Viraraghavan, 2004). Non-wood pulp and paper mills in which water pollutants are difficult to treat are of particular concern, since they make up a large proportion of China's paper production, and most of them are small or medium-sized enterprises (SMEs) (Ren, 1998).

Given that the pulp and paper manufacturing sector is an important source of water pollution in China, multiple pollution control measures need to be taken. It is important for the government to analyze the current industrial conditions and to optimize the management and enforcement system for industrial development and environmental protection targets. This article aims to conduct a review of the environmental framework of the pulp and paper manufacturing sector in China, and some recommendations are proposed with reference to the experiences of other developing countries. In addition, peer-referred articles in international journals, peer-reviewed and non-reviewed Chinese articles, and governmental reports have been consulted to conduct a comprehensive assessment.

2. Industrial management of the pulp and paper sector

2.1. Institutional development of the environmental framework for the pulp and paper sector

Since 1986, the Chinese government has conducted over 200 approaches related to the pulp and paper sector (CPA, 2009). China has made great efforts to eliminate outdated techniques and products, to transform traditional industries by adopting advanced technologies, and to take cleaner production measures (Zhang & Wen, 2008). Many of these approaches have greatly affected the environmental pollution levels from the industry. Table 1 shows the most important environmental policies, legislation and standards for the pulp and paper industry in China.

Before 1978, most Chinese paper enterprises were state-owned or in collective ownership, with their production plans, material supply, product sales, technical innovation, and staff income all determined by the government. After 1979 the Economic Reform was implemented concerning state-owned enterprises and the rural economic regime. The *Decision on Some Issues for Promoting Rural Development by the China Communist Party* accepted the important role of township enterprises in China's economic development. A range of small township paper enterprises was established in the central regions of China (wheat cultivation region). With considerable flexible management mechanisms and abundant straw resources, the yield proportion of these enterprises saw an increase compared with the total national yield. The reform progress of state-owned enterprises was quite slow and it was the first time, between 1979 and 1984, that the total paper yield of state-owned enterprises had declined. The paper yield of township enterprises in some provinces exceeded those of state-owned enterprises. For

Table 1. Regulations, standards and specifications relating to environmental protection for the pulp and paper manufacturing industry in China.

Regulations, standards and specifications		
Law and Regulations	Issuers	Effective from
'12th Five-Year' Plan of Paper Industry	National Development & Reform Commission, Ministry of Industry & Information Technology, Ministry of Forestry	2012.1
'12th Five-Year' Plan of Industrial Cleaner Production Implementation	Ministry of Industry & Information Technology, Ministry of Science & Technology, Ministry of Finance	2012.1
'12th Five-Year' Plan of Henan Environmental Protection	Henan Provincial Government	2011.12
'12th Five-Year' Plan of Shandong Environmental Protection	Shandong Provincial Government	2011.12
Guidance Catalogue of Industrial Structure Adjustment	National Development & Reform Commission	2011.6
Cleaner Production Technical Implementation Measures for Paper Industry	Ministry of Industry & Information Technology	2011.3
Guidance Catalogue of Some Backward Production Processes, Facilities and Products to be Eliminated from Many Industrial Sectors	Ministry of Industry & Information Technology	2010.10
Rearrangement & Revitalization Plan on Light Industry	State Council	2009.5
Henan Provincial Plan on Water Pollution Prevention & Control among Upper & Middle Reaches of Huai River & Yellow River Basins (2006–2010)	Henan Provincial Government	2009.2
Water Pollution Prevention & Control Plan on Songhua River Basin (2006–2010)	Ministry of Environmental Protection	2008.4
Water Pollution Prevention & Control Plan on Liao River Basin (2006–2010)	Ministry of Environmental Protection	2008.4
Water Pollution Prevention & Control Plan on Hai River Basin (2006–2010)	Ministry of Environmental Protection	2008.4
Water Pollution Prevention & Control Plan on Huai River Basin (2006–2010)	Ministry of Environmental Protection	2008.4
Guide Comments on Enhancing Environmental Supervision & Management to Corporations	State Environmental Protection Administration[a]	2008.2
Inspection Guidance on Discharge Fee Collection	State Environmental Protection Administration[a]	2007.12
Announcement on Elimination of Backward Production Capacity among Pulp & Paper, Alcohol, Monosodium Glutamate, Citric Acid Industrial Sectors	National Development & Reform Commission, State Environmental Protection Administration[a]	2007.10
Paper Industry Development Policy	National Development & Reform Commission	2007.10
National Implementation Plan on the Stockholm Convention	State Council	2007.4
List of Backward Paper Manufacturing Enterprises to be Eliminated in 2007	National Development & Reform Commission, State Environmental Protection Administration[a]	2007.2

(*Continued.*)

Table 1. (*Continued.*)

Regulations, standards and specifications		
Law and Regulations	Issuers	Effective from
Comments on Accelerating the Elimination of Backward Production Capacity & Promotion of Industrial Structure Upgrading	Shandong Provincial Government	2006.11
National Major Pollutants Discharge Loads Control Plan during 'Eleventh-Five-Year' Period	State Environmental Protection Administration[a]	2006.8
Energy Conservation Approach of 1000 Enterprises	National Development & Reform Commission	2006.4
Guidance Catalogue for Industrial Structure Adjustment (2005)	National Development & Reform Commission	2005.12
Announcement on Enhancing Pollution Prevention & Control within Huai River Basin	State Council	2004.12
National Forestry-Paper Integration Project and the 2010 Special Plan	National Development & Reform Commission	2004.1
List of Backward Production Capacity, Processes, and Productions due to Elimination (3rd Batch)	State Economics & Trade Commission	2002.6
'10th Five-Year' Plan of Light Industry	State Economics & Trade Commission	2002.5
'10th Five-Year' Plan of Shandong Province on Environmental Protection	Environmental Protection Bureau of Shandong Province	2002.4
Feedback of Issues on Environmental Management to Paper Manufacturing by Wastepaper	State Environmental Protection Administration[a]	2002.3
Scheme on '10th Five-Year' Plan of Industrial Structure Adjustment	State Economics & Trade Commission	2001.11
'10th Five-Year' Plan of Industrial Water Conservation	State Economics & Trade Commission	2001.10
'10th Five-Year' Plan of Environmental Industry Development	State Economics & Trade Commission	2001.10
'10th Five-Year' Plan of Paper Industry	State Economics & Trade Commission	2001.8
List of National Key Encouraged Water Conservation Facilities (Products) (1st Batch)	State Economics & Trade Commission, State Administration of Taxation	2001.7
Some Comments on Promotion of Raw Material Forest Base Construction Paper Industry	National Planning Committee, Ministry of Finance, Ministry of Forestry	2001.2
Comments on Improvement of Industrial Water Conservation	State Economics & Trade Commission, Ministry of Water Resources, Ministry of Housing & Urban-Rural Development, etc.	2000.10
List of National Key Encouraged Industries, Products & Technology (Revised 2000)	National Planning Committee, State Economics & Trade Commission	2000.8
Technical Policy on Wastewater Pollution and Prevention within Straw Pulp & Paper Industry	State Environmental Protection Administration[a], State Light Industry Administration	1999.6
Environmental Protection Policy, Technical Policy and Pollution Prevention Strategy of Pulp & Paper Industry	China National Light Industry Council	1997.8
Decisions on Several Issues Concerning Environmental Protection	Environmental Protection Committee of the State Council	1996.8
Interim Regulations Concerning the Prevention and Control of Water Pollution in the Huai River Basin	State Environmental Protection Administration[a]	1995.5

(*Continued.*)

Table 1. (*Continued.*)

Regulations, standards and specifications		
Law and Regulations	Issuers	Effective from
Provisions on Water Pollution Prevention and Control of Paper Industry	Environmental Protection Committee of the State Council, Ministry of Light Industry (former), Ministry of Agriculture, Ministry of Finance	1989.1
Standards	**Codes**	**Effective from**
Norm of water intake – Part 5: Pulp, paper and paper board production	GB/T 18916.5-2012	2013.1
Discharge standard of water pollutants for pulp and paper industry	GB 3544-2008	2008.8
Tianjin integrated wastewater discharge standard	DB12/35-2008	2008.1
Discharge standard of main water pollutants for municipal wastewater treatment plant & key industries of Taihu area	DB32/1072-2007	2008.1
Shaanxi discharge standard of water pollutants for paper industry	DB61/387-2006	2007.4
Beijing water pollutants discharge standard	DB11/307-2005	2005.7
Henan discharge standard of water pollutants for paper industry	DB41/389-2004	2005.7
Norm of water intake – Part 5: Pulp, paper and paper board production	GB/T18916.5-2002	2005.1
Shandong discharge standard of water pollutants for paper industry	DB37/336-2003	2003.5
Discharge standard of water pollutants for paper industry	GB 3544-2001[b]	2001.1
Discharge standard of water pollutants for paper industry	GB 3544-1992[b]	1992.7
Technical Specifications	**Codes**	**Effective from**
Cleaner production standard – Waste paper pulping (paper industry)	HJ 468-2009	2009.7
Technical guidelines for environmental protection in paper industry project for check and accept of completed project	HJ/T 408-2007	2008.4
Cleaner production standard – Production of kraft chemical wood-pulp (paper industry)	HJ/T 340-2007	2007.7
Cleaner production standard – Production of bleached soda straw pulp (paper industry)	HJ/T 339-2007	2007.7
Cleaner production standard – Process of bleached alkali bagasse pulp (paper industry)	HJ/T 317-2006	2007.2
Cleaner production assessment system of pulp & paper industry (on trial)		2006.12

[a]The State Environmental Protection Administration was replaced by Ministry of Environmental Protection in March 2008.
[b]The 1992 version and 2001 version of the national water discharge standard for paper industry have been replaced by the latest 2008 version.

example, the yields of township enterprises in Henan took 76.13% of the total yield of the whole province (CNLIC, 1991). However, due to technical shortcomings and the small scale of these enterprises, most of them did not include alkali recovery systems, leading to direct black liquor discharge, not only wasting energy, but also polluting the ambient environment.

During the 1990s, rapid economic growth led to increasing demand for paper and paper board, and also for higher requirements on paper quality. However, poor-quality paper products (such as copper print paper and Kraft liner boards) could not fulfill the needs for national economic development (relying on imports). The drastic conflict between supply and demand, especially during the late 1990s, led to a comprehensive scarcity of paper resources, and paper prices rose.

From 1990 to 1994, state-owned enterprises also implemented joint-stock reforms. In 1992, the 14th Communist Party Summit advocated establishing a market economy system under the socialized society, whose key task was to modify the state-owned enterprises and to promote them in the market. The Chinese Reform terminated the planning economy period and started to consider property rights' reform for state-owned enterprises. At the end of 1995, there were more than 2,400 shareholding companies and 17,500 limited companies, among which pulp and paper enterprises had implemented the shareholding reform, and their property management capacity was improved. As the Ministry of Light Industry was disbanded in 1993 and the General Association of Light Industry was founded, China completely abolished the administrative management rights on paper enterprises, and the enterprises were managed by local governments. The quantity of small paper enterprises was increasing, and their pulp and paper yields were growing during this period. There were 8,267 straw pulp-predominated township paper enterprises in 1992. In 1993, the total yield contributed by township enterprises had exceeded those of state-owned enterprises (SEPA, 1997).

While China's pulp and paper sector was growing rapidly, environmental pollution, especially water pollution, was becoming more and more serious. From 1995 onwards, the major aim of the Chinese pulp and paper sector was converted to 'gradually achieving the diverse material structure by focusing on wood material fiber, expanding waste paper recycling and utilization, and scientifically and reasonably adopting non-wood fiber' (Zhan, 2010). China also enacted regulations and standards such as the *Discharge Standard of Water Pollutants for Paper Industry (GB3544-1992)*, *Interim Regulations Concerning the Prevention and Control of Water Pollution in the Huai River Basin (1995)*, *Decisions on Several Issues Concerning Environmental Protection (1996)* and *Technical Policy on Wastewater Pollution and Prevention within Straw Pulp & Paper Industry (1999)*. Among these regulations and standards, the *Interim Regulations Concerning the Prevention and Control of Water Pollution in the Huai River Basin (1995)* announced that any paper mill whose annual yield was less than 5,000 tons should be closed. *Decisions on Several Issues Concerning Environmental Protection (1996)* specified that 15 kinds of heavily polluting small enterprises should be closed before 30 September 1996. It also stated that any heavily polluting small paper-making mills should be closed. According to the provisions of the State Environmental Protection Agency (SEPA), small paper-making mills meant 'any small chemical pulping and paper-making mills with an annual pulping capacity less than 5,000 tons'. In 1999, China formulated the *Technical Policy on Wastewater Pollution and Prevention within Straw Pulp & Paper Industry*, specifying that all paper-making enterprises should have achieved their discharge targets by the end of 2000; pollution treatment facilities of non-wood fiber pulp and paper-making enterprises had to reach certain scales; any newly built wheat straw pulping and paper-making enterprise should have an annual pulp capacity of over 34,000 tons; any non-wood pulp enterprise, other than a newly built wheat straw pulping and paper-making mill, should have an annual pulp capacity of over 50,000 tons; any

alkali chemical straw pulp mill should have an annual capacity of no less than 17,000 tons for the building of alkali recovery facilities; any chemical pulping mill (workshop) with an annual capacity of less than 5,000 tons was to be banned; and for any small chemical pulping enterprise with an annual capacity of less than 17,000 tons, environmental improvement measures had to be implemented through treatment, closure, suspension, combination and transition, before the end of 2000. The Technical Policy also proposed straw pulp wastewater pollution and prevention technologies, such as dry-wet stocking, and alkali recovery (SEPA, 1999). This Technical Policy was implemented by local environmental departments and industrial departments. Technologies recommended in this Technical Policy were widely used by Chinese straw pulp manufacturers, and alkali recovery has been widely adopted since 2000 (SEPA, 2001).

After 2000, China announced increasingly stringent requirements for environmental protection and enacted a series of regulations and standards to eliminate any straw pulp manufacturing installation with an annual capacity of less than 34,000 tons. These included the '*10th Five-Year*' (2001–2005) *Plan of Paper Industry*, the *National Forestry-Paper Integration Project and the 2010 Special Plan* (2004), the *Guidance Catalogue for Industrial Structure Adjustment* (2005) and *Industrial Policy within Paper Industry*. The *Discharge Standard of Water Pollutants for Paper Industry (GB3544-2001)* was also introduced during this period. Later, this was replaced by the *Discharge Standard of Water Pollutants for Pulp and Paper Industry (GB3544-2008)* promulgated in 2008, making more stringent rules on water pollutants discharged from the pulp and paper sector. Following the *National Special Plan of the Forestry-Paper Integration Project* released in 2004, China launched a number of forest-paper integration projects, increasing to 4 million tons of pulp production capacity, 1.58 tons of paper-making capacity, and 10.17 million acres of paper materials' forest base. The Forest-Paper Integration approach was an important strategy for China's sustainable development. The plan favored the adjustment of the raw materials' structure of the paper industry, by which wood pulp (or bamboo pulp) could replace straw pulp as the major raw material, to reduce energy consumption and pollutant discharge.

China also ratified the *Stockholm Convention on Persistent Organic Pollutants*, which came into force in 2004. The Chinese Central Government developed the *National Implementation Plan of China for the implementation of the Stockholm Convention on Persistent Organic Pollutants* (NIP). In May 2005, the National Coordination Group for Implementation of the Stockholm Convention was established, consisting of 11 ministries and agencies. During this NIP, the best available techniques and best environmental practices (BATs/BEPs) were proposed, through which the unintentionally produced dioxin from pulp chlorine bleaching in the pulp and paper manufacturing sector was addressed and alternative technologies were recommended.

The *Guidance Catalogue of Industrial Structure Adjustment* (2011) replaced the previous 2005 version, which not only imposed restrictions on elemental chlorine bleaching, and specified elimination of any single non-wood pulp production line with an annual capacity of less than 34,000 tons and any lime ground pool pulping facilities, but also encouraged cleaner production processes with an annual capacity over 100,000 tons for construction of each non-wood pulp production line (NDRC, 2011). In March 2011, the Ministry of Industry and Information Technology (MIIT) promulgated the *Promotion Scheme of Cleaner Production Technology* for the pulp and paper sector, in which technologies including non-wood ECF (elemental chlorine-free) bleaching and displacement cooking were recommended. At the end of 2011, the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the Ministry of Forestry jointly formulated the '*12th Five-Year' Plan of Paper Industry*, in which the following proposals were also noted: to utilize non-wood resources scientifically and reasonably; to implement innovative cleaner production processes; to improve energy

Table 2. Pulp consumption and raw materials' consumption of China's pulp and paper sector.

		Wood pulping		Non-wood pulping		Recycled fiber pulping	
Year	Total pulp consumption/ 1,000 tons	Total consumption/ 1,000 tons	Proportion/ %	Total consumption/ 1,000 tons	Proportion/ %	Total consumption/ 1,000 tons	Proportion/ %
1990	13,930	2,040	14.6	7,970	57.2	3,920	28.1
1995	22,590	2,830	12.5	11,360	50.3	8,400	37.2
2000	27,910	5,350	19.1	11,160	40	11,400	40.9
2005	52,000	11,300	21.7	12,600	24.2	28,100	54
2006	59,920	13,220	22	12,900	21.5	33,800	56.4
2007	67,690	14,500	21.4	13,020	19.2	40,170	59.3
2008	73,600	16,240	22	12,970	17.6	44,390	60.3
2009	79,800	18,080	22.7	11,750	14.7	49,970	62.6
2010	84,610	18,590	22	12,970	15.3	53,050	62.7
2011	90,440	21,440	23.7	12,400	13.7	56,600	62.6
2012	93,480	22,910	24.5	10,740	11.5	59,830	64

conservation, pollution reduction and comprehensive utilization levels; and to improve paper quality from non-wood fiber pulping.

Apart from policies issued by the central government, some local governments also enacted policies, regulations and standards on structure adjustment. For example, Shandong Province introduced the *Comments on Accelerating Elimination of Backward Production Capacity & Promotion of Industrial Structure Upgrading* (2006), specifying that any manufacturing enterprise with an annual wheat straw pulp capacity of less than 50,000 tons should be shut down by the end of 2007, and any straw pulp production line with a capacity of less than 100,000 tons/year should be adjusted, modified or shut down (Shandong Government, 2006).

Table 2 indicates the structural changes of raw materials in China's pulp and paper sector. Figure 1 illustrates the annual production of China's paper products. Figures 2–4 respectively show wastewater discharge, COD_{cr} discharge, and water consumption in China's pulp and paper sector[1] with the average intensities[2]. These data were jointly provided by the China Paper Association (CPA), the China Technical Association of Paper Industry (CTAPI) and the China National Pulp and Paper Research Institute (CNPPRI). It can be seen that pulp and paper manufacturing with non-wood materials was predominant before the year 2000, with rapid growth in pulp and paper manufacturing from wood materials and waste paper occurring from the late 1990s. Nevertheless, paper production using various kinds of raw materials has been increasing, and while paper production in China has been steadily growing every year the discharge of wastewater and COD_{cr} and the discharge intensities have been gradually

[1] The data on pulp consumption, raw materials' consumption, annual paper yield, annual wastewater discharge, COD_{cr} discharge, and water consumption and reuse come from the Annual Reports of China's Paper Industry (2001–2013). Each year's annual report records the pulp consumption and paper production of the present year and the environmental conditions of the previous year. So China produced 10.11 million tons of paper in 2013 but the environmental data for 2013 were not available.

[2] Intensities of wastewater discharge, COD_{cr} discharge, and freshwater consumption are calculated by dividing annual wastewater discharge, annual COD_{cr} discharge, and annual freshwater consumption by the annual paper yield.

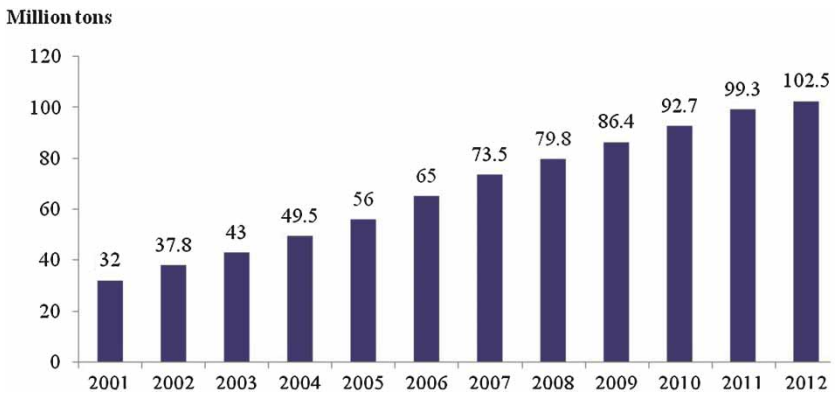

Fig. 1. China's annual paper yield.

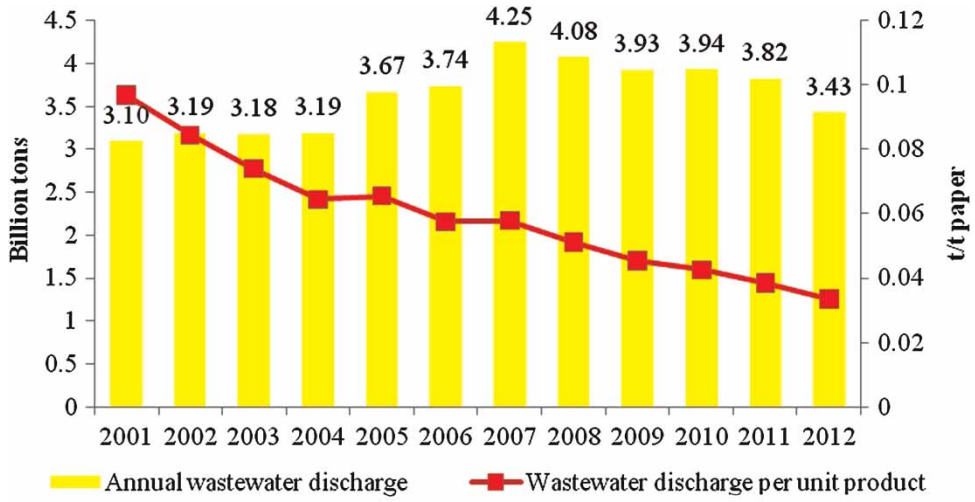

Fig. 2. Wastewater discharge from China's pulp and paper sector. *Note:* 't/t paper' represents the metric tonnes of wastewater discharged to produce each metric tonne of paper product on average.

declining. Using these indicators, the environmental performance of China's pulp and paper sector would seem to have been improving. Moreover, freshwater consumption within the sector has more or less remained constant though the annual total water consumption is rising, showing that more and more water has been reused. It should also be noted that the intensities of wastewater discharge, COD_{cr} discharge, and freshwater consumption have all been declining, reflecting an improvement in the environmental conditions.

2.2. Analysis of environmental management and control of the pulp and paper sector

Pollutant discharge in the pulp and paper manufacturing sector has been greatly reduced. The effect can be attributed to those pollution prevention and control measures conducted by the whole industry.

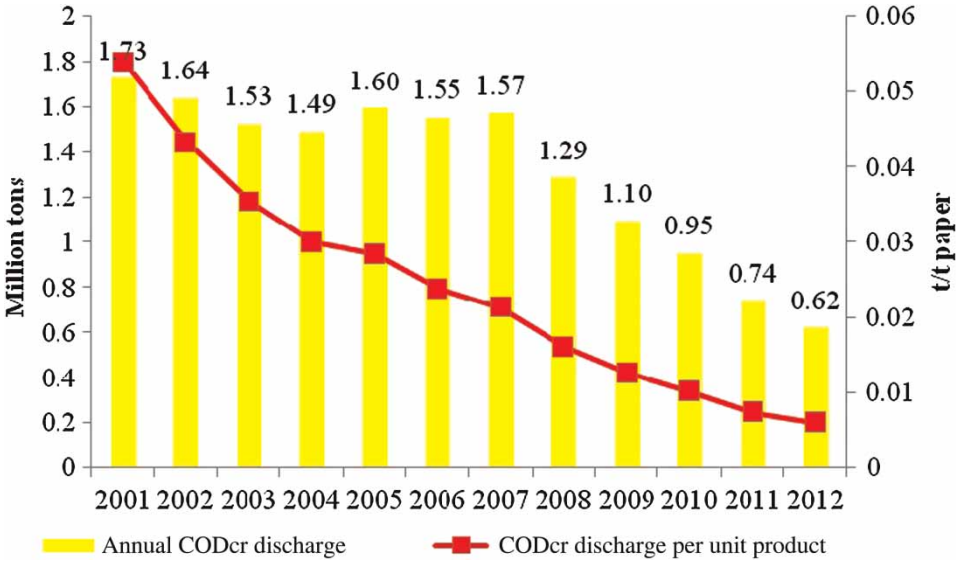

Fig. 3. COD_{cr} discharge from China's pulp and paper sector. *Note:* 't/t paper' represents the metric tonnes of COD_{cr} discharged to produce each metric tonne of paper product on average.

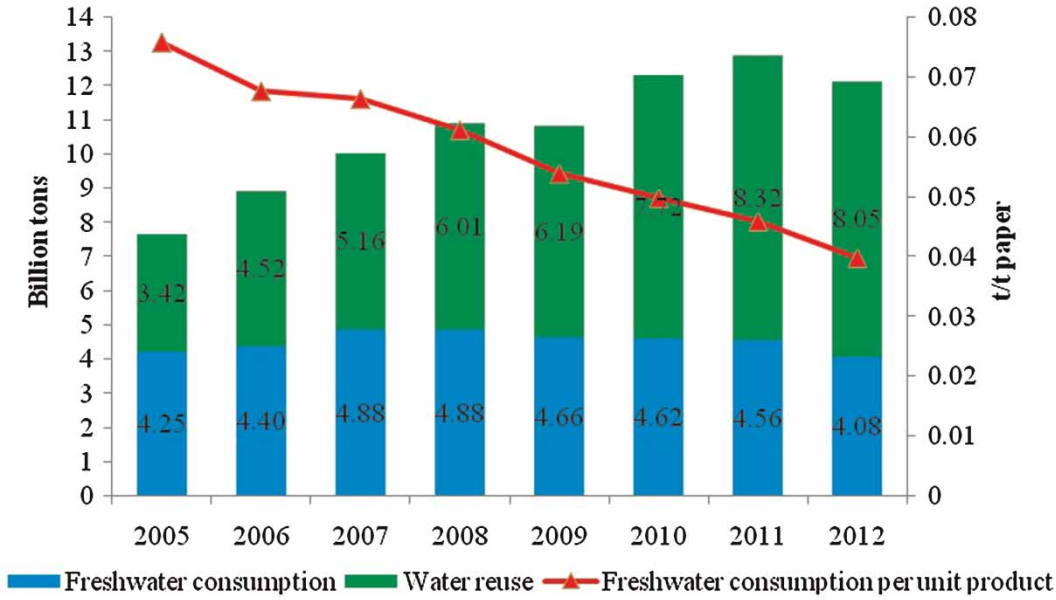

Fig. 4. Water consumption of China's pulp and paper sector. *Note:* 't/t paper' represents the metric tonnes of fresh water consumed to produce each metric tonne of paper product on average.

Some positive effects have been seen with the industrial pollutants' reduction through those policies, regulations and technical specifications. The Ministry of Environmental Protection, the National Development and Reform Commission, and the Ministry of Industry and Information Technology have all played a very important role in environmental policy-making activities. The closure and merging of

small pulp mills or paper mills formed the industrial plan for many years. For instance, according to the *Guidance Catalogue of Industrial Structure Adjustment* (2011) and the *Guidance Catalogue of Some Backward Production Processes, Facilities and Products to be Eliminated from Many Industrial Sectors*, any non-wood pulp production line with an annual capacity of less than 34,000 tons, any chemical wood pulp production line with an annual capacity of less than 51,000 tons, and any recycled fiber pulping production line with an annual capacity of less than 10,000 tons were all to be shut down. Meanwhile, various advanced technologies were advocated through many other policies. For example, the promotion of ECF and TCF (total chlorine free) bleaching processes was emphasized in the '*12th Five-Year' Plan of Industrial Cleaner Production Implementation*, the '*12th Five-Year' Plan of Paper Industry* and various other policies and regulations concerning AOX and dioxin (Zhang *et al*., 2012a), which were adopted by many pulp mills using wood or non-wood materials.

It should be noted that non-wood stock such as straw, bamboo, and reed were used as pulp and paper manufacturing materials before the 2000s in China due to the scarcity of wood resources. Unfortunately, straw pulp generally is more material-consumptive and will thus generate more pollutants than wood pulp (Shen & Wu, 1998). Most non-wood pulp (especially straw) mills in China were generally small-scale and posed the risk of extremely severe environmental pollution from the black liquor that had high toxicity and poor biodegradability in the effluent (Huang *et al*., 2007), and in 2005 alkaline non-wood pulp (or chemical non-wood pulp) contributed ~75% of the total COD_{cr} amount and was also the biggest pollution source in the pulp-making sector (Zhang *et al*., 2009). The change in the raw materials' composition was largely due to the joint effects of the forest-paper integration policy (Ministry of Finance, State Forestry Bureau, 2001; Chen, 2003a, b) and the closure of numerous small straw pulp mills that caused serious water pollution problems (SEPA, 1997). Among these approaches, the increased recycling of fibers has reduced the need for virgin fibers in recent years (Huang *et al*., 2007). China's pulp and paper sector was characterized by small-scale operations using obsolete technology with poor environmental performance before the 1990s (Yang, 2003). Since the early 1990s, a series of advanced technologies such as modified continuous cooking (MCC), displacement cooking system (DDS), ECF, closed screening, countercurrent washing, high-yielding pulping processes, and black liquor recovery have been introduced into China's pulp and paper sector. Apart from technical upgrading, a reduction in the number of small-scale, low-efficiency installations was also necessary as these tend to create much heavier pollution (Chen & Porter, 2000). Hence, by the merging and acquisition of small-scale pulp mills and paper mills, the existing pulp and paper enterprises on a relatively larger scale appear to be more energy-saving and environment-friendly. Currently, dozens of excellent enterprises have completed the transition from conventional pulp and paper manufacturing patterns to modern ones. In 2010, Nine Dragon Paper (Holdings) Ltd, Lee & Man Paper Manufacturing Ltd, and Shandong Chenming Paper Corporation became the three largest paper enterprises in China, respectively producing 7.3 million tons, over 3.7 million tons, and 3.3 million tons of paper products. The development of these kinds of large enterprise has also supported and promoted the rearrangement and the upgrading of the overall industrial structure (CTAPI, 2011).

Management of environmental pollution in the pulp and paper manufacturing sector in China is currently under the control of different ministries and administrations, including the Ministry of Environmental Protection (MEP), the Ministry of Industry and Information Technology (MIIT), the National Development and Reform Commission (NDRC), the Ministry of Agriculture (MOA), and the Ministry of Forestry (MOF). For instance, industrial planning is governed under the NDRC, environmental discharge standards are regulated under the MEP, utilization of non-wood pulp materials is generally controlled by the MOA, and utilization of wood pulp materials is usually managed by the MOF.

Pulp and paper mills use different raw materials and adopt different processes, which leads to varying amounts of pollutant loads. Wood pulp, non-wood pulp, bleached pulp and unbleached pulp are classified in the *Discharge Standard of Water Pollutants for Paper Industry (GB 3544-1992)* (SEPA, 1992). To comply with this 1992 version of the national discharge standard, the *Shandong Discharge Standard of Water Pollutants for Paper Industry (DB37/336-2003)* (EPDSD, 2003) and the *Henan Discharge Standard of Water Pollutants for Paper Industry (DB41/389-2004)* (EPDHN, 2004) were formulated in Shandong Province and Henan Province with much stricter limit values. However, the latest 2008 version of the national water pollutants' discharge standard for the paper sector has become extremely stringent with parameters for ammonia nitrogen, total nitrogen, total phosphorus, and dioxin being augmented, and parameters for COD_{cr}. A comparison of different domestic water pollutants' discharge standards for the pulp and paper sector at both national and local levels is shown in Table 3. Parameters for the water discharge rate and AOX discharge became mandatory in the 2008 version, and most of the parameters in the 2008 version of the national standard are more strict than some of the local standards in Shandong, Henan and other provinces. Therefore, pulp mills and paper mills in those provinces have to comply with the latest national standards, or those local governments may have to amend their local standards and set much more stringent regulations (Wang *et al*., 2011) for the sustainability of their local pulp and paper enterprises.

Moreover, four clauses on cleaner production standards were formulated concerning pulp manufacturing from alkali bagasse, bleached soda straw, kraft chemical wood, and recycled fiber. Parameters on pollutant generation intensities (per unit product) such as wastewater, COD_{cr}, and AOX were regulated, with three cleaner production levels (cleaner production leading level, cleaner production advanced level, and cleaner production general level) being allocated for each parameter.

However, only pulp mills, paper mills, and combined pulp–papermaking mills were categorized in the *Discharge Standard of Water Pollutants for Pulp and Paper Industry* (*GB 3544-2008*) (MEP, 2008), which was so general that many problems were triggered. For example, a comparison of an unbleached chemical pulp production system, a mechanical pulp production system, and a bleached chemical pulp production system found that both the first two (able to achieve 'zero discharge') usually discharge much lower volumes of effluent and pollutants than the third system, but the discharge limits for all three systems are the same. Thus, a new, established discharge standard should be revised in the future. Furthermore, CTMP (chemical thermo-mechanical pulp) mills and other pulp products should also be categorized due to their rapid development.

The creation of an environmental permit should be considered as an extremely important policy for regulating the industry. In China, an environmental permit is based purely on the environmental impact assessment (EIA), from which the national discharge standard and other regulations are referred.

3. Some aspects of environmental frameworks of the pulp and paper industry in other jurisdictions

Pollution prevention and control approaches have been conducted in many major pulp and paper manufacturing countries, covering not only emission tendencies and control measures (Gupta, 1994), but also the effects from process-integrated cleaner production and technical changes (Malinen *et al*., 1994; Hailu, 2003). Besides, different countries or regions have set related environmental policies and standards according to the nature of the industry.

Table 3. Comparison of different domestic water pollutant discharge standards of the pulp and paper sector in China.

Indicator	Activity		Unit	National standard (GB3544-2001)[a]	Shandong standard (DB37/336-2003)	Henan standard (DB41/389-2004)	Shaanxi standard (DB61/387-2006)	National standard (GB3544-2008)[b]
Water discharge rate	Pulp making	Unbleached wood pulp	m^3/t	150	100	80	80	50
		Bleached wood pulp		220	150	120	120	
		Unbleached non-wood pulp		100	100	100	60	
		Bleached non-wood pulp		300	150	150	150	
		Recycled fiber (without de-inking)		–	15	20	20	
		Recycled fiber (with de-inking)		–	20	30	35	
	Paper making			60	20	20	20	20
	Pulp-paper combination[c]							40
COD_{cr} discharge	Pulp making	Unbleached wood pulp	kg/t	52.5	12	12	20	100
			mg/L	350	120	150	250	
		Bleached wood pulp	kg/t	88	18	18	30	
			mg/L	400	120	150	250	
		Unbleached non-wood pulp	kg/t	40	12	15	21	
			mg/L	400	120	150	350	
		Bleached non-wood pulp	kg/t	135	18	22.5	52.5	
			mg/L	450	120	150	350	
		Recycled fiber (without de-inking)	kg/t	–	1.5	2	2	
			mg/L	–	100	100	100	
		Recycled fiber (with de-inking)	kg/t	–	2	3	5.25	
			mg/L	–	100	100	150	
	Paper making		kg/t	6	2	2	2	
			mg/L	100	100	100	100	80
	Pulp-paper combination[c]		kg/t					
			mg/L					90

(*Continued.*)

Table 3. (*Continued.*)

Indicator	Activity		Unit	National standard (GB3544-2001)[a]	Shandong standard (DB37/336-2003)	Henan standard (DB41/389-2004)	Shaanxi standard (DB61/387-2006)	National standard (GB3544-2008)[b]
BOD_5 discharge	Pulp making	Unbleached wood pulp	kg/t	10.5	3	2.4	4	20
			mg/L	70	30	30	50	
		Bleached wood pulp	kg/t	15.4	4.5	3.6	6	
			mg/L	70	30	30	50	
		Unbleached non-wood pulp	kg/t	10	3	3	3.6	
			mg/L	100	30	30	60	
		Bleached non-wood pulp	kg/t	30	4.5	4.5	9	
			mg/L	100	30	30	60	
		Recycled fiber (without de-inking)	kg/t	–	0.45	0.6	1	
			mg/L	–	30	30	50	
		Recycled fiber (with de-inking)	kg/t	–	0.6	0.9	1.75	
			mg/L	–	30	30	50	
	Paper making		kg/t	3.6	0.6	0.6	0.6	
			mg/L	60	30	30	30	20
	Pulp-paper combination[c]		kg/t					
			mg/L					20
SS	Pulp making	Unbleached wood pulp	kg/t	15	7	6.4	5.6	50
			mg/L	100	70	80	70	
		Bleached wood pulp	kg/t	22	10.5	9.6	8.4	
			mg/L	100	70	80	70	
		Unbleached non-wood pulp	kg/t	10	7	8	4.2	
			mg/L	100	70	80	70	
		Bleached non-wood pulp	kg/t	30	10.5	12	10.5	
			mg/L	100	70	80	70	
		Recycled fiber (without de-inking)	kg/t	–	1.05	1.6	1.4	
			mg/L	–	70	80	70	
		Recycled fiber (with de-inking)	kg/t	–	1.4	2.4	2.45	
			mg/L	–	70	80	70	
	Paper making		kg/t	6	1.4	1.6	1.4	
			mg/L	100	70	80	70	30
	Pulp-paper combination[c]		kg/t					
			mg/L					30

(*Continued.*)

Table 3. (*Continued.*)

Indicator	Activity		Unit	National standard (GB3544-2001)[a]	Shandong standard (DB37/336-2003)	Henan standard (DB41/389-2004)	Shaanxi standard (DB61/387-2006)	National standard (GB3544-2008)[b]
NH_3-N	Pulp making	Unbleached wood pulp	kg/t	–				
			mg/L					12
		Bleached wood pulp	kg/t					
			mg/L					
		Unbleached non-wood pulp	kg/t					
			mg/L					
		Bleached non-wood pulp	kg/t					
			mg/L					
		Recycled fiber (without de-inking)	kg/t					
			mg/L					
		Recycled fiber (with de-inking)	kg/t					
			mg/L					
	Paper making		kg/t					
			mg/L					8
	Pulp-paper combination[c]		kg/t					
			mg/L					8
Total-N	Pulp making	Unbleached wood pulp	kg/t	–				
			mg/L					15
		Bleached wood pulp	kg/t					
			mg/L					
		Unbleached non-wood pulp	kg/t					
			mg/L					
		Bleached non-wood pulp	kg/t					
			mg/L					
		Recycled fiber (without de-inking)	kg/t					
			mg/L					
		Recycled fiber (with de-inking)	kg/t					
			mg/L					
	Paper making		kg/t					
			mg/L					12
	Pulp-paper combination[c]		kg/t					
			mg/L					12

(*Continued.*)

Table 3. (*Continued.*)

Indicator	Activity		Unit	National standard (GB3544-2001)[a]	Shandong standard (DB37/336-2003)	Henan standard (DB41/389-2004)	Shaanxi standard (DB61/387-2006)	National standard (GB3544-2008)[b]
Total-P	Pulp making	Unbleached wood pulp	kg/t	–				0.8
			mg/L					
		Bleached wood pulp	kg/t					
			mg/L					
		Unbleached non-wood pulp	kg/t					
			mg/L					
		Bleached non-wood pulp	kg/t					
			mg/L					
		Recycled fiber (without de-inking)	kg/t					
			mg/L					
		Recycled fiber (with de-inking)	kg/t					
			mg/L					
	Paper making		kg/t					
			mg/L					0.8
	Pulp-paper combination[c]		kg/t					
			mg/L					0.8
AOX[d]	Pulp making	Unbleached wood pulp	kg/t	–				12
			mg/L					
		Bleached wood pulp	kg/t	2.64	1.8	1.35	1.2	
			mg/L	12	12	11.2	0	
		Unbleached non-wood pulp	kg/t	–				
			mg/L					
		Bleached non-wood pulp	kg/t	2.7	1.8	1.35	1.2	
			mg/L	9	12	9	1	
		Recycled fiber (without de-inking)	kg/t	–				
			mg/L					
		Recycled fiber (with de-inking)	kg/t					
			mg/L					
	Paper making		kg/t	–				
			mg/L					12
	Pulp-paper combination[c]		kg/t					
			mg/L					12

(*Continued.*)

Table 3. (*Continued.*)

Indicator	Activity		Unit	National standard (GB3544-2001)[a]	Shandong standard (DB37/336-2003)	Henan standard (DB41/389-2004)	Shaanxi standard (DB61/387-2006)	National standard (GB3544-2008)[b]
Dioxin	Pulp making	Unbleached wood pulp	kg/t	–				30
			pgTEQ/L					
		Bleached wood pulp	kg/t					
			pgTEQ/L					
		Unbleached non-wood pulp	kg/t					
			pgTEQ/L					
		Bleached non-wood pulp	kg/t					
			pgTEQ/L					
		Recycled fiber (without de-inking)	kg/t					
			pgTEQ/L					
		Recycled fiber (with de-inking)	kg/t					
			pgTEQ/L					
	Paper making		kg/t					
			pgTEQ/L					30
	Pulp-paper combination[c]		kg/t					
			pgTEQ/L					30

[a]In the GB 3544-2001 standard, parameters of water discharge rate and AOX discharge are set as reference limit values (not mandatory).
[b]In standard GB 3544-2008, only concentration limit values have been illustrated for indicators COD_{cr}, BOD_5, SS, AOX, and dioxin, so the discharge intensity should be calculated as the concentration multiplied by the water discharge rate.
[c]For standards GB 3544-2001, DB 37/336-2003, DB 41/389-2004, and DB 61/387-2006, the limit values of pulp-paper combination activities are the same as the corresponding pulp making activities. The discharge rate of water and pollutants for pulp-paper combination activities is divided by each unit of pulp product.
[d]In the GB 3544-2008 standard, limit values on AOX are focused upon chlorine bleaching processes only.

3.1. The United States

The United States has a comprehensive policy system for the environmental management and control of the pulp and paper industry. In the United States, pulp and paper mills are listed according to various kinds of point sources that discharge pollutants into waters, which are controlled by the National Pollutant Discharge Elimination System (NPDES) permit program.

For conventional pollutants such as COD_{cr} and SS (suspended solids), discharge limits related to best practicable control technology (BPT) and best conventional pollutant control technology (BCT), and discharge limits on toxic and harmful substances are allocated according to the best available technology (BAT). New source performance standards (NSPS) are set for wastewater direct discharge from newly built or extended mills. For new pulp mills or paper mills that have implemented the NSPS, environmental permits are issued according to the feedback from the EIA. In addition, for both existing plants and newly built or extended plants, pretreatment standards have been formulated: *Pretreatment Standards for Existing Sources* – PSES and *Pretreatment Standards for New Sources* – PSNS, respectively (EPA, 2000).

Best management practices (BMPs) have also been adopted for pulping waste liquor's management and overflow prevention and control (EPA, 1997).

3.2. Europe

In Europe, environmental management and policies are usually in the form of regulations, directives or acts.

The Water Framework Directive (WFD) was adopted on 23 October 2000 and entered into force on 22 December 2000. It is a core piece of legislation for water conservation and pollution control measures within its member state regions. The detailed context in the WFD relates to all objectives on water resources' conservation. River basin management and water pollution control are effectively integrated under the WFD (EC, 2000). With regard to point source pollution, the WFD emphasizes that all member states must adopt the unique water pollutants' standard and employ the most advanced environmental technologies. To fulfill the criteria, some stricter pollution control measures need to be adopted. Meanwhile, all member states should take steps to reduce the release of hazardous substances, especially highly toxic substances. In addition, some economic approaches have also been adopted under the WFD, such as the water pricing policy.

In June 1985, the European Commission put forward the *Directive of Assessment of the Effects of Certain Public and Private Projects on the Environment (85/337/EEC)* (known as the Environmental Impact Assessment (EIA) Directive) and in 2001 the European Commission proposed the *Directive of European Parliament and of the Council on the Assessment of the Effects of Certain Plans and Programmes on the Environment (2001/42/EC)* (known as the Strategic Environmental Assessment (SEA) Directive). Both Directives aimed to provide high-level environmental protection and to contribute to the integration of environmental considerations in the preparation of projects, plans, and programs, to reduce their environmental impacts. Within these two Directives, public participation was emphasized in the decision-making process (EC, 2010).

In 1996, the EU adopted a set of rules for the authorization and control of industrial installations under the *Integrated Pollution Prevention & Control (IPPC) Directive* (Directive 96/61/EC), which was codified as Directive 2008/1/EC. In essence, the IPPC Directive was about minimizing pollution

from various industrial sources throughout the European Union, covering around 52,000 installations. The *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry* was compiled in December 2001 as a tool for pulp and paper mills to adopt best available techniques and best environmental practices (EC, 2001).

The European Pollutant Release and Transfer Register (E-PRTR) is a new Europe-wide registration providing easily accessible key environmental data from industrial facilities in European Union member states and other European countries. It contains data reported annually by some 28,000 industrial facilities covering 65 economic activities within nine industrial sectors, including paper and wood production and processing (EC, 2006). For each facility, data have been provided concerning the amounts of pollutants released through different media including wastewater discharge.

The Environmental Technologies Action Plan (ETAP) was adopted by the European Commission in 2004. Its objective was to promote environmental technologies to improve the environmental quality and enhance the market competitiveness of industrial enterprises. ETAP aims to overcome barriers such as the complexity of switching from traditional to advanced technologies and insufficient access to capital, which hinders the development of environmental technologies (EC, 2004). This is being achieved through a series of measures to promote eco-innovation of such technologies.

3.3. Canada

In Canada, each provincial government has set a number of measures on water pollution control for the pulp and paper sector.

In Alberta, for example, the Environmental Protection and Enhancement Act (EPEA) and associated regulations are the principal legislation governing the environmental aspects of pulp and paper mill developments (Alberta Environment, 2005). Among the principles, wastewater standards are based on the most stringent best available technology economically achievable or required to fulfill the environmental quality objectives (Alberta Environment, 1995). The public has the opportunity to review and provide comments on approvals, and has access to approval-related information. The legislation establishes a formal appeal mechanism for both approval holders and directly affected parties, empowers the government to inspect and monitor the operations of pulp mills to assess performance against approval requirements, and creates a wide range of administrative and judicial measures for ensuring compliance with requirements. The Alberta Government has also established a strategic 'systems approach' to achieve sustainable environmental outcomes, which puts the government in the role of 'systems manager' and Alberta Environment as the 'systems coordinator' (Alberta Environment, 2005). A shared responsibility with the industry, the public, and the scientific–technical communities to achieve provincial environmental targets is thus established.

4. Recommendations on environmental framework development of water pollution control for China's pulp and paper sector

It is very important to take integrated measures and actions to cope with the great challenges and complex issues surrounding the severe environmental conditions and the major weaknesses currently found in China's environmental framework (Wang, 2010). Since China's paper production is growing year by year, it has been estimated that by 2030 the COD_{cr} discharge volume from the Chinese pulp and paper

sector will reach 2.2 million tons (Zhang *et al*., 2009). However, in the future, water pollution load emissions must be strictly controlled at lower levels than currently, due to the requirement for industrial sustainable development, especially in such heavy pollution sectors as pulp and paper manufacturing. The environmental quality data presented above show that pollutant generation can be mitigated by pollution control measures such as material structure adjustment, extension to enterprise scales, and technical upgrading. Therefore, water pollutant reduction measures should be further enhanced in China's pulp and paper sector for the purposes of water quality improvement. From this point of view, there would be quite a large difference between the scenarios with and without reduction policies. A study on the European paper industry by Wagner (2005) revealed that pulp mills and paper mills that have pollution prevention strategies show more positive relationships with higher economic performance. Therefore, pollution reduction policies can play a significant role in pollutant discharge, environmental quality, and even economic growth.

The overall framework of environmental management and control systems in the pulp and paper industry in China can be divided into governmental aspects, non-governmental organization (NGO) aspects, and entrepreneurial aspects. The specific functions of each party are shown in Figure 5. Among these groups, the government remains the most important source of pressure on enterprises in the pulp and paper sector to improve their environmental performance (Doonan *et al*., 2005). It should be emphasized that communities or NGOs can act to create incentives for local industrial facilities to reduce environmental pollution (Cohen, 1998; World Bank, 2000; Foulon *et al*., 2002). This is because increasing public awareness, informing public opinion, and enhancing public participation in, and supervision of, the development and application of environmental regulations can provide incentives for polluters to consider environmental protection in their operations and take steps to strengthen their pollution control (Li *et al*., 2008; Zhang & Wen, 2008).

Nowadays, most EU countries are putting efforts into the control and reduction of total nitrogen, total phosphorus, AOX, and dioxin in many industries, including the pulp and paper sector, as they have

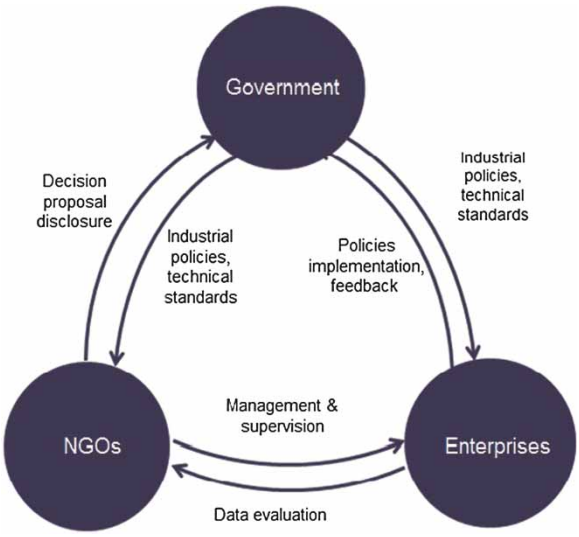

Fig. 5. Functions of different groups on the environmental framework of China's paper industry.

become pollutants of major concern. China, on the other hand, is still making great efforts in terms of wastewater COD_{cr} control, with COD_{cr} emissions being emphasized in most industrial pollution discharge standards and other regulations. A study conducted by Song *et al*. (2012) found that although China's COD_{cr} emission limits in the *Discharge Standard of Water Pollutants for Pulp and Paper Industry (GB3544-2008)* were even more stringent than related standards in many developed countries, the emission limits on total nitrogen, total phosphorus, and AOX were far less stringent. Thus, it is important to specify the key water pollutants in the pulp and paper sector in China, and the requirement for deeper research on these water pollutants and the manufacturing processes. Therefore, cooperation between the government, research institutions, and enterprises should be strengthened.

Unlike the discharge standards in many Western countries, only concentration limit values are present in the 2008 version of China's national discharge standard for the pulp and paper sector, while limit values on discharge intensity (per unit product) have not been allocated. In this respect, the previous 2001 version of the national standard, with limits on both concentration and intensity, was more rational and technically based. Therefore, the water pollutants' discharge standard should be further updated.

The environmental permit system has become a crucial policy to regulate the behavior of enterprises in most developed countries, and is more significant than other policies such as the EIA. In some European countries, the permit contains all aspects of environmental quality surrounding the operation, with detailed permit conditions. The approval of a permit may be conducted by the environmental court and may go through processes such as public-hearing sessions. In China, however, the permit system has not yet been sufficiently organized. The authorization of a permit is conducted by the local environmental department. Usually, the operator (enterprise) can easily obtain a permit by fulfilling the criteria of only a few of the wastewater discharge parameters (such as pH, COD_{cr}). Its verification period is much shorter, even lacking some necessary processes. In addition, there may be a lack of consistency between the discharge permit and industrial policies and environmental regulations in some regions as they are implemented by different departments. Therefore, the legal status of the environmental permit system and its policy design should be enhanced so that it is possible to effectively regulate the water use and wastewater discharge of pulp and paper manufacturing enterprises in China.

While a number of technical requirements on pollution prevention and control have been addressed under various regulations and standards of the pulp and paper sector, the system should be integrated. For the environmental management and control of the pulp and paper sector in countries such as China that have relatively small-scale enterprises, less-advanced technologies, and funding shortages, a compulsory approach may be more effective (Bruvoll *et al*., 2003). Practices have shown that the pulp and paper sector and other industrial guiding policies have promoted technical development through industrial restructuring and technology improvement. Environmental quality standards and emission standards are the benchmark criteria for carrying out environmental impact assessments in the paper industry (Wang *et al*., 2003). Furthermore, the application of BAT control and pollution reduction measures is key for China (Huang, 2003). Since the structure of China's pulp and paper sector is different from those in other paper-producing countries due to its high proportion of non-wood materials such as bamboo, straw, reed, and bagasse, it is necessary to carry out pilot projects on key pulp enterprises using non-wood materials.

Cleaner production, a strategy to address pollution generation as well as efficient use of resources and energy, has played a predominant role in China's industrial and environmental protection policies (Hicks & Dietmar, 2007). It is an important strategy to achieve the targets for the pulp and paper

sector by implementing cleaner production measures and reducing pollutant generation and emissions from the sources and the processes. Thus, China should increasingly rely on innovative technologies. Recently, advanced technologies and equipment have been developed and adopted for cooking, washing and screening, bleaching, chemical recovery, and papermaking, with significant reductions in pollutant emissions and resources' consumption (Huang, 2003; Yang, 2003; Cao, 2009). Cleaner production technologies such as extended delignification cooking, super-batch cooking, multi-stage countercurrent pulp washing, closed screening, medium-consistency pulping and refining, oxygen delignification, ECF, TCF, advanced alkali recovery, and white water reuse have all been recommended (Yang & Liu, 2007; Wang & Song, 2010). At present, techniques such as ECF and TCF bleaching have been widely adopted in those pulp and paper manufacturing plants using wood as the raw material, but applications in pulp and paper mills using non-wood materials should be further promoted. Meanwhile, with increasingly stringent controls over wastewater discharge, secondary treatment has widely been introduced into newly built pulp and paper mills (Wan & Ma, 2008). Technical measures should be taken based on the conditions of different enterprises (Zhang, 2010) to properly adopt these approaches.

Environmental monitoring is also required to understand the severity of environmental issues. Due to the complexity of the production processes, safeguards for technical staff and the environment, data quality assurance, and the prevention of secondary pollution must all be considered during the operation processes. It is also important to establish a scientific management system to ensure the reliability of data and a stable operation. In addition, although some countries and international organizations have developed tools for environmental monitoring in various industries, China's pulp and paper sector has considerably different facilities and operating conditions from other countries due to the complex process structures (Zhang *et al*., 2012b). Therefore, it is necessary to carry out various on-site monitoring activities to gain enough data for emission-factor adjustments for different industrial pollutants and to establish pollutant emissions' inventories. In particular, environmental monitoring of dioxin and AOX emissions should be enhanced.

Most pulp and paper mills in China are still applying the conventional production processes, due to the financial issues of the enterprises, being unable to afford the high costs of technical upgrades. Therefore, one of the most important issues is how to overcome the funding problems. There should be a more-accurate estimation of the required funds for China's pulp and paper sector to meet the requirements of international conventions and pollution load reduction, but it is also necessary to assess all possible financing channels from which the budget can be increased. Financing can be achieved not only through international loans, donations, research and development funding, and baseline investigations, but also through the flexible use of domestic financing mechanisms. To some extent, government funding of operations and management for environmental demonstration projects and other pollution control activities is extremely important. However, it would be better to integrate environmental issues with economic policies at the planning stage rather than at the implementation stage (Zhang, 2008) as far as minimization of environmental effects is concerned.

To further enhance the social responsibilities of the pulp and paper enterprises in terms of environmental protection, their internal environmental management mechanisms should be strengthened. These enterprises should adopt internationally advanced new technologies and processes in order to carry out cleaner production activities so that their facilities and installations can gradually be improved. In addition, to enhance a company's environmental management, there needs to be improvement of the environmental awareness and corresponding capabilities of staff (or employees) through education, training, and other possible efforts.

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