Analysis of CO_2 mitigation policies in the Chinese cement industry

Yufei Wang
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences
10085, China
wyf 24031@hotmail.com

Zhengping Hao
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences
10085, China
zpinghao@rcees.ac.cn

Samuel Höller
Wuppertal Institute for Climate
Environment and Energy Berlin Office
Neue Promenade 6
10178 Berlin
Germany
samuel.hoeller@wupperinst.org

Keywords

cement industry, CO_2 reduction, energy efficiency measures, China

Abstract

The cement industry is one of the major energy consuming and CO_2 emitting sectors in China. In 2010, 1,868 million tons of cement was produced, which accounted for 56.1 % of the world's total cement production.

China's 11th Five-Year Plan (FYP), which spanned the years 2006–2010, included policy measures for CO_2 emission abatement in cement production. Based on the main governmental framework of CO_2 mitigation policies at national level in the cement sector, key policies and technologies used during this period are identified and their effects on CO_2 reduction are assessed. This paper calculates the reduction of CO_2 emissions related to four main policies and technologies for efficient cement production in both the 11th and the 12th FYP (2011–2015) with 2005 as a reference year. The four main policies are closing outdated facilities, waste heat recovery, substitution for clinker production and other technologies aimed at increasing energy efficiency. Due to these measures, we estimate that a total CO_2 emission reduction during the 11th FYP of 397 million tons was saved, which is considerably different to 185.75 million tons estimated by Zeng (2008) and 303 million tons by the National Development and Reform Commission (NDRC) by using different calculation methods. Of the four technologies, the 4th group of energy efficiency increasing techniques was the most important policy and avoided the largest amount of CO_2 emissions. Previous energy intensity reduction was mainly due mainly to the closing outdated facilities and energy efficiency improvements. Based on the assessment of technology performance, it appears that there is still a large emission reduction potential in cement production processes. This paper calculates the potential for the 12th FYP period (2011–2015) based on the four aforementioned policy measures. The result is then compared to the Chinese Government targets in the 12th FYP and promising future CO_2 mitigation policies and technologies are proposed, such as the use of alternative energy.

Introduction

CO_2 accounts for more than 90 % of Greenhouse Gas (GHGs) emissions from industry sectors other than electricity generation (Srivastava et al. 2011). The cement sector is one of the most energy-intensive industry sectors, producing approximately 5 % of global anthropogenic CO_2 emissions (IEA and WBSCD 2009). By considering the pressure of climate protection, cement production is becoming a key industry sector relative to CO_2 emissions. Its production has been increased steadily in past decades at global a level, and with China standing out as the largest producer, accounting for almost half of the world production now. In 2010, 1,868 million tons of cement were produced in China, sharing 56.1 % of the world's total cement production (The European Cement Association 2011). The development of Chinese cement production during the last decade and future five years is illustrated in Figure 1. By considering the significant increase of cement production in recent years, the article focuses on the Chinese cement sector, aiming to analyze CO_2 reduction related policies and abatement potential in the 11th FYP and 12th FYP.

In China, cement industry is one of the top energy-using sectors, consuming 58 % of the total industry energy (Sui 2011). During the last Five-Year Plan for National Economic and So-

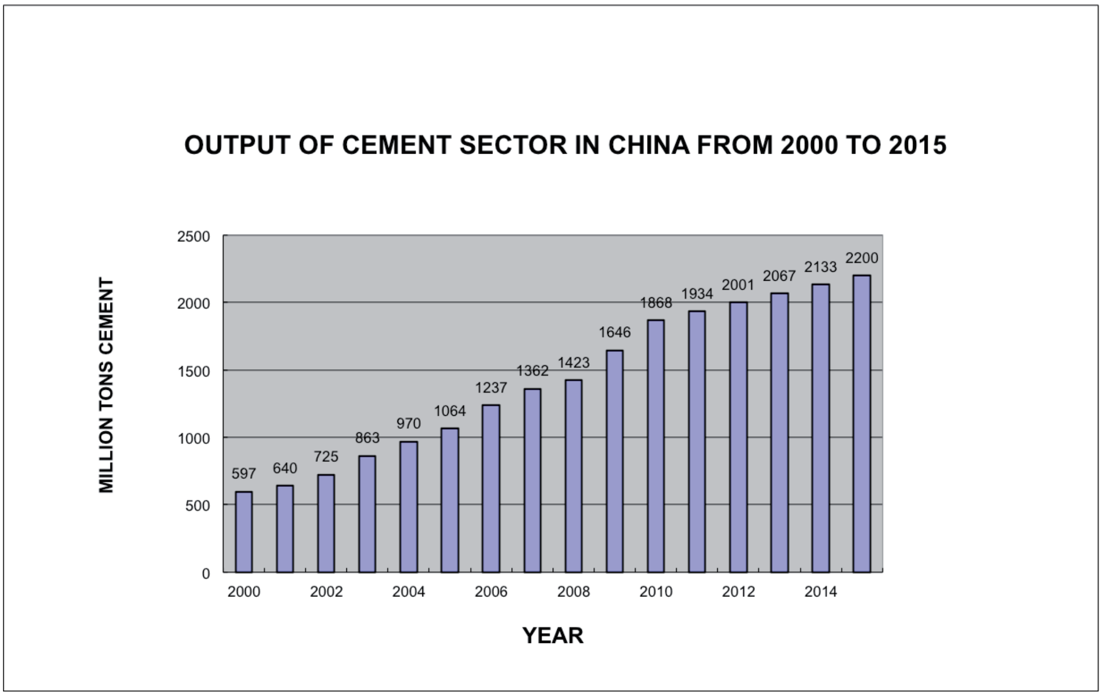

Figure 1. Historic and predicted cement output production in China. Source: (NDRC, 2006 a, 2011).

Table 1: Comparison of energy consumption in cement production between Chinese cement level and global advanced level.

	Advanced level of the world	Average level of new suspension preheater dry process (NSP) in China	Average level in China	China uses more energy than advanced level %
Heating consuming of clinker (Unit: kg coal/t)	100	137	149	49
Electricity use of Cement (Unit: kWh/t)	90	98.3	103	14.4

Source: (Zhang and Guo 2009).

cial Development (11th FYP, 2006–2010), the energy intensity of cement in China declined gradually, with a total reduction rate of 24.6 %. Although its energy efficiency improved greatly, compared with other countries, there is still a large increasing potential for further and increasing energy efficiency of cement production in China, which can be seen in Table 1. The Chinese central government plays a great role of pushing the cement production forward by using energy efficiency related policies, especially during the period of the 11th FYP. For example, in the national energy efficiency-increasing initiative "1000 Enterprise Energy Conservation Program", 87 cement plants were involved, accounting for 90.6 % of all building material sectors (Zeng 2008). This demonstrates that China is committed to large-scale change in the cement industry.

In this article, major CO_2 controlling policies and reduction capacities of different technologies are reviewed, focusing on closing of outdated facilities, waste heat recovery (WHR), substitution of clinker and energy efficiency improvement. Firstly, main policies published and implemented for the encouragement of technology application during the 11th FYP are described. Secondly, calculation methods of CO_2 reduction are introduced, presenting key points of calculation for each policy. After that, CO_2 reduction capacities of each main policy are assessed using historic statistical data. Finally, a discussion about these policies is carried out, and their future impacts on CO_2 reduction in the 12th FYP are projected.

Police description

Facing the pressure of energy security and environmental protection, the Chinese government decided to reduce energy intensity by 20 % during the 11th FYP and aimed to lead a sustainable development for the future. At national level, this means that over the time frame of 2006–2010, energy intensity of the economy should be reduced from 1.28 to 1.02 tce/10,000 RMB GDP in 2005 prices, or some 4 % per year. Over 1.5 billion ton of CO_2 can be reduced annually by 2010 compared to business as usual situation with quantitative and binding targets. A series of policies and measures have been implemented at both national and regional levels and obvious CO_2 reduction targets had been achieved in different sectors (Zhang et al 2011). Cement industry was required to contribute more than 20 % of energy efficiency increase to help the achievement of national reduction targets.

The main policies on CO_2 mitigation in the 11th FYP will be introduced in the following text. As our focus is on their impacts on CO_2 reduction, we describe only the key points of policies related with our assessment.

CLOSING OUTDATED FACILITIES

There are different types of kilns with differing energy efficiencies in China, mainly including shaft kiln, hollow kiln and NSP. NSP is the most efficient; hence this is encouraged to be widely used. The coal use of shaft kilns is 160kgce/t clinker and in terms of hollow kiln, it is 214kgce/t (Zeng 2008). Both the wet process kilns and dry process hollow kilns have been gradually replaced by the new suspension preheater dry process kilns (NSP), with a lower energy intensity of 107 kgce/t clinker. It is required that new production lines should be equipped with NSP technology with daily clinker production capacity of 4,000 tons or above(NDRC 2006a).

According to the "Special Plan for the Development of Cement Industry" implemented in 2006, consolidation through mergers and reorganization are stimulated. It formulates that until 2010, NSP kilns should achieve 70 % and 250 million tons of old production, mainly referring to the wet process kilns and dry process hollow kilns, should be phased out and where possible, vertical kilns should be decreased during the five years. A series of policies were announced, such as the "Policies on the Development of Cement Industry", and the "Provisions for Accelerating the Structural Adjustment of the Cement Industry". The annual production capacity, which is less than 200,000 t and contributes negatively to the environment or cement quality, should be closed or not encouraged to build.

WASTE HEAT RECOVERY (WHR)

In the process of cement production, large amounts of waste heat are generated. The WHR for power generation can mitigate CO_2 emissions as it can satisfy electricity consumption. Low-grade waste heat recovery by using the heat with a temperature between 120–400°C has been encouraged (Wang 2010). Although the first low waste heat recovery started to generate electricity in 1998 with a cement production of 4000t/d clinker, the average technology level in China was very low before the wide application of the NSP kilns (RES 2010). 40 % of the NSP are required to be equipped with waste heat recovery, and in real terms, 55 % has been achieved until the year 2010. The electricity production from waste heat has a huge increase from 50 million kWh to 2,378 million kWh and the total electricity generated during the 11th FYP is 9,143 million kWh. Until 2005, there were only 13 cement production lines with waste heat recovery. However, by the end of 2010, that number has increased to 690.

Moreover, until the end of 2010, there have been 230 projects related to the Clean Development Mechanism (CDM) projects in the cement sector, and 94.3 % of them are waste heat recovery projects. These were approved by the NDRC itself, not including those registered by the Executive Board, which is responsible for supervising CDM under the Conference of Parties (CoP)(Zeng 2011).

SUBSTITUTION FOR CLINKER

Government encourages the production of blended cement and limestone cement to meet the market demands by supportive policies, such as "the Notice to Encourage of the Use of Slag Gas to Produce Cement" etc, resulting in increased application of substituted materials like natural pozzolana, fly ash, or blast furnace slag. According to the new standard of Common Portland_Cement GB 175–2007, the sharing of mixed materials of cement increased to 20 %, replacing 15 % from old standards, which can finally reduce CO_2 emissions. Moreover, CaO in those materials can be combined with CO_2, and coal consuming per cement can be reduced, suggesting that CO_2 can be reduced in this process (NDRC 2006b). The reduction effects of CO_2 by clinker substitution are related with kiln types and production scales. For example, CO_2 reduction amount per year by using limestone technology by slag are 0.153 million ton/year, 0.301 million ton/year and 0.383 million ton/year for the cement production capacity of 1,000 t/d, 2,000 t/d and 2,500 t/d respectively (He and Yi 2010).

OTHER ENERGY EFFICIENCY INCREASING MEASURES

Energy efficiency increase can be the most important policy implemented by the Chinese government in the cement sector. Aside from the policies described above, relative policies include the implementation of production standards, development of energy saving or efficiency increasing technologies, and other policies, such as financial support, and specific electricity price. Firstly, development and research of advanced technologies are encouraged, such as pre-grinding technology, and higher efficiency classifiers. Benchmark tools for energy saving were carried out under the lead of the China Cement Association, providing training and information and analysis tools for energy using. Secondly, government would like to provide financial support to the cement sector, and common policies include low-interest loan programs, interest subsidy, tax credits and tax reduction and exemption. For example, when the blending proportion of rotary kiln waste is more than 30 % in the process of the cement or clinker production, enterprises can receive the VAT rebate benefits. Thirdly, in 2004, China started to implement a Differentiated Electricity Pricing policy for high energy-consuming industry sectors, including the cement sector, which were charged based on their energy intensities. The electricity prices have been changed and adjusted for three times since 2006 among "restricted" and "eliminated" enterprises, which are categorized according to different types of production levels. For example, the eliminated plants should pay 0.2 RMB/kWh more than normal plants since 2008, whose electricity price is 0.05 RMB/kWh.

Methodologies for CO_2 reduction assessment

Main technology policies implemented in the 11th FYP have been identified, including closing of outdated facilities, waste heat recovery, substitution of clinker and energy efficiency improvement. Total CO_2 amounts saved are calculated based on the energy intensity reduction of cement (in forms of ton CO_2/ton cement) multiplied by the output of the production (unit: million tons). In order to better understand, details can be found in equation (1) and (2). 2005 is selected as reference year, and the data used for the 11th FYP and 12th FYP is mainly from published articles, policies, and reports.

$$\Delta CO_2 = \Delta\left(Energy\_Intensity_{coal} \times Emission\_factor_{coal \rightarrow CO_2}\right) \qquad (1)$$

Where: the unit of $Energy\_Intensity$ is ton coal/ton cement, and the unit of $Emission\_Factor_{coal \rightarrow co_2}$ is ton CO_2/ton coal.

$$CO_2 saved = \Delta CO_2 \times output\_production\_cement \qquad (2)$$

CO_2 saved amount of each year can be calculated equation (2). Total amount of CO_2 saved for five years will be obtained by summing up the amount of CO_2 saved each year. The following calculation is all based on this principle.

The methodologies to calculate these four methods will be described as follows.

CLOSING OUTDATED PRODUCTION

Assume that outdated production, which mainly refers to shaft kiln and hollow kiln, will be replaced by new suspension precalcination (NSP). Shaft kiln accounts for around 81 % and the hollow kiln shares 19 % of the total outdated facilities (Zeng 2008). Clinker production of the 11th FYP mainly comes from published reference, and the production of clinker can be calculated based on clinker-to-cement ratio and cement output amount. CO_2 emitted from the shaft kiln, hollow kiln and NSP are 0.419 t CO_2/t clinker, 0.561 t CO_2/t clinker and 0.281 t CO_2/t clinker, respectively, which are calculated based on Zeng's research (Zeng 2008). It means that 0.139 t CO_2 /t clinker and 0.281 t CO_2/t clinker can be saved for shaft kiln and hollow kiln when they are replaced by the NSP. Using the saved CO_2 amount per clinker multiplied by the closing clinker production one can assess CO_2 reduction capacity. Clinker to cement ratio was employed when doing the transfer from cement production to clinker production.

$$CO_{2saved} = Closing\_production \times Emission\_factor_{out\text{-}dated\_production} - Replaced\_production \times Emission\_factor_{NSP} \quad (3)$$

As the closing production and replaced production are the same, we can get:

$$CO_{2saved} = Closing\_production \times (Emission\_factor_{out\text{-}dated\_production} - Emission\_factor_{NSP}) \quad (4)$$

Where: the unit of emission factor is ton CO_2/ton clinker.

WASTE HEAT RECOVERY (WHR)

Data of electricity generated by the waste heat recovery in the 11th FYP are collected, and those for the 12th FPY are assumed based on the policy "until 2015, the electricity from WHR can satisfy 65 % of the NSP electricity requirements while it was 55 % in 2010". The standard coal use for power plants is 380 kg coal/kWh, which means 996 kg CO_2/kWh (emission factor of coal burning is 0.715 t C/t coal) can be saved by using WHR. This technology mainly started to develop during the 11th FYP, so in the reference year, we assume that in 2005, technological level is very low, perhaps almost zero. The use of WHR technology can be equated to technology improvement. CO_2 reduced by WHR is calculated by using emission factors multiplied by the electricity amount produced from WHR plant, which can be expressed in the following equation:

$$CO_{2saved} = Electricity\_generated \times Emission\_factor \quad (5)$$

Where the unit of Electricity_generated is kWh, and the unit of Emission_factor is ton CO_2/kWh.

SUBSTITUTION OF CLINKER

The substitution of clinker depends on the ratio of clinker to cement. The more clinker is replaced by materials like fly ash, blast furnace slag etc, the more CO_2 can be saved. The ratio of 2005 is selected as reference. The calculation of clinker to cement ratio of the 11th FYP is mainly from history data of the output of clinker and cement.

$$CO_{2avoided} = Substitution\_amount \times Emission\_factor_{clinker} \quad (6)$$

Where $CO_{2avoided}$ means that by using substitution materials for clinker, the amount of CO_2 that can be saved, the unit of Emission_factor$_{clinker}$ is ton CO_2/ton clinker.

The calculation of clinker substitution is a bit different with the two methods above, as CO_2 saved calculated through equation (6), does not address the reduction of energy intensity. A comparison with reference year is required, by using the following equation:

$$CO_{2saved\_targeted\_year} = CO_{2avoided\_targeted\_year} - CO_{2avoided\_reference} \quad (7)$$

OTHER ENERGY EFFICIENCY MEASURES

In this article, except for the three measures mentioned above, the reduction of energy intensity of cement or clinker is all due to improvements in energy efficiency. CO_2 reduction compared with the 2005 level, are calculated based on the energy intensity reduction with the output of cement production. In 2005, the energy intensity of cement was 129 kgce/t cement and in 2010, it reduced to 95.8 kgce/t cement. For the 2015, the Chinese government wishes to reduce that figure to 93 kgce /t cement. Energy intensity reduction of each method compared with 2005 levels can be gained by using their CO_2 amount/ output cement. Removing these CO_2 savings from the total amount, the CO_2 reduced by energy efficiency improving can be assessed.

$$CO_{2saved\_energy\_efficiency\_increasing} = CO_{2saved\_energy\_intensity\_reduction} - CO_{2saved\_other\_methods} \quad (8)$$

Where $CO_{2\,saved\_other\_measures}$ refer to $CO_{2\,saved\_closing\_old\_facilities}$, $CO_{2\,saved\_WHR,}$ and $CO_{2\,saved\_subsitution\_for\_clinker.}$

Results

CO_2 SAVED IN THE 11TH FYP

By using the reduction of energy intensity multiplied by the output amount according to equation (1) and (2), 397 million tons CO_2 was saved for the 11th FYP compared with 2005 level.

Closing out-dated facilities

The sharing of NSP kilns increased from 50 % in 2006 to 81 % in 2010, by enhancing new technologies and eliminating small-scale or obsolete production capacity of 345.7 million tons cement total (NDRC 2011). By using equation (1) and (2) mentioned above, we calculate that in the past 11th FYP, 35.16 million tons CO_2 were saved by shutting down the old production. Compared with the reference case of 2005, 115 million tons CO_2 was saved.

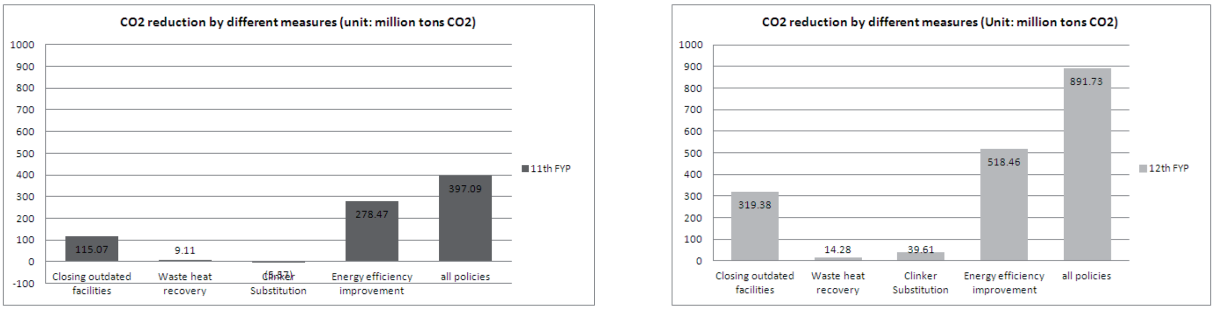

Figure 2, 3. CO_2 saved by different mitigation policies in the 11th and 12th FYPs compared to 2005.

Waste heat recovery

During the period of the 11th FYP, 9,143 million kWh electricity has been generated. By using the emission factor of 0.996 tce CO_2/kWh and equation (5), an amount of 9.1 Million tons CO_2 was avoided by WHR during the 5-year period.

Clinker Substitution

Using the equation (6) and (7), in the period of 11th FYP, 845 million tons of CO_2 were avoided by clinker substitution. However, compared with the 2005 level, the technology level of clinker substitution reduced. This could be attributed to improvement of cement quality after the wide application of NSP, with a higher ratio of clinker-to-cement.

Other energy efficiency improvement measures

Using the methods described above and equation (8), we can assess that CO_2 saved by energy efficiency improvement during the 11th FYP is 278.5 million tons compared to 2005, which shares the major part of CO_2 saved amount.

PROJECTION OF CO_2 SAVED IN THE 12TH FYP

Policies that have been implemented in the 11th FYP will continue to be executed. Their contribution towards CO_2 emission reduction in the 12th FYP (2011-2015) is assessed using the same methodologies mentioned above. The demand of cement production is projected to be increased, and will reach its peak around 2020. In 2015, the cement production will be 2.2–2.3 billion tons with an annual growth rate of 3–4 % (NDRC 2011). In this article, we assume that it will reach 2.2 billion tons. CO_2 emission produced per unit industry added value should be reduced 18 %, making the energy intensity of cement decrease to 93 kgce/t cement. It should be noticed that, both the 11th and 12th FYP are based on 2005 level.

Totally, with current policy and development trend, 891 million tons CO_2 would be saved in the 12th FYP compared with the 2005 level, and 494.6 million tons more than the 11th FYP. Firstly, 250 million tons old or small facilities of cement will be closed during this time, mitigating 25 million ton CO_2 as an absolute value. However, with 2005 as reference year, 319 million tons of CO_2 will be saved by this measure. Compared with the 11th FYP, its reduction amount in the 12th FYP rises, which is mainly due to the increase of cement production. Secondly, the application of waste heat recovery will keep on increase, additionally, however, compared with the 11th FYP, it impacts on CO_2 mitigation will not be huge in the 12th FYP. Thirdly, we calculate that clinker substitution can save 39.6 million tons CO_2 and energy efficiency improvement can mitigate 518 million tons in the next five years. The ratio of clinker-to-cement is assumed to reduce to 0.61, leading to 39 million tons CO_2 saved.

Finally, CO_2 saved by different mitigation policies in the 11th and 12th FYPs are show in figure 2 and 3.

Discussion

For better comparison of the contribution of each policy on CO_2 reduction, their CO_2 reduction amount is divided by output amount of cement in both 11th FYP and 12th FYP. CO_2 reduction per ton cement of each measure in the 11th and 12th FYP is shown in Figure 4. It demonstrates that CO_2 reduction amount per ton cement of each method in the 12th FYP is higher than the 11th FYP. For example, closing out dated facilities can save 15.27 kg CO_2 in the 11th FYP, while 30.9 kg CO_2 in the 12th FYP. This increase is not because of increasingly motivated policies. As we select 2005 as reference year, the result of 12th FYP is compared with 2005 level and it is a cumulative effect. The application of WHR is expanding with the development of NSP these years. However, as the electricity consumption process does not produce too much CO_2, its CO_2 saved capacities in both 11th and 12th FYP are not so high. Moreover, the value of CO_2 reduced per ton cement of clinker substitution is negative in the 11th FYP, which we think it is because in the reference year 2005, the ratio of clinker to cement is lower. The increasing use of clinker substitution can mitigate CO_2 emissions, which can lead the decline of clinker to cement ratio. However, Chinese cement enterprises are also trying to increase the quality of its production, which requires a higher ratio of clinker to cement.

From figure 5, we found out that energy efficiency improvement is always a major technique to reduce CO_2 emissions and shares the largest percentage of energy intensity reduction. Meanwhile, outdated-production closing also plays an important role in energy intensity reduction per ton cement.

For the assessment of 11th FYP, according to which concluded that 303 million tons of CO_2 was saved by the reduction of clinker unit energy consumption (NDRC 2010), our result a bit higher**.** The main reason is that their calculation is based on clinker while our assessment results come from cement energy consumption. In other research of Zeng (Zeng 2008) , it was claimed that 185.75 million tons CO_2 were saved however, that is because she selected a different reference situation and calculation methods.

Regarding the 12th FYP, although it is not easy to project that whether its targets will be achieved, policies in cement sector in the next five years will continue to play an important role in

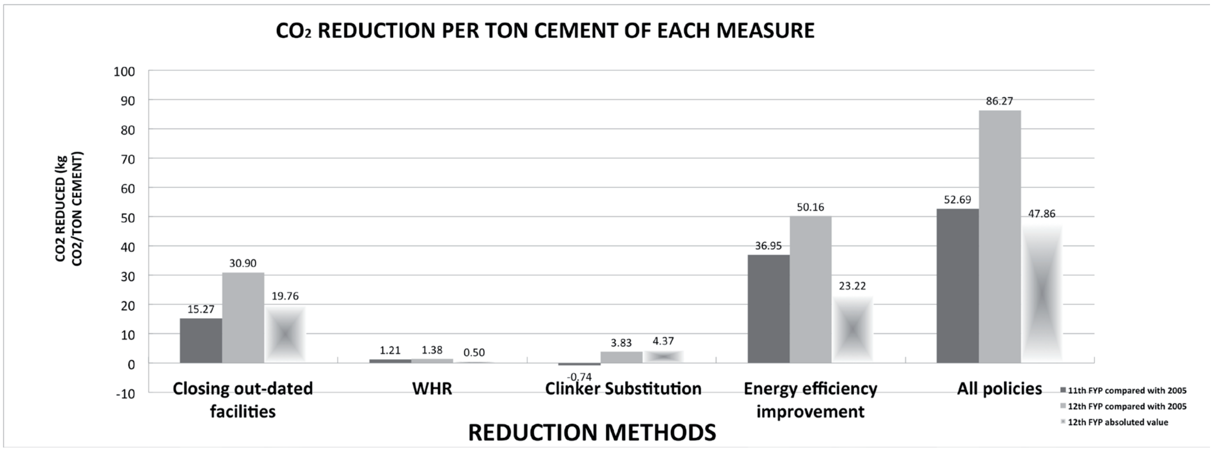

Figure 4. CO_2 reduced per ton cement of each measure in the 11th FYP and 12th FYP.

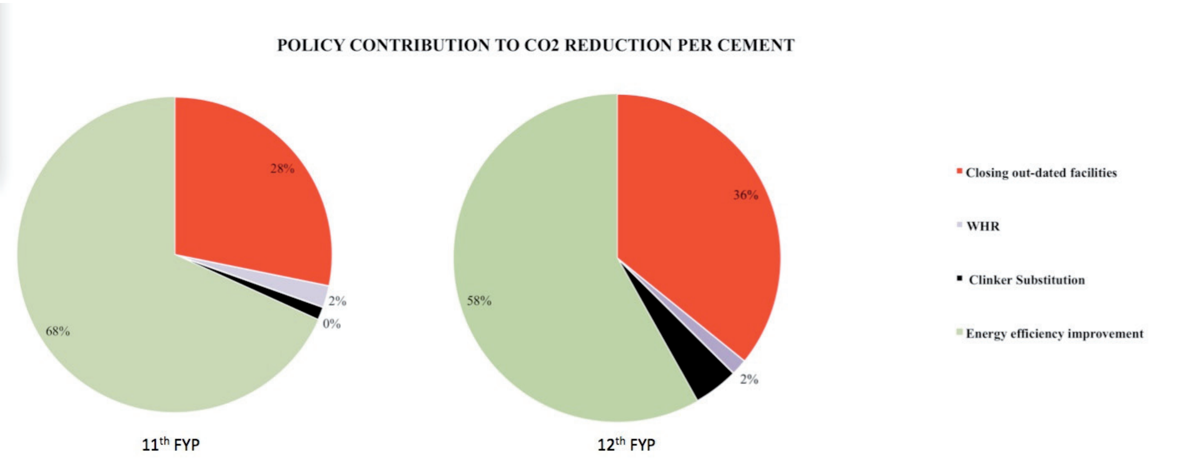

Figure 5. Share of the contribution to CO_2 reduction of each measure in the 11th FYP and 12th FYP (Compared with 2005).

CO_2 mitigation. Efforts on CO_2 controlling will continue to be made through the implementation of different technology to reduce the energy intensity of cement production.

Conclusion

Main policies, including outdated facilities closing, waste heat recovery, clinker substitution, and energy efficiency improvement, in the period of the 11th FYP in the Chinese cement sector, which can result into CO_2 reduction, have been reviewed and assessed. Energy efficiency improvement and outdated facility closing contributed the most to CO_2 reduction. In the coming five years, these policies will impact CO_2 reduction. In addition, it is time to do research and lay foundations to advanced technologies, such as alternative fuels and carbon capture and storage (CCS), which can greatly mitigate CO_2. We did not start to evaluate these technologies in this study since in China the use of alternative fuels just starts and CCS, in cement sector will not be commercially used until 2020 at earliest. Consequently, more positive policies, which have a huge capacity of CO_2 reduction potential, are required to be proposed to publish and implement at sector level.

Reference

Cui, Y. (2006): Potential and major strategies for energy saving and CO2 emission reduction in Chinese cement industry. Retrieved from http://www.iea.org/work/2006/cement/Cui.pdf.

Hasanbeigi, A.; Menke, C.; Price, L. (2010): The CO2 abatement cost curve for the Thailand cement industry. *Journal of Cleaner Production*, *18*(15)1509-1518. doi: 10.1016/j.jclepro.2010.06.005.

He, H.; Yi, H. (2010): Effect on Raw Alternative and Clinker Reduction on CO2 Emission Reduction. *China cement*, *1*.

IEA; WBCSD (2009): Cement Technology Roadmap 2009: Carbon emissions reductions up to 2050. Technology Roadmaps. Paris, France: International Energy Agency and World Business Council on Sustainable Development.

Kiang, C. S.; Du, T.; Zhao, C. (2011): Key Features of China's Energy Efficiency Strategy. Retrieved from http://transatlanticenergyefficiency.eu/sites/default/files/China_Kiang.pdf.

NDRC (2004): China Medium and Long Term Energy Conservation Plan. Retrieved from http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/04/china-medium-and-long-term-energy-conservation-plan.doc.

NDRC (2006a): Special Plan for the Development of Cement Industry. Retrieved from http://www.ndrc.gov.cn/zcfb/zcfbtz/tz2006/t20061019_89080.htm.

NDRC (2006b): the new standard of Common Portland_Cement GB 175-2007.

NDRC (2011): 12th Five Year Plan of Building materials in China. Retrieved from http://www.gov.cn/gzdt/att/att/site1/20111129/001e3741a2cc103e75b901.pdf.

RES (2010): Introduction of low-temperature Waste heat recovery power generation (WHRPG) technology in Cement Kiln. Retrieved from http://rahbordsanat.com/pdf/Introduction%20to%20WHRPG.pdf.

Srivastava, R. K.; Vijay, S.; Torres, E. (2011): Global Climate Change - The Technology Challenge. Advances in Global Change Research (Vol. 38). Springer Netherlands. Retrieved from http://www.springerlink.com/content/j6x0l5061q414430/abstract/.

Sui, T. (2011): China's cement industry towards sustainability. Retrieved from http://www.italcementigroup.com/NR/rdonlyres/4FFAD881-52B9-439B-8D51-965D7C-C4588F/0/Tongbo_UK.pdf.

The European Cement Association (2011): Activity report 2010, CEMBUREAU. Retrieved from http://www.cembureau.eu/sites/default/files/Activity_Report_2010.pdf.

Wang, Y. (2010): Current Situation and Prospect of China Cement Industry CO2 emission reduction. Retrieved from http://www.ccement.com/news/2010/3-23/C10373080_2.htm.

Zeng, X. (2007): Energy saving methods in cement sector and changes of investment in cement sector. Retrieved from http://www.ccement.com/news/2007/10-1/C13634798.htm.

Zeng, X. (2008): the status quo and energy efficiency improvements in Chinese cement sector. Retrieved from http://www.iea.org/work/2008/comparison/ZENG_CEMENT_CN.pdf.

Zeng, X. (2009): Waste heating recovery power generation contributing to cement sector. Retrieved from http://www.cnsb.cn/html/news/255/show_255809.html.

Zeng, X. (2011): The cement industry, as a good example of a low carbon sector. Retrieved from http://www.xbsn.com/news/sports/2011-08-09/6001.html.

Zhang, D.; Kristin Aunan,; Seip, M.; Haakon, V.The energy intensity target in China's 11th Five-Year Plan period--Local implementation and achievements in Shanxi Province. Retrieved from 4115- http://ideas.repec.org/a/eee/enepol/v39y2011i7p4115-4124.html.

Zhang, N.; Guo, L. (2009): Current development of Chinese cement sector. *Journal of Chifeng Univeristy (Nature science edition)*, *25*(2)129–131.

Acknowledgements

The China Scholarship Council supports this work.