Anonymous Referee #1

Cement industry is one of the largest contributors to the industrial emissions of carbon dioxide and air pollutants in China. Based on intensive unit-based information, this study investigated the carbon and air pollutant emissions from China's cement industry during 1990-2015, explored the emission trends, evolution of technologies and drivers to changes of emissions. This work contributed to the development of China's high resolution emission inventory, which is very useful for the atmospheric community. The manuscript also provided new insights for future emission mitigation of China's cement industry. The topic is within the scope of ACP and the manuscript is generally well written. I have a few comments before it can be accepted for publication.

Response: We thank the Referee for the insightful comments. We have revised the manuscript according to the suggestions and respond to the concerns below.

1. One major advantage of the new emission inventory is the unit level data. I believe this should be emphasized throughout the manuscript.

Response: Accepted. Thanks to the review's comment, we have rewritten some of the contents in the manuscript and added unit-level emission analysis to emphasize the advantage of new unit-level emission inventory:

(1) Abstract: "*In 2010, nationwide 39% and 31% of the* $PM_{2.5}$ *and* NO_x *emission were produced by 3% and 15% of the total capacity of the production lines, indicating the disproportionate high emissions from a small number of the super-polluting units*".

(2) Introduction: " *Based on the background above, the aim of this study is to quantify the decadal changes of carbon dioxide and air pollutant emissions from China's cement industry, investigate the evolution technologies, identifying the super-polluting units, and quantify the major drivers of the emission changes over a period of 25 years. The analysis is based on intensive unit-based information on activity rates, production capacity, operation status, and control technologies, which improves the accuracy of the estimation of cement emissions, provides a comprehensive view of the effectiveness of technologies on air pollutant emission control in the past, quantifies the contribution from different drivers to de changes of emissions, and highlights the opportunities and challenges for future mitigation of carbon dioxide and air pollutant emissions in China.* "

(3) Results (3.2.4 Unit-level emissions): "*Fig. 11 shows the unit-level $PM_{2.5}$ and NO_x emissions by capacity in 2010 and 2015, which highlights the most polluting production lines whose emission intensity is over 90th percentile values of the emission intensity defined as the emissions per unit of capacity. During 2010−2015, dramatic changes had taken place in China's cement industry. In 2010, there were over 2400 cement production lines, in which PC had a share of 54% in terms of the number of production lines, followed by SK, with a considerable share of 44%. Typically, the SKs had smaller capacities and older ages, which were majorly within the range of 100−1000 t-clinker/day and started to operate before 2000, but had substantial contributions to $PM_{2.5}$ emissions. In 2010, nationwide 39% and 31% of the $PM_{2.5}$ and NO_x emission were produced by 3% and 15% of the total capacity, indicating the dipropionate high emissions from a small number of the super-polluting units. Specifically, the super-polluting units for $PM_{2.5}$ were dominated by SKs, whereas the super-polluting units for NO_x were majorly PCs. In 2015, driven by the rapid replacement of traditional SKs with PCs, and the elimination small-scale production lines, the disproportionalities were alleviated compared with the situation in 2015. Allowing for the dominant role of PC in China's cement industry since 2015, future mitigation should focus on the control of cement demand growth, improvement of energy efficiency, and implementation of high-efficiency end-of-pipe emission control devices.*

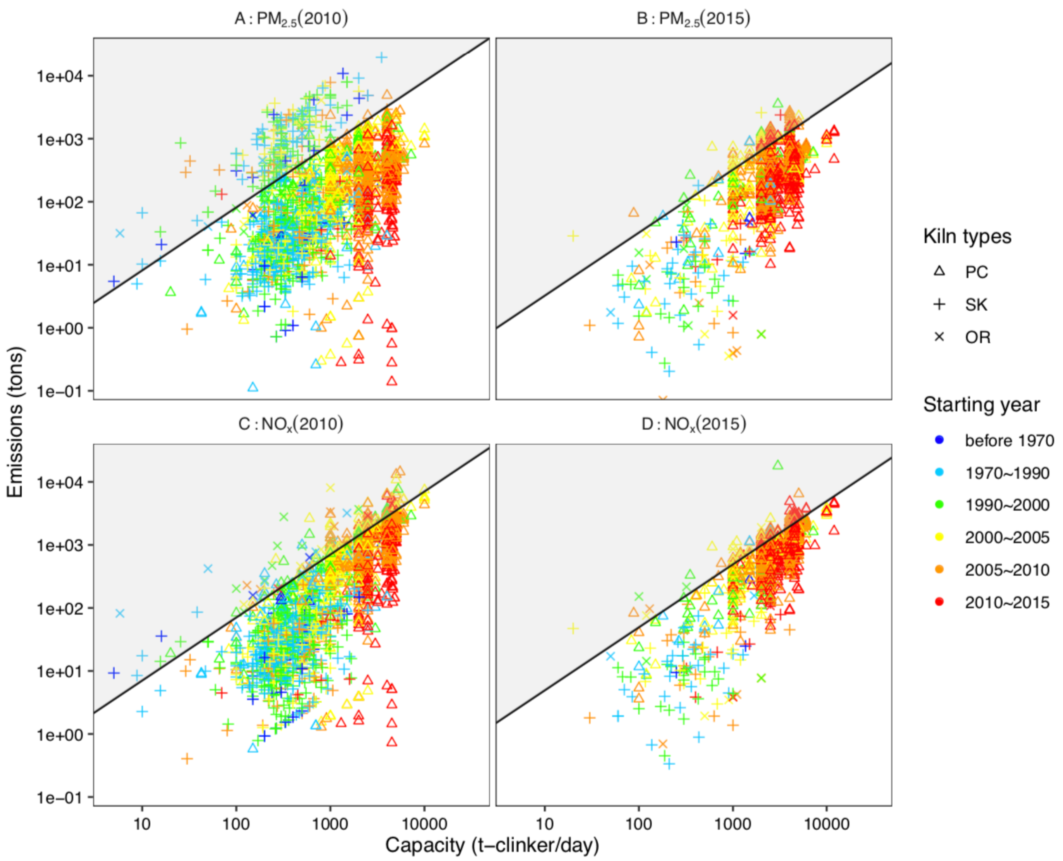

Figure 11 in manuscript: Unit-level $PM_{2.5}$ and NO_x emissions during clinker calcination in production lines by capacity in 2010 and 2015. The black lines and gray shades illustrate the production lines whose emission intensity is over 90th percentile values of the emission intensity defined as the emissions per unit of capacity.

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2. Is the cement output in 2014 the same with the output in 2015? Otherwise the growth rate between 1990-2014 and 1990-2015 should be different. Page 1, Line 16: "We found that, from 1990 to 2015, accompanied by a 10.9-fold increase in cement production, CO2 , SO2, and NOx emissions from China's cement industry increased by 626%, 59%, and 658%, whereas CO, PM2.5 and PM10 emissions decreased by 9%, 66%, and 63%, respectively. " Page 8, Line 246: "From 1990 to 2014, the production of cement and clinker increased from 0.21 and 0.16 billion tons to 2.5 and 1.4 billion tons, i.e., by 10.9 and 8.2 times, respectively.

Response: Accepted. We've made a calculation mistake here. The cement production increase from 0.21 billion tons in 1990 to 2.49 billion tons in 2014, and then dropped to 2.36 billion tons in 2015. Therefore, the cement growth rate between 1990 and 2014 is 10.9 times, and the growth rate between 1990 and 2015 is 10.3 times. We've corrected the numbers in the manuscript. Besides, we've also corrected the inconsistent numbers as mentioned in comment No. 5.

(1) Page 1, Line 16: "*We found that, from 1990 to 2015, accompanied by a 10.3-fold increase in cement production, CO_2 , SO_2, and NO_x emissions from China's cement industry increased by 627%, 56%, and 659%, whereas CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively.*"

(2) Page 8, Line 246: "*From 1990 to 2014, the production of cement and clinker increased from 0.21 and 0.16 billion tons to 2.49 and 1.42 billion tons, i.e., by 10.9 and 8.2 times, respectively.*"

3. Page10: Line 282- 291, the chapter of 3.2.1 CO_2 emissions, the contents are mixing the period of 1990-2014 with the period of 1990-2015, which is unclear to readers.

Response: Accepted. We have rewritten the paragraph to make the contents consistent:

"*Fig.6 shows the historical CO_2 process and fuel emissions in China's cement industry. The total emissions of CO_2 increased in line with the growth of cement production. Driven by the 8.2-fold increase in clinker production from 1990 to 2014, the total CO_2 emissions in China's cement industry increased from 0.15 Pg to 1.18 Pg; then the CO2 emissions dropped to 1.10 Pg in 2015, as a result of the decrease in cement production (Fig. 5). The growth of CO_2 emissions was slightly lower than that of clinker production due to the offset effect from improved energy efficiency. Over the whole period of 1990-2015, the CO_2 process emissions increased from 77.7 Tg to 694.2 Tg, i.e., by 7.9 times, which was consistent with the growth of clinker production, whereas the CO_2 fuel emissions increased more slowly, from 73.5 Tg to 405.9 Tg, i.e., by 4.5 times, because the energy intensity of cement kilns decreased significantly at the same time (Fig. 6). During the 1990-2015 period, the energy intensity of precalciner kilns, shaft kilns and the other rotary kilns decreased by 17%, 16% and 27%, respectively. As a result, the proportion of CO_2 emissions from coal consumption also decreased from 49% in 1990 to 37% in 2015.* "

4. Page 11: Line 320-323, "The decline of PM emissions after 1996 was due to the implementation of the new emission standards for the cement industry issued in 1996 (GB4915-1996, Table S1) and the slowing down of the economy in the Asian financial crisis. The PM emissions rebounded after the financial crisis but dropped again after 2003, despite a continuous increase in cement production at an annual growth rate higher than 10%." In Fig. 9, the PM2.5 emissions kept decreasing during 1990-2002, and only rebounded in 2003. It's difficult to judge whether the rebound is due to the financial

crisis or not.

Response: Accepted. Thanks to the review's comments. We agree it's difficult to judge whether the rebound is due to the financial crisis or not. We revisited the data and found that the rebound in 2003 was directly caused by the increase of clinker to cement ratio in that year. Therefore, we revised the manuscript as follow:

"*The decline of PM emissions after 1996 was due to the implementation of the new emission standards for the cement industry issued in 1996 (GB4915-1996, Table S1) and the slowing down of the economy in the Asian financial crisis. Then the $PM_{2.5}$ emissions rebounded in 2003 as a result of the increase of clinker to cement ratio in that year (Fig. 2). Afterwards, despite a continuous increase in cement production at an annual growth rate higher than 10%, the PM emissions kept a downward trend.* "

5. There is some inconsistency of the numbers. The authors should carefully double check the data: (1) Page 1, Line 16: "We found that, from 1990 to 2015, accompanied by a 10.9-fold increase in cement production, CO_2 , SO_2, and NO_x emissions from China's cement industry increased by 626%, 59%, and 658%, whereas CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 66%, and 63%, respectively. " Page 9, Line 275, During the 25 years, the cement production increased dramatically, by 10.5 times. During that time, the CO_2 , SO_2 , and NO_x emissions from the cement industry increased by 627%, 56%, and 659%, whereas the CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively, indicating that significant technology transitions occurred in the past 25 years. Page 15, Line 438, "From 1990 to 2015, the CO_2, SO_2, and NO_x emissions from the cement industry increased by 627%, 56%, and 659%, whereas the CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively. " (2) Page 6, Line 169- 291, "From 2011 to 2015, the proportion of kilns equipped with LNB technology increased from 3% to 40%, and the installation percentage of LNB in newly established kilns increased from 13% to 64%. The SNCR technology developed later in the 2000s. During the 12th FYP, the SNCR installation experienced unprecedented explosive growth. The penetration rate has increased even faster than that of the LNB technology, from 1% of all the kilns in service in 2011 to 88% in 2015. " Page10, Line 307-308, "In 2011, only 11% and 1% of the clinker was manufactured in kilns equipped with LNB and SNCR facilities, whereas by 2015, the percentages sharply increased to 50% and 97%."

Response: Accepted. We have carefully double-checked the data, and corrected the inconsistent numbers.

(1) Page 1, Line 16: "*We found that, from 1990 to 2015, accompanied by a 10.3-fold increase in cement production, CO_2, SO_2, and NO_x emissions from China's cement industry increased by 627%, 56%, and 659%, whereas CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively.*"

Page 9, Line 275: "*During the 25 years, the cement production increased dramatically, by 10.3 times. During that time, the CO_2 , SO_2 , and NO_x emissions from the cement industry increased by 627%, 56%, and 659%, whereas the CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively, indicating that significant technology transitions occurred in the past 25 years.*"

Page 15, Line 438: "*From 1990 to 2015, the CO_2, SO_2, and NO_x emissions from the cement industry increased by 627%, 56%, and 659%, whereas the CO, $PM_{2.5}$ and PM_{10} emissions decreased by 9%, 63%, and 59%, respectively.*"

(2) The inconsistency is caused by differences in description. Previously we mix the proportion in the number of kilns with the proportion in the amount of clinker produced in the kilns. We've clarified them in in the revised manuscript.

Page 6, Line 169- 291: "*From 2011 to 2015, the proportion in the number of kilns equipped with LNB technology increased from 5% to 40%, and correspondingly, the proportion of clinker manufactured in kilns equipped with LNB facility increased from 11% to 50%. The installation percentage of LNB in newly established kilns increased from 13% to 64%. The SNCR technology developed later in the 2000s. During the 12th FYP, the SNCR installation experienced unprecedented explosive growth. The penetration rate has increased even faster than that of the LNB technology, from 1% of the number of kilns in service in 2011 to 88% in 2015, and thus the proportion of clinker manufactured in kilns equipped with SNCR facility increased from 1% to 97%.*"

Page10, Line 307-308, "*In 2011, only 11% and 1% of the clinker was manufactured in kilns equipped with LNB and SNCR facilities, whereas by 2015, the percentages sharply increased to 50% and 97%.*"

6. Please explain the meaning of the cumulative ratio occurred in Fig. 4 and Fig. 10 in more details.

Response: Accepted. We explained the meaning of cumulative ratio in Section 3.1, near the occurrence of Fig. 4:

"*To draw the curve for the cumulative ratio, we summarized the number of production lines by capacity (t-clinker/day), and calculated the ratio to the total number of production lines, from which we derived* *the cumulative ratio for each level of capacity. Therefore, the cumulative ratio represents the share of production lines with the capacity below a certain level.*"