CC 3

Comment: This study analyzes the global and regional uptake of CO_2 by cement material through carbonation from 1930 to 2021. This study is of interest for the global carbon community, as it is important to more accurately account for sources and sinks of CO_2 by cement-containing materials for better estimation of its impact on the carbon cycle. However, the manuscript is not clear for certain aspects of the study. Please, find my comments below.

Response: Thank you for your precious comments and suggestions. Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. The responds to the reviewer's comments are as following:

1. **Comment:** What is your contribution compared to the previous study (Such as Guo et al., 20201; Xi et al., 2016; Cao et al., 2020)? Please justify the importance and advancement of this dataset.

   Response: Thanks for your questions. We noticed this when we developed our works. Basically, our work is the extension of Guo's work. We calculated the carbon uptake from cement since 1930 till 2021 which is 3 years further than his study. But we keep the methodology same for a more systematic and accurate dataset generation and updating. Thus, difference between Xi's work and us is the same as that between Xi's and Guo's which has been discussed in Guo's paper (Guo et al., 20201). Cao's also make an improvement under this theme especially establish the future estimation system but the focus of this study is the amount of 2016. Thus, as we described in the texture, our work aims at updating the data within the same framework, enhancing the completeness of our database, thereby providing a reliable data foundation for our future forecasting endeavors. Plus, as you mentioned below, we included the data during the pandemic, which is also our spark.

2. **Comments:** Please provide reasons for regional division.

   Response: Thanks for your question. In our previous study (Xi et al., 2016), the world cement production was geographically divided into four primary countries and aggregated regions, including China, the United States (US), Europe and central Eurasia (including Russia), and the rest of the world (ROW). The cement production in ROW is obtained by subtracting China, the United States, and Europe and central Eurasia from global cement data. In our subsequent study (Guo et al., 2021), we noticed that India has now become the second-largest cement producer after China, with approximately 8 % of the world total in 2014 (IEA and WBCSD, 2018), then it divided geography into five primary countries and aggregated regions, including China, the United States (US), Europe and central Eurasia (including Russia), India and the rest of the world (ROW) (Guo et al., 2021). The data of India was directly collected from United States Geological Survey (USGS). The cement production in ROW is obtained by subtracting China, the United States, Europe and central Eurasia, and India from global cement data. To keep the consistency with the prior geographical division (Guo et al., 2021), thus, we also use this division for our study. Meanwhile we followed USGS's geographical category of the cement production (US, China, EU, India, rest of world) to make our data source more convincing. USGS is one of the most completable databases of cement production which has the same statistics standard and criteria for each area. When we collected these data, we also considered to create a database manually by using other data source such as national statistics year books. But it is hard to combine these data with different statistics standards and criteria. Finally, we divided the world into these 5 areas.

3. **Comments:** The cement production process is an energy-intensive and CO_2-emitting process. I find you only focused on the CO_2 generated by the decomposition of calcium carbonate. What about the carbon emissions generated by energy consumption?

   Response: Appreciate for your comment. Generally, according to the definition of IPCC's carbon emission method (IPCC, 2006), emissions in cement production arise from fuel combustion (to heat limestone, clay, and sand to 1450 °C) and from the calcination reaction. Obviously, this kind of CO_2 in fuel combustion can be regarded as unnatural process in cement producing. There is a big potential to replace the current energy source to the renewable one and increase energy efficiency to reduce the CO_2 emission. (IPCC Fourth Assessment Report: Climate Change 2007:

https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch7s7-4-5.html) However, the processing emission that we defined in our study is a natural one which means it is hard to change the fact via a technical way. We noticed there are a lot of researches focusing on improving materials'(clinker) structure and characteristic to reduce the embodied carbon. However, they are not mature for industries currently. Thus, we decided to compare this kind of emission amounts to our uptake amount to show the potential of carbon reduction, which can solve the real issues in the real production and industry. This is what we do think having more practical value.

4. **Specific comment:** There are many types of cement, including fly ash cement, steel slag cement, etc. Sometimes, cement production does not originate from the decomposition of calcium carbonate directly, instead it is the mixing of purchased cement clinker. Will it affect the evaluation of carbon emissions and cement carbonization absorption in the cement industry process?

   Response: Thanks for your question. Now, with the development of technology, the addition of alternative materials such as steel slag, fly ash, natural pozzolans in cement has already increased in recent years (Schneider et al., 2015; Xu et al., 2022). The addition of clinker substitutes reduces the use of clinker, thereby reducing the process carbon emissions from limestone calcination (Xu et al., 2022). Indeed, the cement constituents has a significant impact on the cement process emissions. This means that using clinker production is more accurate than using cement production when calculating cement process emissions (Andrew, 2019). Like other study (Andrew, 2019), we try to use clinker production to accurately calculate cement process emission in this study, while there is no cement clinker statistics, we use the cement clinker ratio parameter recommended by IPCC to calculate the cement process emissions (Andrew, 2019). In this study, to maintain data homology with the cement carbon absorption formula, we use cement production and variant clinker ratio to calculate cement process emissions. Certainly, the variant clinker ratio is transformed from clinker production and cement production, and the clinker production has been corrected by import and export.

   The theme of the article is to calculate the carbon absorption of cement. There are many types of cement, and using cement production to calculate cement carbon absorption is correct. If only clinker is used to calculate cement carbon absorption, the carbonization of additives in other types of cement will be excluded, which will underestimate the amount of cement carbon uptake. Certainly, the cement additives will also affect the carbonation of cement due to the alkaline minerals such as CaO in the cement additives. In this study, we have considered the effect of additives on cement carbonization through the correction coefficient of additives, which has expressed in the SI-Table 1 (data can be accessed from SI-Table 1 of sheet 10 of from https://doi.org/10.5281/zenodo.7516373) and method of formula (1) in Supplementary document.

Changes: In the revised Data and Methods part, we further indicate the impacts of cement addition on carbon emission, for example "Given the current types of cement additives, if statistical data on cement clinker production is available, it is recommended that cement clinker production data be used directly to accurately estimate process emissions (Andrew, 2019)." in line 151-154.

5. **Comments:** The updated data is during the period of the Covid-19. Please add the detail elaboration on the impact of the Covid-19 on cement carbon emissions and uptake.

   Response: Thanks for your suggestion. In our work, we mentioned this in the text (line 39-42, 361-364, 429-432). According to our calculation and estimation, the pandemic showed little impact on global cement industry. It is a fact during these years, the global carbon emission increased, but this can be explained by the continuous growth in the production of cement and related clinker as well, but showing a slightly lower average annual growth rate of 2019 (8.57%) than that of recent past decades (8.68%). We noticed there are many reports mentioned it is indeed affected by the pandemic but it is from perspectives of supply chain, consumption and labor and also showing the imbalance of demand and production. (Schlorke et al., 2020). This can also be a proof of our results.

Changes: In the revised version of line 266-278, we have added more expression on the impact of pandemic on cement uptake, for example "Meanwhile, based on our calculation, during the pandemic (2020-2021), the global cement producing amount shows a continuous increasing trend since 2019, leading the CO_2 emission rising. Globally, the producing amounts for 2020 and 2021 are 1590.38 and 1819.48 Mt respectively, ROW's contribution ranked first, from 495.75 in 2020 to 725.83 Mt in 2021. It is believed that in 2021, with the recovery of pandemic, The demand for cement increases alongside the resumption of delayed construction projects during the pandemic. (Schlorke et al., 2020). But China is an exception, showing a slight drop on the cement production during 2019 to 2021 with 752.40, 774.45 and 748.64 Mt separately. This can be explained by the stick restriction policy and property crisis in China in 2020 and 2021. (Hale et al., 2022)"

6. **Specific comment**: I suggested that the authors could provide a clearer explanation of the importance of their research in achieving the goal of global carbon neutrality. They could further elaborate on why this issue is important and how their research can contribute to addressing it. Additionally, they could explore the practical application of carbon capture technology, as well as the cost and feasibility of this technology.

    Response: Thanks for your suggestion. The importance of our series of research were in building cement carbon uptake accounting methods and quantitative calculation of its carbon absorption, which has made up for the lack of methods in the IPCC national greenhouse gas inventories guideline (IPCC, 2006; Xi et al., 2016), and provided data and technical support for precise calculation of global carbon balance and carbon neutrality. For example, in the global carbon budget report, it has begun to consider the impact of cement carbon sequestration on global carbon balance (Friedlingstein et al., 2022). According to the analysis conducted in the present study, the cement materials' annual carbon uptake in 2021 is equivalent to 7.67% of the global industrial process emissions of CO_2 (Friedlingstein et al., 2022), approximately 8.23 % of the average global land carbon sink from 2010 to 2020 (Friedlingstein et al., 2022), approximately 23.80% of the average net global forest sink from 1990 to 2007 (Pan, et al., 2011). The cement carbon sink of China alone in 2021 was about 0.43 Gt CO_2 yr^{-1}, which accounts for 48% to 60% of the terrestrial carbon sink in China during the past decades (Yang et al., 2022). The substantial cement carbon sequestration making it one of the important carbon sinks that cannot be ignored in the national and global carbon cycle and carbon neutrality evaluation. Meanwhile, the carbonization of cement materials is considered as one of the most promising carbon dioxide capture and storage technology. Scientists and engineers are inspired by the carbonization effect of cement to develop carbon capture and storage technologies by using construction waste (Skocek et al., 2020; Hargis et al., 2021).

According to IPCC special report on carbon capture, and storage (CCS) (Rubin and Coninck, 2005; Kheshgi et al., 2012), in principle, CCS is technically feasible and plays a major role in long-term scenarios where there is significant reduction in greenhouse gas emissions. However, CCS through geological storage is also facing questions due to its cost-effective in reducing emissions, uncertain potential storage capacity, uncertain long-term impacts and stability of the storage sites. A potentially suitable alternative to the geological storage is the mineral carbonation (Sanna, et al., 2014), also called mineralization, i.e. the concept of storing CO_2 in the form of calcium and magnesium carbonates and to use. Now, expert community proposed the mineralization of concrete waste and their utilization in cement can be realized within the construction sector since the carbonatable materials come from demolished concrete and the carbonated paste comprise a part of cement used in new concrete, which is in line with the concept of circular economy and the conservation of natural resources (Skocek et al., 2020). Certainly, the carbon capture, utilization and storage (CCUS) technology of mineralization is technically feasible, but further research is still needed to reduce economic costs and identify suitable application department scenarios. In the future, use of alkaline mineral carbon sequestration to achieve emission reduction will play an important role in achieving carbon neutrality goals (Chiang and Pan, 2017; Hargis et al., 2021).

Changes: In the revised version, we added some expression in the Result and Discussions part to identify the importance of cement carbon sequestration. For example, the sentences "Our series of research in building cement carbon uptake accounting methods and quantitative calculation of its carbon absorption has made up for the lack of methods in the IPCC national greenhouse gas inventories guideline (IPCC, 2006; Xi et al., 2016), and provided data and technical support for precise calculation of global carbon balance and carbon neutrality. In the global carbon budget report, it has begun to consider the impact of cement carbon sequestration on global carbon balance (Friedlingstein et al., 2022). According to the analysis conducted in the present study, the cement materials' annual carbon uptake in 2021 is equivalent to 7.67% of the global industrial process emissions of

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