External Review Report

Sino-Swiss Cooperation Project：

Clear Air China Phase I

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August, 2023

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External Review Report of the Sino-Swiss Cooperation Project—Clear Air in China

1. Evaluation Background

1.1. Evaluation Period

The evaluation for this project began on April 5, 2023 and concluded on July 31, 2023. Due to the impact of the COVID-19 Pandemic, the Clear Air in China (CAC) project was extended twice with the closing date of the project extended from the end of July 2022 to the end of Year 2023. As a result, during the evaluation process, some aspects of the project were still in progress and being enhanced.

1.2. Evaluation Objectives and Methods

As required by the Swiss Agency for Development and Cooperation (SDC), the objectives of this evaluation included:

- evaluation of achieved results against initial mandates given by SDC to PSI and IEE.
- Provide recommendation to SDC for the design of the next phase of the Clean Air China project.

The external review follows OECD evaluation criteria, covering: Relevance, Efficiency, Effectiveness, Coherence, Impacts, Sustainability, followed by recommendations.

1.3. Evaluation Process

This evaluation thoroughly reviewed the technical documents and reports submitted by the project team to SDC as of July 2023 (see Annex B). The reviewer joined the exchange meeting between the project team and the senior staff from the Chongqing Municipal Ecology and Environment Bureau (EEB) in as well as reviewed some videos about the discussion with Beijing and Wuhan EEB. Concurrently, discussions were conducted with some members of the project team. And the reviewer also communicated with persons in charge of air pollution prevention and control, atmospheric environment monitoring and research technology from the six pilot cities, specifically: Beijing, Xi'an, Chongqing, Wuhan, Shijiazhuang, and Langfang (see Annex C). The reviewer collected feedback from the six cities on the project's implementation process, the impact of its results on local air quality improvement and the prospects for its promotion and application. To properly evaluate the real time source apportionment technology developed by the project, the reviewer sought opinions from Professor Min Hu, a senior expert in source apportionment technology at Peking University (see Annex D). Based on the above work, the project was evaluated in an independent and objective method.

2. Project Overview

Air pollution is a major environmental threat to public health in China and other developing countries. The Chinese government has made strong effort to abate air pollution at both central and local levels. With the enforcement of the upgraded air quality standard since year 2012 and implementation of clean air actions at all levels through the country since 2013, air quality in most Chinese cities have been substantially improved in the past decade. However, further improving air quality encounters certain bottleneck because it demands precise air pollution management in terms of well-targeted emission reduction measures and policies in place. Air pollution managing authorities need to distinguish different polluting sources and quantify their contribution to air pollution. They also need to predict heavy air pollution days ago. During the pollution episode, they need to analyze in details the chemical composition of pollutants thus being able to understand well their potential health impacts. With all these knowledge, air pollution managing staff and policy makers are able to propose cost-efficient emission reduction measures from both long-term perspective and short-term emergency response.

To meet the air pollution managing needs as above, in year 2019 the Swiss Agency for Development and Cooperation (SDC) initiated the Clean Air in China (CAC) project, concentrating on the air pollutant source apportionment, which is regarded as a strong science-based tool to support efficient and targeted clean air policy making.

The overall objective of the CAC project is to reduce the air pollution in key Chinese cities and regions, thereby improving people's health and well-being, through more effective policies as a result of applying state-of-the-art pollutant source analysis techniques, and the Sino-Swiss experience is shared regionally and globally.

Four outcomes are envisaged:

Outcome 1: The capacity of Chinese cities to do accurate air pollutant source apportionment is improved;

Outcome 2: Chinese cities better understand their air pollution profile through dynamically updated and reliable air pollution emission inventories;

Outcome 3: More effective air pollution control policies are designed and implemented based on the source apportionment results and the updated emission inventories;

Outcome 4: The knowledge and experience developed by the Project are effectively disseminated and used in China, regionally and globally;

The cooperation is based on the already established academic cooperation between two top institutes in source apportionment field in China and Switzerland. The leading Swiss implementing agency is the Paul Scherrer Institute (PSI), who takes the leading position in the world in air pollutant chemical analysis and receptor-oriented sourcing. Federal Institute of Technology in Zürich (ETHZ) contributes to the project from source-oriented approach, establishing and updating the emission inventory. On the Chinese side, the Institute of Earth Science (IEE) of the Chinese Academy of Sciences (CAS) plays a leading role. IEE partners with its air quality monitoring network in Chinese cities, which has assured the data sampling campaigns in pilot cities during Covid-19 period. Scientists from China and Switzerland have been working closely in the past 3 years. Core and the most innovative element of the CAC project is to develop a real-time source apportionment method by deploying a set of advanced air pollutant sampling and analysis instrument. A protocol real-time source apportionment product has been developed and tested in the pilot cities, with preliminary results generated. Policy implications of the results and findings are still to be discovered through the on-going policy workshops with pilot cities. Knowledge, methods and experience gained in the CAC project have been and will be further shared with neighboring Asian cities as India, Mongolia and Nepal.

3. Evaluation Conclusion

3.1. Relevance

3.1.1. Has the project been relevant to and in line with China's national strategy

in reducing air pollution and international best practices?

- The overall objective of the project is to enhance the effectiveness of air pollution control technologies, improve the air quality in the pilot cities and safeguard the health of the people by sharing advanced source apportionment technologies and management experience regionally and globally. This goal is highly consistent with China's national commitment to winning the battle against air pollution and continuously improving air quality. As a nation, China implemented "Ten Measures" to improve air quality and achieved remarkable progress in air pollution control, and then the State Council issued the ***Three-Year Action Plan to Win the Blue Sky Defense War*** (G.F. [2018] No. 22) in Year 2018. This action plan specifically called for further improvements of air quality in the Beijing-Tianjin-Hebei metropolitan region and surrounding areas, as well as the Chengdu-Chongqing area. And also mandated the regular compilation of source emission inventories and source apportionment in key regions and cities to form the dynamic pollution traceability. During Year 2021, the Chinese government issued the ***Opinions of the Central Committee of the Communist Party of China and the State Council on Promoting the Nationwide Battle to Prevent and Control Pollution***, in which specific set targets for air pollution control are formulated by 2025. The targets include a proposed 10% reduction in PM2.5 concentration in cities at the prefecture level and above, achieving 87.5% of days with good air quality and basically eliminating what should be considered as "heavy" pollution days. The project is expected to enhance the air pollution control capabilities of each pilot city and facilitate the achievement of national goals for continuous air quality improvement while concurrently supporting the national construction of ecological civilization.

- The online source apportionment monitoring system, along with the online and real-time source apportionment models (SoFi and HERM) developed and used by the project are all world-leading technologies for PM2.5 source apportionment. In particular, staff from PSI, have combined significant online and offline monitoring and analysis of particle composition and with the aid of the improved SoFi, a source apportionment model, the project identified partial sources of secondary organic aerosols (SOA) in PM2.5 components, thus providing further insights into the pollution sources of PM2.5. HERM developed by IEE also enables online source apportionment of PM2.5. The temporal resolution of the results gained through both source apportionment models has been significantly improved, achieving hourly levels. In addition, the PM2.5 composition online monitoring systems used in the project, namely AXA (ACSM, Xact and aethalometer), provides a mature monitoring solution for online and real-time source apportionment. Moreover, PSI developed a set of equipment that combines EESI-TOF for determining organic molecular composition and AMS for quantifying the organic aerosol composition. This equipment is essential for achieving source apportionment of secondary organic aerosols, analyzing the oxidative potential (OP) of organic aerosols and studying their impact on human health. Advanced monitoring technologies and source apportionment models mentioned above will aid in improving China's source apportionment capabilities and technical levels.

3.1.2. Does the project meet the air pollution managing need of the Chinese pilot cities?

- The online and real-time source apportionment technologies and dynamic updating techniques for pollution source inventories developed in this project can provide guidance for relevant cities in accurately identifying the sources and contribution of air pollution. These results will also enhance the dynamic traceability of urban air pollution, and help to formulate targeted pollution control policies and measures. Specifically, the online and real-time source apportionment technologies can accurately track the changes in pollution sources during "heavy" pollution events, thus providing guidance for implementing peak shaving and emission reduction measures during such events. As a result, these technologies can effectively support the pilot cities in achieving the goal of "basically eliminating heavy pollution days" by Year 2025. However, due to the impact of the COVID-19 Pandemic, real-time source apportionment models developed by PSI have not been available to the pilot cities, and the model HERM developed by IEE has only been briefly introduced. Therefore, managers of pilot cities have not yet fully mastered the relevant technologies or received fine-scale source apportionment results. In response, it is recommended that the project team expedite the release of the working model to respective managers for each pilot city and organize relevant training activities.

- The dynamic updating method for pollution source inventories developed by the project is based on the Year 2017 version of the Multi-Resolution Emission Inventory for China (MEIC) developed by Tsinghua University. Through model-based calculations, the pollution source inventories for the pilot cities were updated to Year 2021. However, it should be noted that the MEIC inventory is designed for large-scale applications across China and the spatial resolution is rather low for small and medium-sized cities. Additionally, significant pollution control measures have been implemented in major Chinese cities, leading to substantial changes in the spatial distribution of pollution sources between Years

2017 and 2021. It should be further considered whether some assumptions made for the model-based calculations in this project apply to these pilot cities. For example, model-based calculations assume that the spatial distribution of pollution sources remains unchanged, but it has changed due to the coal substitution and industry closures. In fact, before Year 2018 (prior to the implementation of the project), the six pilot cities had already established their own air pollution source inventories under the guidance of a national expert team. If the project could be based on the pilot cities' source inventories for updating, it may yield more accurate results. As of now, the project teams have not interfaced with the EEB of the pilot cities about the updated pollution source inventory. Furthermore, a comparison with the inventory of Year 2021 updated by Tsinghua University has not been conducted. Therefore, it is difficult to evaluate its accuracy and practicability.

3.1.3. Are the activities and outputs of the project consistent with the overall goal and the attainment of the project objective, and the intended impacts and effects?

- From the overall design of the project, the four expected outcomes of the main Credit Proposal can meet the general objectives of the project. However, the project team paid more attention on scientific outputs, as the project team independently observed PM2.5 components in the pilot cities, obtaining comprehensive and high-quality monitoring data. Based on this data, they developed online and real-time source apportionment models and created a "top-down" approach for dynamically updating city-level pollution source inventories. Throughout the project, there has been limited communication with the ecological and environmental authorities of the five pilot cities of Beijing, Chongqing, Wuhan, Shijiazhuang and Langfang. It was not until after the first half of 2023 that the relevant cities became aware of the CAC project being conducted within their jurisdictions at the meeting organized by SDC. The project has not achieved its goals of enhancing source apportionment capabilities and levels of the pilot cities. Concurrently, targeted measures for air pollution control have not been proposed for the pilot cities based on the research findings.

- During the on-site monitoring process, the environmental monitoring departments of the six pilot cities were not basically involved in the fieldwork. The monitoring members of the project did not provide practical training on instrument operation for the monitoring staff in each of the respective pilot cities. In some cases, managers from varied pilot cities don't understand the necessary monitoring equipment needed for online and real-time source apportionment. They are not familiar with the more advanced monitoring equipment, such as

EESI-TOF and AMS, required for in-depth apportionment of secondary organic aerosols. As a result, the six pilot cities currently are unable to perform relevant monitoring operation for real-time and online source apportionment.

- The updated air pollution source inventories of Year 2021 were not offered to managers of the pilot cities, and there were no discussions with any of the pilot cities regarding the method of updating the inventories or whether the updated inventories conform to the actual pollution emission characteristics of each city. Due to the structure of the original MEIC inventory, the updated source inventories lack information on dust sources, which does not meet the needs of the pilot cities. In fact, before Year 2018, as the nationwide "battle" to prevent and control pollution deepened, the six pilot cities had already established their own air pollution source inventories under the guidance of national expert teams. For example, Beijing updated its inventory on a quarterly basis. The project team should promptly communicate with the managers from each pilot city about the methods and results of source inventory updates and conduct timely validation and improvements to ensure that the results are better suited for each city's specific needs. After the project concludes, if only the updated inventories of Year 2021 are provided to the project manager of each respective pilot city without communication and validation, it would be challenging for them to effectively adopt the results. Moreover, it will not provide strong support for project pilot cities in effectively addressing air pollution.
- The project team has developed high-resolution models for online and real-time source apportionment, and communicated with the respective pilot cities on part of source apportionment results at seminars. However, as time was limited and the ways of presenting the results differed, these cities have not yet evaluated the accuracy of the apportionment results. Moreover, the project team has not sufficiently demonstrated the advanced and precise nature of their apportionment methods theoretically. Most important are that the two source apportionment models developed in the project, along with their usage methods and operation manuals, have not been made publicly available to the managers of each respective pilot city and necessary training has not been organized. As a result, the actual source apportionment capabilities of the pilot cities have not improved, and they are currently unable to independently conduct source apportionment by using the results of the project.
- Considering that the project will conclude at the end of this year (2023), the project team still has many tasks to undertake and will not able to apply its research findings and advanced methods to the pilot cities in the left short term.

Furthermore, there are no corresponding activities scheduled in the work plan of the project teams. Given the current progress and outcomes of the project, there is still some gap in achieving the overall objective of “proposing more effective control measures, improving the environmental quality of the pilot cities and safeguarding public health through the implementation of project outcomes and advanced technologies from both China and Switzerland” by the end of this year (2023).

3.1.4. Does the project have regional and global relevance in knowledge sharing for other countries?

- From the perspective of technical outcomes, the online monitoring system, as well as the online and real-time source apportionment models and methods, have all reached internationally advanced standard. They can provide guidance for tracing the sources of air pollution and implementing targeted control measures which is particularly valuable for developing countries with severe air pollution and a need for overall improvement in pollution control measures. For example, it is of great importance to countries, such as India, in quantitatively identifying sources of air pollution and establishing efficient air pollution control systems.
- The project also analyzed and researched the oxidative potential of organic aerosols in PM2.5 components, quantifying the toxic and harmful substances to human health. This study lays the foundation for further research on the health impacts of atmospheric environment.
- The project team has already made progress in the sharing of knowledge and technologies. First, a dedicated section for this project has been opened on the IEE website to share research results. Second, the team has published more than 10 high-quality papers in domestic and international journals, which contributes to the dissemination of advanced technologies within the industry. Third, some members have presented the project outcomes at international events such as the International Aerosol Conference, Greece, the 12th Asian Aerosol Conference, and the Global Clean Air Summit in the United States, where they engaged in in-depth discussions with fellow experts.

3.2. Efficiency

3.2.1 Is the project achieving the planned outputs?

Based on the comparison with the Main Credit Proposal to Opening Credit and the Terms of Reference on the Extension of Clean Air China Phase 1, as of the end of

July 2023, the project has not achieved planned outputs. It was found that the unfinished reports are as follows:

- TR2-final report, including Inventory reports and Forecast reports for pilot cities
- TR3 on source apportionment results for all pilot cities (including Methodologies for timely source apportionment developed for each city individually and for pilot cities in a combined model, Model codes should be available)
- TR4 on health component
- TR5 on policy impacts
- Final operational report including financial statements and final TRs

3.2.2 Could the use of the resources allocated to the project be improved?

Was the project adequately resourced to enable the achievement of the desired outcomes?

- Overall, the resources have been adequately allocated to the project and the resource is used reasonably to achieve the project objectives. However, in order to facilitate the application of project outcomes and maximize their impact on air pollution control in the pilot cities, it is necessary to further improve the allocation of the resources.
- On-site air quality monitoring and PM2.5 component online monitoring and analysis are crucial for the project. Due to insufficient core monitoring instruments of AXA, it was not possible to simultaneously conduct on-site monitoring in all six pilot cities. Besides, combined with the COVID-19 Pandemic, the monitoring was delayed and the overall project was extended by 1.5 years, which has to some extent hindered the application of project outcomes. Additionally, monitoring conducted in different cities during different years and seasons also affected data analysis. If pilot cities had the necessary monitoring equipment, it would not only facilitate the project progress as planned but also form the basis for applying project outcomes in the future. It will also enable the pilot cities to better and more quickly adopt advanced online and real-time source apportionment technologies and improve their overall pollution control management.
- The project has obtained a significant amount of monitoring data, which is of great reference value for understanding pollution sources, pollution patterns and the impact on public health in the pilot cities. To maximize the use of the data, IEE and PSI may share the basic monitoring data collected during the project

with the EEB of six pilot cities. In this way, the EEB will have a more comprehensive and deeper understanding of their city's air pollution characteristics, enabling them to make more effective strategies for pollution prevention and control.

- The ultimate goal of this project is to promote the application of collaborative research outcomes of the Chinese and Swiss teams to provide more scientific and effective decision-making support for pollution control in the pilot cities. It aims to enhance their capabilities in source apportionment, source inventory updating, and other management abilities, leading to continuous improvement in urban air quality. Therefore, the transformation and application of project outcomes should be a crucial task. However, during the project design, the allocation of responsibilities, necessary tasks, and expected outcomes were not clearly defined. Moreover, the resources allocated to this aspect was limited.

3.2.3 Is the project working with the best arrangement of partners? How do you assess, critically, the performance and the capacity of the implementation institutions, and the cooperation relations between the Swiss and Chinese teams, as well as the project management in general?

- The Swiss teams from PSI and ETH, along with the IEE under the Chinese Academy of Sciences have deep experience coupled with strong technical abilities in atmospheric environmental chemistry, particulate matter source apportionment, and source inventory establishment. They are recognized as top research institutions in both Switzerland and China, and the high-quality research outcomes of the project further validate their expertise. It should be noted that there were still some challenges about the communication, interaction, and collaboration with the pilot cities. IEE, which is an affiliated institute of the Chinese Academy of Sciences and located in Xi'an in western China, has long been providing technical support for air pollution control in Xi'an. However, prior to the implementation of this project, IEE had made limited interactions with environmental authorities in other pilot cities. Throughout the project implementation, timely communication with the pilot cities was lacking, and the research results were not promptly shared with the local authorities. The communication with most of the pilot cities was solely dependent on SDC, which hindered the guidance for the pilot cities. As a result, the project team would not understand the specific needs and requirements of the pilot cities regarding source apportionment and source inventory, and there was a lack of timely feedback and guidance for the research. For example, IEE has maintained long-term communication with Xi'an City, and the Xi'an EEB highly recognized the project's guidance on source apportionment and promptly formulated a policy to ban straw burning based on the suggestions of the project team. This policy effectively reduced the concentration of PM2.5 in the air. Therefore, a dedicated organization can act as a bridge between the research team and the urban management departments, which can improve the working efficiency of the project.

- The evaluation found that the project team has put in place a monthly regular communication mechanism to facilitate the cooperation. However, there are issues that still remain to be improved. The three institutions focus on their own research programs, failing to share and discuss research outcomes by stages. The Swiss team has not promptly communicated with the Chinese team about the methods, models, and outcomes related to high-resolution real-time source apportionment and health impacts. Both PSI and IEE have obtained the source apportionment results for the six pilot cities. However, the two methods and their respective results have not been compared and analyzed for further improvement. ETH has updated the source inventories for the six pilot cities, and the source inventories can be used for mutual validation and comparison. The project teams have not yet done it, which might lead to inconsistent or even inappropriate pollution control recommendations for the pilot cities.
- According to project management rules, a senior manager should be appointed to coordinate between different teams in a consistent manner. Besides resolving relevant conflicts and issues, the senior manager should ensure that all teams complete their tasks on schedule. The senior manager should also ensure consistency in the research findings and provide relevant policy recommendations. The evaluation found that this project appears to lack a leader within the team. The collaboration between the three research teams is not sufficient, and some work was lagged behind schedule. The project was delayed twice. To some extent , this also inceased the diffichlty of SDC's project management.

3.3. Effectiveness

3.3.1. What are the major results/findings/achievements so far generated directly from the project? Have the outcomes/outputs envisaged been achieved?

To date, the project has completed the following work:

- The project has established advanced online monitoring methods for atmospheric particulate matter, successfully completed on-site monitoring in each of the respective six pilot cities and collected high-quality monitoring data.

- The project has developed advanced online and real-time source apportionment methods and built two source apportionment models: SOFI for real-time source apportionment and HERM for online source apportionment. Using the HERM model, the project successfully conducted PM2.5 source apportionment in all six pilot cities. Besides, the model SOFI was applied to perform source apportionment in some of the pilot cities.
- The project has established a dynamic updating method for pollution source inventories and updated source inventories in some cities. However, the updated source inventories have not been provided to the pilot cities yet. The project is currently conducting a comparative analysis between the updated source inventories and the MEIC inventory from Tsinghua University.
- The project has obtained the oxidative potential (OP) of organic aerosols in PM2.5 in the six pilot cities and is currently conducting health impact studies based on the data.
- The project has been disseminating and promoting its research outcomes through various channels, including the project website, participation in domestic and international conferences, and publication of research papers in professional journals.

Due to the extension until the end of 2023, the project has not, to date, completed all the specified tasks.

3.3.2 To check and confirm the qualitative and quantitative indicators against the defined logframe;

As the project is still ongoing, some reports have not been completed according to the list of project outputs and indicators in the Logical Framework of Credit Proposal of the CAC project (see section 3.2.1). The quality assessment for each outcome is as follows:

- Outcomes 1: (source apportionment): the capacity of Chinese cities to do accurate air pollution source apportionment is improved.

Overall, the project has established online source apportionment monitoring methods, conducted research on online and real-time source apportionment models, as well as developed the relevant software models. However, hands-on training has not been provided to the pilot cities for effectively using these advanced source apportionment methods. As a result, most of the pilot cities have not yet mastered the techniques above, and should still improve the ability to utilize the advanced source apportionment methods.

- ◆ Output 1.1. The project team has completed on-site monitoring in the six pilot cities and obtained high-quality monitoring data. However, the research team has not yet provided detailed instructions on how to do the measurements in details (in English and Chinese), which is vital to the applications in the pilot cities.
- ◆ Output 1.2. Apportionment results for the six pilot cities derived from PSI's real-time source apportionment method have not yet been submitted.
- ◆ Output 1.3. The project has not yet submitted the "model codes for the individual cities and the united model" as required by the completion indicator.

- Outcome 2: The relevant work is in progress. To ensure the production of high-quality source inventories, it is essential to communicate with the pilot cities and Professor Qiang Zhang from Tsinghua University (the developer of MEIC) regarding the updated source inventories. After receiving feedback and making necessary adjustments, the final report should be submitted.
- Outcome 3: Various research issues of the project are still being refined, and conclusive findings on source inventories and source apportionment have not been gained yet. The communication and exchange with the pilot cities, except for Xi'an, were limited (with only one meeting for each city apart from Xi'an), and policy recommendations have not been submitted to the pilot cities. As a result, the project has a limited impact on the pilot cities. It is essential to improve it in the second half of this year. Moreover, the Ministry of Ecology and Environment is a leading authority and policy maker in China's air pollution control. Therefore, it is crucial for the project team to engage in in-depth communication and exchange with the ministry to further expand the project's influence in other regions of China.
- Outcome 4: The project team has effectively promoted the project through various channels, including the project website, publication of more than 10 papers in high-level journals, and participation in various seminars and conferences. The team plans to publish more papers in high-level journals, and IEE will publish a special issue to further showcase the project's outcomes. These efforts will significantly expand the project's influence and outreach both in China and internationally. To further expand the project's impact, it is suggested that the project team should cooperate with other countries facing air quality improvement challenges, such as India, Mongolia and Pakistan under the guidance of SDC after generating all outputs.

3.3.3 Critically assess the quality of the project outputs and activities, and their

relevance to the project outcomes.

From the perspective of project design, the activities and outputs of the project directly support the objectives and planned outcomes. However, as the project is still ongoing, some key reports and conclusions have not yet been provided, making it difficult to accurately evaluate the quality of each output. Based on the existing results, the project has established world-leading online monitoring methods, online and real-time source apportionment models. These achievements can provide reference and guidance for the development of source apportionment techniques in China and hold practical significance for the pilot cities in their future efforts towards air quality improvement.

3.3.4 Identify areas with potential for improvement?

Further improvements should focus on providing the pilot cities with a more in-depth, detailed, and comprehensive presentation of the project's outcomes. It is important to demonstrate the technical advantages and demonstrate how these research outcomes can form the basis for air pollution control strategies and measures tailored to each pilot city. In this way, the pilot cities will recognize the practicality of these technological outcomes and their significant guidance in achieving targeted air pollution control in their urban areas.

3.4. Coherence

3.4.1. In the global context, is the approach used throughout the project supporting other efforts on clean air?

The online particle monitoring method, online and real-time source apportionment methods, and software models developed by the project can be applied in other countries and regions for reference, thus promoting global air pollution control actions. The project has conducted extensive analysis of primary and secondary organic aerosol components in PM2.5, as well as their oxidative potential and impact on human health. These studies can also guide the control of volatile organic compound (VOCs) emissions and prioritize the treatment of atmospheric pollutants with higher oxidative potential. VOCs in the air are precursors to ozone formation. Ozone-related pollution control is a challenging task faced by countries worldwide in air pollution control. Hence, this research is of reference value for air pollution control in relevant areas.

3.4.2. Has the project build on and address synergies and interlinkages with other projects in China, regionally and globally? (incl. implemented by other actors).

The online particle monitoring method, online and real-time source apportionment technique, and software models developed by the project can guide the nationwide battle to prevent and control pollution as well as the ***Action Plan for Continuously Improving Air Quality*** which is being formulated by the MEE. To guide all provinces and cities in further enhancing their PM2.5 source apportionment capabilities, MEE is currently formulating the ***Technical Specifications for PM2.5 Source Apportionment Based on Receptor Models***. Additionally, some research institutions and provincial environmental departments have already initiated the online source apportionment of PM2.5, which is closely related to the technical results of this project. The project has completed online and real-time source apportionment for the six pilot cities in Year 2021. If these achievements are recognized by MEE or the governments of the pilot cities, team members can actively participate in their air pollution control efforts and contribute to the implementation of the national ***Action Plan for Continuously Improving Air Quality***. The Chinese team from IEE has actively participated in the air pollution control efforts in Xi'an city. Project members, Professor Shaofei Kong from China University of Geosciences and Professor Yang Chen from the Chongqing branch of Chinese Academy of Sciences, have maintained close communication with Wuhan and Chongqing EEB. They also serve as technical support experts for their air pollution control. These collaborative efforts have laid a firm foundation for further application of the project's results.

3.5. Impact

3.5.1. Which learnings or changes have occurred as a result of the project?

To date, IEE has successfully established a mature online particle monitoring method and developed the online source apportionment software HERM. Hence, IEE is able to provide training for other Chinese research institutions or municipal ecology and environment bureaus in implementing similar projects, thus promoting the advancement of online source apportionment technologies in China.

3.5.2. To analyze and better understand the Chinese central government and local cities' need in the field of air pollution management and associated clean air policy making. Make assessment of the contribution of CAC project to the pilot cities in terms of local clean air policy formulation and the effectiveness of these policies and actions.

- In accordance with the national overall plan and the ***Opinions of the Central Committee of the Communist Party of China and the State Council on Promoting the Nationwide Battle to Prevent and Control Pollution***, all provinces and cities are actively engaged in the air pollution control efforts. The goal is to achieve a 10% reduction in PM2.5 concentration in cities at the prefecture level and above, and basically eliminate heavy pollution days by Year 2025. MEE will recently issue the ***Action Plan for Continuously Improving Air Quality*****,** proposing new goals, tasks and measures for the improvement of air quality in various provinces and cities. These measures mainly include eliminating heavy pollution days, ozone pollution control and diesel vehicle pollution control, as well as the coordinated control of PM2.5 and ozone pollution.

- The CAC project will provide a mature set of methods for online monitoring of PM2.5 components, as well as real-time and online source apportionment technology. These advanced technologies enable pilot cities to better understand the sources and variations of their air pollution. Through real-time data of apportionment, they will monitor the changes in PM2.5 components and sources during heavy pollution events. It can guide pilot cities in developing more precise emergency response plans to effectively reduce peak pollution concentrations, lower overall pollution levels, and minimize the occurrence of heavy pollution days. By analyzing organic components of PM2.5, pilot cities can identify organic pollutants that contribute to both PM2.5 and ozone formation, determine their source, and enable targeted emission reduction. In this way, the coordinated control of PM2.5 and ozone pollution will be conducted more efficiently and easily.

3.5.3. Has the project had any impact beyond the pilot cities, e.g. influencing regional transboundary air pollution management or influencing Chinese national clean air policies?

As the project is still in progress, some major outputs, such as PSI's real-time source apportionment method, have not been fully showed to the national and provincial environmental authorities. In addition, the air pollution control strategies for the five pilot cities except Xi'an have not been submitted yet. As a result, environmental authorities in regions beyond the pilot cities still know little about the CAC project, and it has a limited impact on the formulation of national and other city-level environmental policies.

3.5.4. To what extent the project may have impacts beyond China?

The technical methods and outcomes of the CAC project focus on more accurate source apportionment to effectively control PM2.5 air pollution, improve air quality, and safeguard public health. Therefore, this project can guide countries and regions with heavy air pollution but relatively weak technical support capacity, such as India, Pakistan and Mongolia. Even for countries and cities where air quality has improved but the concentrations of PM2.5 have not yet reached the WHO guideline of 10μg/m3, the project can still offer guidance.

3.5.5. Critically assess project communication and knowledge management in terms of quality of knowledge products, publications, outreach of project website and social media.

The project has successfully disseminated its findings through various channels, such as the project website, conferences, and publication of professional papers. While it has achieved its overall objectives, there is still potential for further improvement in some aspects.

- The project is promoted on the publicity website of IEE under the Chinese Academy of Sciences. However, this academic-oriented website has a limited outreach to a broader audience. Furthermore, the project's webpage is not prominently featured, which further restricts its promotional impact.
- The project should further increase the communication and exchange with the national and provincial environmental authorities, which will affect the application of the project's outcomes.

3.6. Sustainability

3.6.1. What results have been used or have potential to be up-scaled in other places of China?

The evaluation found that IEE has been offering long-term support for air pollution control in Xi'an. During the project, IEE used the online source apportionment model HERM to conduct the source apportionment of PM2.5 in Xi'an. Based on the results, they proposed pollution control measures, such as further strengthening the control of straw burning. This policy has been implemented in Xi'an. So far, other applications of the project's outcomes have not been identified.

3.6.2. What actions are still needed (gap) to establish very solid and convincing results?

Technically, the CAC project has developed new online and real-time PM2.5 source apportionment methods and apportionment model software, as well as explored the dynamic updating methods for pollution source inventories based on model calculations. Based on these outputs, the project successfully obtained PM2.5 source apportionment results and updated pollution source emission inventories for six pilot cities. With the deepening of air pollution control in China in recent years, technical support capabilities have been improving, and management investments have been increasing. Online source apportionment methods have been developed in cities and provinces such as Beijing, Shanghai and Zhejiang, and guidance have been offered for the management. The Chinese government has issued guidelines on building the source inventories, and the annual or even quarterly updates of source inventories have been realized in some provinces and cities. For sure, in terms of technical methods, the CAC project is distinctive. To enhance the credibility and applicability of the research outcomes, the project team needs to conduct a comparative analysis of the advantages and disadvantages of their methods with existing domestic technologies. They should also analyze and discuss the results with the pilot cities and address any identified issues to further improve the methods. The advantages of the project in terms of stability, practicality, accuracy and cost-effectiveness should be analyzed comprehensively. A peer review of the CAC project is preferred before the project concludes.

3.6.3. To what extent was technical and institutional know-how transfer achieved? Will the Chinese partners in the future still rely on technical expertise from Swiss partners to implement the findings/methods of the project?

- As of now, the technical outputs of the project are only shared and used within the project. Only partial PM2.5 source apportionment results have been shared with environmental managers in Beijing, Xi'an, Chongqing, and Wuhan. It should be noted that the source apportionment results of this project are based on receptor models, which include both external transport sources and local sources for PM2.5 pollution. The source apportionment results obtained by pilot cities are mainly based on the local sources, making it difficult to directly compare the results of the two methods.

- The evaluation found that the Chinese team at IEE has not mastered the real-time source apportionment method developed by the Swiss team at PSI. The Chinese team has not yet obtained the relevant data and methods for further apportionment of secondary organic aerosols. PSI needs to offer technical surpport if the relevant methods are applied to guide domestic cities.

4. Recommendations

4.1 Further Improving Source Apportionment Results

4.1.1 Since Year 2013, MEE has required key cities to conduct source apportionment of PM2.5 to accurately trace the sources of air pollution. Most cities have completed two or more rounds of source apportionment. To guide management departments on formulating targeted pollution control policies, the source apportionment results should clearly indicate the proportions of the emission from local sources and emission from external transmission. For the emission from local sources, they can be classified into coal combustion, motor vehicles, industries, residential activities, and dust, all of which directly contribute to PM2.5 emissions. The source apportionment results provided by this project include both local sources and external transmission sources. The contributions are presented in the form of the proportion of secondary sulfate, secondary nitrate, and secondary organic aerosols (SOA) and so on. However, the emission processes that contribute to these sources are not identified. For instance, in the case of Beijing, the source apportionment results indicate that sulfate remains an important contributor to its PM2.5 levels, but local authorities are unaware of the sources of these sulfate particles. In fact, a significant portion of these sulfates might come from external sources, making it difficult for local authorities to take targeted measures. The results of the source apportionment lack direct guidance for policy formulation and require further processing and transformation. During the evaluation, all pilot cities hope that the source apportionment results could clearly identify the contribution of local direct emissions to PM2.5. In this way, it will prioritize the control of key emission sources. By combining the source apportionment results with air quality models and emission inventories, they can be transformed into the desired outcomes for pilot cities.

4.1.2 The greatest advantage of this project lies in its ability to provide online and real-time source apportionment. Hence, the report should present source apportionment results with higher temporal resolution, reflecting the typical process or period of heavy pollution in each pilot city, and propose recommendations and measures accordingly.

4.2 In-depth Communication with relevant authorities from Pilot Cities

4.2.1 After the completion of TR2 and TR3, it is recommended that the team should engage in in-depth discussions with EEB of the pilot cities and their technical support units involved in the earlier research of source apportionment and source inventories. The outcomes of this project should be also compared with the existing findings. If any significant gap exists, the cause should be identified. Necessary adjustments should be made to address the limitations and issues of this project and make the outcomes of this project more solid and credible. Therefore, the project will embrace a brighter prospect for application.

4.2.2 The online monitoring support system with AXA and more advanced monitoring equipment required for the apportionment of secondary organic aerosols are not widely used in China. These devices serve as the foundation for applying PSI's advanced real-time source apportionment technology. However, due to a lack of training on the usage of the technique among the environmental monitoring personnel in the pilot cities during the project implementation, it is recommended that the project team provide operation manuals in both Chinese and English and organize necessary hands-on training.

4.3 Sharing High-Quality Data

4.3.1 This project has obtained a wealth of high-quality original monitoring data, including online and offline monitoring data of PM2.5 components in the pilot cities, the components of secondary organic aerosols, and toxic and harmful substances content in PM2.5. The data are of significant value for future research and are also the precious asset left by the project. It is important to provide these data for all six pilot cities, enabling them to play a more significant role in urban air pollution control.

4.3.2 Furthermore, all monitoring data from IEE has been shared with PSI and ETH. As of now, PSI's OP and aerosol toxicity component-related monitoring data, as well as the usage guidelines for the model SOFI, have not been offered to IEE, and comparative analysis has not been conducted on the source apportionment results between PSI and IEE. The project team should strengthen internal communication, promote data sharing, and jointly enhance the overall quality of the final report to expand the project's impact.

4.4 Strengthening Project Publicity

4.4.1 At the international level, besides presenting the project's new outcomes and breakthroughs at international academic conferences, it is recommended to organize an international symposium. This symposium should invite ecological and environmental management and technical personnel from countries facing air quality improvement challenges, such as India, Pakistan and Mongolia. The symposium will focus on systematically introducing the technical achievements of this project in the field of source apportionment and its guiding role in the precise control of PM2.5. It will help to address pollution problems in these countries.

4.4.2 At the national level, it is important to present and demonstrate the technical advantages of this project, especially in terms of advanced techniques such as the refined apportionment of secondary organic aerosols, to the atmospheric environment management staff of MEE and the technical personnel from the National Joint Research Center for Tackling Key Problems in Air Pollution Control (NAPC). The NAPC offers decision-making support for the air pollution prevention and control policies issued by MEE. It undertakes the task of guiding air pollution control efforts in key regions of China. Its members include senior experts on air pollution prevention and control in China. They are also part of the expert teams responsible for formulating strategies ("One Policy for One City") for the national Blue Sky Protection Campaign and the nationwide battle to prevent and control pollution. As MEE is formulating the technical guidelines and standards for PM2.5 source apportionment, the project team should actively promote the real-time source apportionment methods used in this project to the standard makers from Nankai University. It will promote the adoption of these advanced techniques on a nationwide scale.

4.4.3 At the provincial and municipal level, economically-developed eastern provinces and cities such as Beijing, Shanghai, Jiangsu, Zhejiang, and Guangzhou have always been leaders in the control of air pollution nationwide. They have devoted abundant resources to the ecological improvement. Besides having a solid foundation for air pollution control technologies, they also boast a number of high-level technical and management teams. Moreover, they are more capable of accepting and adopting new technologies. The project team can engage in exchanges with these provinces and cities regarding the project outcomes.

4.4.4 In terms of public media promotion, the project can create easy-to-understand promotional materials and display them on high-traffic government websites, such as the MEE or the ecology and environment departments of various pilot cities. In this way, the project can increase its influence and reach a broader audience.

4.5 Continuously Promoting the Application

After nearly four years of efforts, the project has yielded world-leading technological outcomes. Due to the impact of the COVID-19 pandemic, technological exchange activities of the project were hindered in the first three years of the project. As a result, the impact of the project has been relatively weak, and some key technologies are not effectively utilized in the pilot cities. The progress in promoting and expanding the project's outcomes failed to live up to the expectation. As the first phase of the project is approaching its conclusion, it is recommended to focus on promoting and utilizing the project's findings in the second phase.

4.5.1 Training and seminars will be conducted nationwide for environmental management and technical personnel from various provinces and cities. Organized by MEE or its affiliated agencies, these training sessions include online monitoring methods for PM2.5 components and equipment needed (developed by the project); real-time source apportionment techniques and models (developed by the project), model usage guidelines; the role of technological outcomes in urban air pollution control. The training will enable these provinces and cities to better understand the technique and gain the basic ability for application.

4.5.2 Two to five cities with strong technical capabilities and interest in applying the PM2.5 real-time source apportionment technology will be selected as pilot cities (or other cities). The PM2.5 real-time source apportionment technology will be integrated into the routine work of the local EEB. The experts from the project team will provide on-site technical guidance and conduct hands-on training to ensure that environmental monitoring and technical personnel master the relevant skills. Besides providing the basic instruments and equipment, the local EEB should select the monitoring sites. For the application of advanced monitoring equipment such as EESI-TOF developed by PSI, relevant personnel can be sent to receive training at PSI. Considering significant spatial variations in air pollution and the difference in the sources of PM2.5 between domestic megacities such as Chongqing, the number of actual monitoring sites in cities may increase in the next stage.

4.6 Leveraging Switzerland's Advanced Technologies - Facilitating the Prevention and Control of Ozone Pollution

Ozone pollution is one of the most severe air pollution problems faced by China. Since the implementation of the ***Air Pollution Prevention and Control Action Plan*** in Year 2013, remarkable progress has been made in controlling major air pollutants such as PM2.5, SO_2, and NO_x in key regions, greatly reducing their concentrations in the air. However, due to the complexity of the ozone formation mechanism, controlling ozone pollution in major cities has proven to be more challenging, and in some cases, ozone pollution even shows a trend of intensification. To address this issue, ***Opinions of the Central Committee of the Communist Party of China and the State Council on Promoting the Nationwide Battle to Prevent and Control Pollution*** was enforced. As clearly proposed in the opinions, during the 14th Five-Year Plan period, the ***Ozone Pollution Prevention and Control Action Plan*** will be implemented and researches will be conducted on the sources and formation mechanisms of ozone pollution. Moreover, the coordinated control for PM2.5 and ozone pollution will be implemented. Human-made emissions of organic compounds and NO_x are not only significant sources of PM2.5 formation but also precursors for ozone formation. PSI is a leading institution in atmospheric chemistry and boasts advanced technologies to understand the generation and transformation of pollutants in the atmosphere. During the first phase of the project, the organic components of particulate matter in the six cities have been researched, resulting in a wealth of data. It lays a solid foundation for further studying ozone-related issues, especially in the coordinated control of PM2.5 and ozone pollution. This is also a crucial pollution challenge currently faced by China. Therefore, there is considerable potential for cooperation between both sides.

4.7 Sino-Swiss Cooperation in the Impact of Air Pollution on Human Health

In this project, PSI conducted a study on the toxic and harmful particles in the PM2.5 components, which gained attention in the pilot cities. The results revealed significant differences in the health impacts of particulate pollution in different regions, even at similar PM2.5 concentration levels. This finding highlights the importance for policymakers to prioritize the control of particles containing toxic and harmful substances and provides a deeper understanding of the harmfulness of PM2.5. In recent years, research on environmental health has also been conducted by institutions such as Peking University in China. All these efforts have laid the groundwork for further cooperation between China and Switzerland.

Annex A

List of Abbreviations and Term Definition

SDC Swiss Agency for Development and Cooperation

PSI Paul Scherrer Institute

IEE Institute of Earth Environment, Chinese Academy of Science

ETHZ Federal Institute of Technology in Zurich

CRAES Chinese Research Academy of Environmental Science

MEE Chinese Ministry of Ecology and Environment

EEB Ecology and Environment Bureau

WHO World Health Organization

PM2.5 Mass of All Particles with Aerodynamic Diameters≤2.5 micrometers

ACMS Aerosol Chemical Speciation Monitor Instrument

Xacts Element Monitor Instrument

SoFi professional version of Source Finder, developed by PSI

HERM Hybrid Environmental Receptor Model, Developed by IEE

On line source apportionment method developed by CAC project refers to the method used by IEE.

Real time source apportionment method developed by CAC project refers to the method used buy PSI.

Annex B

Documents Reviewed

1. Main Credit Proposal to CAC Project
2. Terms of Reference On The Extension of Clean Air China Project, Phase 1
3. Project Document : Breaking down the Dome, July 2019
4. Operational Report for Year 3
5. Technical Report 2
6. On line Source Apportionment and Evolution Characteristics of Chemical Components of Atmospheric Particulate Satter for Six Pilot Cities（by IEE）

Annex C

List of People Visited and Interviewed

name	Institution/role	Title
Nadia Benani	SDC	Counselor, Swiss Embassy
Liyan Wang	SDC	Senior Advisor
Andre Prevot	PSI, Coordinator of Swiss Activities in the Project	Prof.
Lu Qi	PSI, Special Campaigns using EESI, source apportionment	Postdoc
Xiaole Zhang	ETH, Development of modeling framework and Data Assimilation methods	Dr.
Junji Cao	IEE, Design and Implement the Project works in China	Prof.
Yong Zhang	IEE, Source Apportionment	Dr.
Shaofei Kong	China University of Geosciences, monitoring Campaigns, Wuhan	Prof.
Yang Chen	CAS, monitoring Campaigns, Chongqing	Dr.
Jinkai Xie	Beijing EEB , Atmospheric Environmental Management Division	Deputy Director
Yanyan Yang	Beijing EEB, Monitoring Center	Senior Engineer
Xue Li	Beijing EEB, Science and Technology Division	Deputy Director
Chao Chen	Xian EEB, Atmospheric Environmental Management Division	Director
Defeng Pu	Chongqing EEB, Environmental Management Division	Director

Wei Liu	Environmental Protection Academy, Hubei Province	Prof.
Shengwen Liang	Environmental Monitoring Center. Hubei Province	Director
Jian Quan	Shijiazhuang EEB, Atmospheric Environmental Management Division	Director
Xuguang Wang	Langfang EEB, Atmospheric Environmental Management Division	Director
Min Hu	Peking University	Prof.
Fahe Chai	CRAERES	Prof.

Annex D

The general comments and suggestions by Min HU

The Sino-Swiss Cooperation on Air Pollution Source Apportionment for Better Air ("Clean Air China") was conducted for 4 years from August 2019 to July 2023. The project's objectives are to support Chinese policy in its fight for better air quality and public health. There are three complementary major sections：

- To create a solid database for developing and implementing the best current source apportionment techniques on datasets collected from key Chinese pilot cities.
- To create appropriate models for predicting air pollution events based on emission inventories and ambient data.
- To research health effects and disseminate the findings, as well as to assist the government and local governments with the implementation, testing and application of the new tools.

The project team has made significant progress in the four areas of source apportionment, emission inventory, policy influence, and regional & global outreach. Accurate air pollutant source apportionment is improved in up to six pilot cities, and then health impact is estimated. The top-down emission inventory is dynamically updated and applied to improve air quality prediction. More effective science-based control policies for air pollution will be designed and implemented. Some project results and experience have been disseminated by paper publications, workshop and etc.

The following comments are made based on the third year (August 2021 to July 2022) report.

It is suggested to clarify the highlight results or capacities of the three major sections or tasks, and strengthen the linkage among source apportionment techniques, forecasting models and estimation of health effects.
It needs to provide more detail information on the solid database for developing and implementing the best current source apportionment techniques based on the measurements of up to six pilot cities.

Based on the measurement data in the pilot cities, various receptor models were tested to conduct source apportionment, and numerical source modeling to estimate the source locations, strengths, and contributions to air quality. For the policy makers it is better to identify regional transport vs local contribution, primary emission vs secondary formation, and then anthropogenic source vs biogenic processing. It is suggested to integrate the receptor models of source apportionment, air quality models and emission inventory to accurately distinguish local and regional contributions, quantify the contribution of anthropogenic sources and natural sources, and give operational policy suggestions.

It is helpful to improve the time and spatial accuracy of source analysis. Thus, a source analysis method based on the pollution episode is needed to establish, which is centered on air quality management.

As the summary said: the various techniques produced solutions with four to eight factors that generally agreed well across approaches, but differences in the details necessitate further investigation. How to integrate the emission inventory and factors from receptor models will need to be further discussed.

The project obtains online and offline data in both intensive and long-term measurements in 4-6 cities from north to south. It is suggested to make intercomparisons among the cities. As to example real-time source apportionment comparison between Chongqing and Xi'an in the summary, five sources were identified, it is good to make comparison between two cities and give a reasonable explanation.

It is also suggested to classify the pollution types combined with air mass and meteorological conditions, highlight the advantages of high-time resolution online measurements, give the source analysis results and control countermeasures of different pollution types, and establish relevant case database of air pollution episodes.

The reactive oxygen species (ROS) was measured and aerosol toxicity linked to the apportioned PM sources. The source apportionment related with health effects will be the next further study.

Decomposing the secondary components into the primary source is the challenge and key to the continuous improvement of air quality. This project can make some discussions and provide future research outlook.

For the Pie figures of aerosol chemical compositions in $PM_{2.5}$, it is better to indicate mass concentration of $PM_{2.5}$.