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Social and Economic Impact Assessment of Air Quality Monitoring Projects under the RCA*

RCA

*REGIONAL COOPERATIVE AGREEMENT TECHNICAL COOPERATION PROGRAMME IN ASIA AND THE PACIFIC

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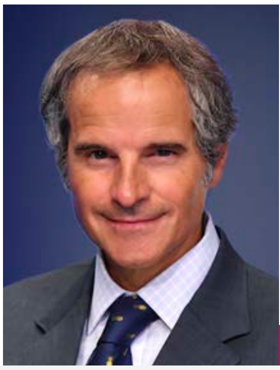

FOREWORD

RAFAEL MARIANO GROSSI

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Making a positive impact through nuclear science and technology

The partnerships between the IAEA and its Member States play an important role in driving social and economic progress. The Asia-Pacific region has a rich diversity and abundant social, economic, technological and intellectual capital to draw from to accelerate sustainable development and drive long term progress. For more than five decades, the IAEA has collaborated closely with and supported RCA State Parties through this regional cooperation platform to promote the peaceful application of nuclear science and technology in addressing critical societal needs. Nuclear applications have contributed significantly to advancements in healthcare, food security, agriculture, water and environmental management, industrial development and safety and security. These contributions have strengthened national and regional capacities, improved livelihoods and stimulated economic growth across the region.

This series of reports evaluates the social and economic impact of RCA projects in application of nuclear techniques in air quality monitoring, food safety, nuclear medicine and isotope hydrology, highlighting the tangible benefits and lasting outcomes of nuclear technology in these key development areas.

The IAEA is increasing its impact through the IAEA's flagship initiatives I have launched over the past five years. These include: Rays of Hope, which is helping close the gap in cancer care; Atoms4Food, which is boosting food security and safety, and agricultural progress together with the Food and Agriculture Organization of the United Nations (FAO); NUTEC Plastics, which is helping to reduce microplastic pollution in the ocean and improve plastic recycling; Zoonotic Disease Integrated Action (ZODIAC), which is increasing countries' ability to spot and stop the next zoonotic disease outbreak; and Atoms4NetZero, which supports energy transitions, including through the use of nuclear energy. The continued commitment of RCA Member States to these strategic initiatives is important to ensuring long term sustainability and ongoing beneficial impact to lives and livelihoods across the region.

Rafael Mariano Grossi
Director General, International Atomic Energy Agency

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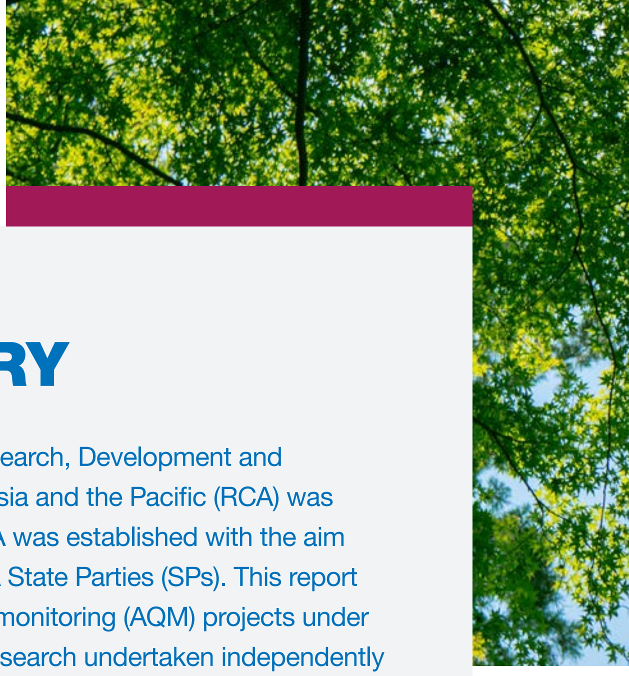


EXECUTIVE SUMMARY

The treaty-level Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA) was established in 1972 under the auspices of IAEA. The RCA was established with the aim of strengthening and promoting cooperation among RCA State Parties (SPs). This report assesses the social and economic impacts of air quality monitoring (AQM) projects under the RCA, focusing on value added beyond the primary research undertaken independently by individual countries.

Air pollution caused by ambient (outdoor) airborne particulate matter (APM) is a severe problem in the Asia and Pacific region. These particles can be inhaled deep into the lungs, posing serious health risks such as respiratory and cardiovascular problems. It has been estimated that globally 2.1 million people die prematurely each year due to fine air pollution [1]. Air pollution does not respect national borders, rather it is a transboundary problem that requires transboundary solutions. Identifying the sources and contributions of APM enables environmental protection authorities (EPAs) to make informed decisions about reducing and/or banning polluting activities. RCA SPs received training and support to set up infrastructure that enabled them to sample air quality, undertake data processing, interpretation and modelling, and set up national and regional databases. These systems are used when reporting to the EPAs of SPs to encourage necessary management measures to protect people's health and the environment better.

This impact assessment was designed and undertaken by a team of external experts in consultation with the IAEA and RCA SPs[1]. It involved gathering evidence through an online survey that was completed by 19 of the 22 participating SPs, analyzing IAEA administrative data, gathering information from air quality experts at the IAEA and SPs, analyzing narrative success case examples of AQM programmes from four SPs and examining the economic analysis of costs and benefits of AQM activities under the RCA.

The impact assessment found that the RCA supported SPs to:

- Develop nationally trained personnel who can carry out consistent air quality sampling, analysis and apportionment in every country where training has occurred. Between 2000 and 2023, **135** people were trained in sampling, **124** were trained in analysis and **112** were trained in source apportionment.
- Increase national research capacity by supporting **98** researchers to become experts at the national and international level in AQM.
- Generate more than **460** research outputs and publications for AQM and regular contributions to national databases by **14** countries, many for over ten years. **Twelve** of

[1] The project was commissioned by the IAEA Technical Cooperation Division for Asia-Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC). Invited experts from the RCA programme provided advice and support. Please refer to the Contributors to Drafting and Review for contributors.

these countries consider that the RCA programme contributed to 'some' or to a 'significant' extent to their capacity to provide monitoring data.

- Strengthen information exchange in the region on transboundary AQM and assessment with more than **150** national personnel participating in **52** international conferences or workshops on transboundary air quality between 2000 and 2023. Furthermore, **68** international projects in AQM were implemented because of participation in the RCA.
- Enhance/establish technical infrastructure and facilities for air quality sampling and analysis (**17** countries) and source apportionment (**14** countries), as well as infrastructure for contributing to regional databases (**13** countries). However, the funding commitments to the sustainability of AQM varied substantially (there are no funding commitments at the moment for six countries).
- Influence national and international health and environmental regulation, policy decisions and intervention, enforcement and behaviour change. Participation in the RCA has enabled at least one contribution across these dimensions in **12** countries, with **8** countries highlighting contributions across two or more dimensions.
- Realize economic benefits by using AQM to support improvements in air quality in some countries, which helped reduce the health-related costs of air pollution.[2]
- Realize small shifts towards improved protection of human health and the environment in some countries.

Pre-defined performance criteria were agreed upon with IAEA and SP experts to provide an evaluative framework for the impact assessment (Tables VII–1 – VII–7, Annex VII). Based on the evidence provided by the IAEA and SPs, the RCA's impacts meet standards for **excellent performance** across two impact domains (nationally trained personnel and economic benefits). Further, it achieved **good performance** across four impact domains (improved research and development capacity; strengthened information exchange; influence on national and international regulation, policy, interventions, enforcement and behaviour change; and improved protection of human health and environment). Finally, the RCA AQM programme achieved **adequate performance** across one impact domain (enhanced/established capacity for air quality monitoring and assessment).

[2] These results for the period 2000–2020 should not be used to make decisions about the future of the RCA or to decide whether the scale of the RCA should be increased or decreased.

1. Introduction

The IAEA is the central intergovernmental forum for scientific and technical cooperation in the nuclear field. Established in 1957 and headquartered in Vienna, Austria, the IAEA works for the safe, secure and peaceful uses of nuclear science and technology, contributing to international peace and security and the United Nations Sustainable Development Goals. The IAEA works in close partnership with Member States, agencies of the United Nations, research organizations and civil society to maximize the contribution of nuclear science and technology to achieving development priorities (Atoms for Peace and Development).

The Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology Technology for Asia and the Pacific (RCA), under the auspices of the IAEA, was established in 1972 and has enjoyed the benefit of the IAEA Technical Cooperation (TC) programme since.

With the RCA celebrating its 50th anniversary in 2022, it is timely to assess the social and economic impacts of the RCA supported under the IAEA TC programme.

At the 48th RCA General Conference Meeting in Vienna, Austria, on 13 September 2019, the RCA endorsed the initiative to conduct social and economic impact assessments. To this end, the TC Division for Asia-Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC) jointly proposed undertaking case studies. In 2022, three social and economic impact assessments were finalized in the fields of human health (radiotherapy), agriculture (mutation breeding) and industry (non-destructive testing). This fourth report presents the social and economic impact assessment findings of air quality monitoring (AQM) collaborations under the RCA. Future case studies are planned for food safety, nuclear medicine and hydrology.

1.1. Air quality monitoring

Air pollution caused by ambient (outdoor) airborne particulate matter (APM) is a severe problem in Asia and the Pacific region. APM is a mixture of solid particles and liquid droplets formed in the atmosphere because of complex reactions of pollutants emitted from natural and anthropogenic (human-made) sources, such as emissions from power plants, industries and motor vehicles. The number of people in Asia exposed to high air particulate matter pollution levels is very high. It has been estimated that globally, 2.1 million people die prematurely each year due to fine particle air pollution [1]. These fine particles can be inhaled deep into the lungs, posing serious health risks such as respiratory and cardiovascular problems.

In addition, air pollution is a transboundary problem because pollutants diffuse, disperse and transfer by air (wind) from one country into another. Thus, air pollutants created by one country can impact people's health and the environment in another country. Identifying the sources and contributions is essential because only with this knowledge can environmental protection authorities (EPAs) make informed decisions about reducing and/or banning polluting activities and countries come together to find regional solutions.

Nuclear analytical techniques: neutron activation analysis (NAA), X ray fluorescence (XRF) and proton induced X ray emission (PIXE) are proven as very effective tools for the analysis and identification of fine air particulate matter (PM2.5 and PM10). Participation in the RCA enabled regional and national training courses, workshops, meetings, and expert missions occurred, which built capacity for using these nuclear techniques alongside experiences and skills for sampling, data processing and interpretation, modelling and national and regional database establishment. In parallel, necessary technical infrastructure was established by providing tools and facilities for sampling, sample preparation, and analysis and technical support systems.

With the trained personnel and the established technical infrastructure, participating countries collected environmental samples. They analyzed the samples, then processed and interpreted received results, developed models, established national and regional databases and shared information about air pollution in their countries. Pollution sources, as well as their transport and distribution, were identified scientifically and systematically. This information, along with relevant warnings and recommendations, was reported to EPAs to take necessary management measures to better protect people's and the environment's health.

1.2. Social and economic impact assessment methods

The social and economic impact assessment methodology was developed specifically for conducting impact assessments for case studies of TC projects under the RCA. The methodology follows the ‘value for investment’ approach and the Kinnect Group approach to evaluation rubrics, combining evidence from quantitative, qualitative and economic analysis, through the lens of an agreed performance framework, to evaluate the impact of AQM programmes under the RCA [2–6].

Social and economic impacts of the AQM programmes are diverse and include contributing to a chain of impacts (see theory of change, Annex VII) that incorporates:

- Established/developed technical infrastructure;
- Nationally trained personnel in sampling, analysis and source apportionment;
- Improved national research and development (R&D) and strengthened information exchange;
- Enhanced and established national and regional capacity for air quality sampling, analysis and apportionment;
- Monitoring, research, publications and the exchange of information influencing national and international regulation, policy and enforcement, resulting in behaviour change;
- Improved protection of human health and the environment as well as economic benefits.

The AQM case study used a mix of methods to assess these different types of impacts, which included:

- An online survey that was deployed to all countries in the RCA and was completed by 19 of the 22 SPs;
- An analysis of administrative data on AQM activities and costs, which was provided by IAEA;
- Additional information from AQM experts at the IAEA and SPs;
- Narrative case examples, written from details provided by four countries on a selection of successful AQM programmes;
- Economic analysis of costs and benefits of AQM programmes under the RCA.

Evaluation rubrics were developed to combine quantitative, qualitative and economic analyses. These rubrics, comprising a matrix of agreed criteria (aspects of performance) and standards (levels of performance), provided a transparent and robust framework for rating the social and economic impact of the AQM programmes under the RCA from the mix of evidence. Refer to Annex VII for full details of the methodology.

2. Social and economic impacts

The RCA has successfully supported participating SPs in the Asia and Pacific region to undertake considerable work to increase AQM capacity[3] and capability[4]. This impact assessment focuses on the last two decades (since 2000). It focuses on the value added by the RCA, beyond the growth that could have occurred within the individual countries if the RCA did not exist.

The key impacts of the RCA include its contribution to increased training about and infrastructure support for AQM, resulting in greater capacity and capability to use this data to influence EPAs to develop new systems and practices that encourage behaviour change to benefit people's health and the environment.

Out of the 22 countries that are part of the RCA, 19 replied to the survey. The following analysis therefore presents the outcomes from the 19 countries that participated in the survey. However, it is essential to acknowledge that four of these countries —Cambodia, Fiji, Nepal and Palau— while being signatories to the RCA, have not been extensively engaged in the activities of the RCA AQM programme. Furthermore, three of them are considered newcomers to the RCA. Consequently, the programme's impact on these countries' accomplishments across all evaluation metrics could be limited. It is therefore recommended that the findings in this report be interpreted with this in mind.

[3] Capacity refers to someone's ability to do a particular thing or fulfil their responsibilities within a given timeframe.
[4] Capability refers to the ability to perform certain tasks or activities. It encompasses having the essential tools, processes and skilled personnel to carry out various functions effectively.

2.1. Nationally trained personnel able to carry out consistent air quality sampling, analysis and source apportionment

Participation in the RCA programme resulted in SPs providing training to in-country personnel to carry out consistent, high quality and synchronized AQM in three areas: sampling, analyzing and source apportionment. Training occurred through various national and regional programmes and focused on multiple aspects of air quality management, including data validation, receptor modelling, and source and advanced analytical techniques.

Sixteen training programmes were used to train in-country personnel between 2000 and 2023. **Fifteen** of the 19 signatories to the RCA reported that their participation in the RCA AQM programme had enabled them to effectively train in-country personnel to carry out consistent air quality sampling, analysis and source apportionment. The four remaining countries indicated that they had not trained in-country personnel. However, three of these countries are considered newcomers to the RCA. Only one country did not receive any training support as part of its membership in the RCA AQM programme.

Between 2000 and 2023, **135** people were trained in sampling, **124** people in analysis, and **112** people in source apportionment across fifteen countries[5]. China, the Philippines and Australia had the highest number of trained personnel.

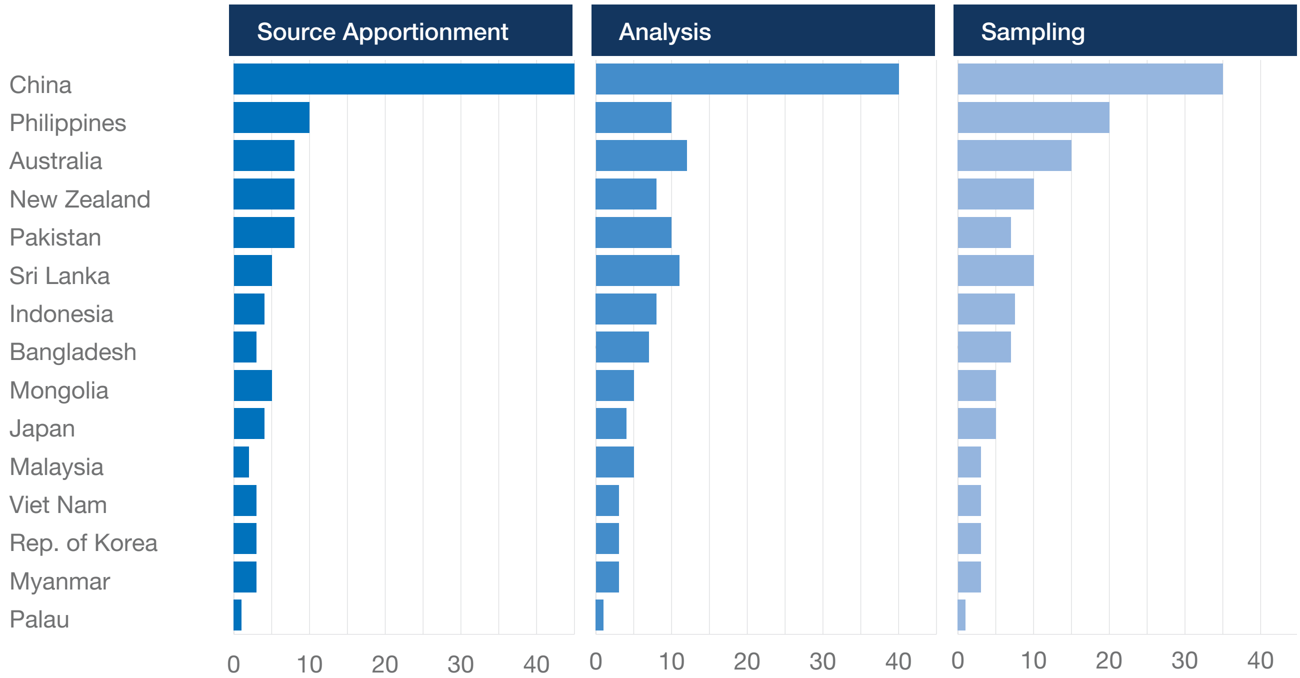
In Australia, for example, the RCA AQM programme contributed to the development of the country's expertise in AQM. Team members of the Australian Nuclear Science and Technology Organization (ANSTO) and other end users of AQM expertise (e.g. local industry and EPA members) participated in specialized training workshops and other learning opportunities. One of the source apportionment techniques they were introduced to in the workshops was positive matrix factorization (PMF), which was adopted throughout Australia within the year, positioning the country as a global leader in the application of PMF source apportionment methods for PM2.5 air pollution studies.

[5] People can be trained in more than one technique.

As Fig. 1 shows, China has the highest number of trained personnel, with more than 40 national professionals acquiring the specialized knowledge and skills essential for effective air quality management. This training, along with the provision of equipment and facilities, has led to more comprehensive and accurate monitoring of air quality, which helps with detecting and addressing pollutions issues in a timely manner. For example, in 2013, China launched the Air Pollution Prevention and Control Action Plan, which intensified efforts to mitigate air pollution on a national scale through a series of measures such as industry emission controls, energy structure adjustment and vehicle exhaust treatment.

FIG. 1. Nationally trained personnel.

Number of nationally trained personnel between 2000–2023



The number of trained personnel demonstrates the investment in capacity building through the RCA AQM programme. It shows a balanced focus on training personnel across all three areas: sampling, analyzing and source apportionment. This suggests a comprehensive approach to developing regional air quality management expertise.

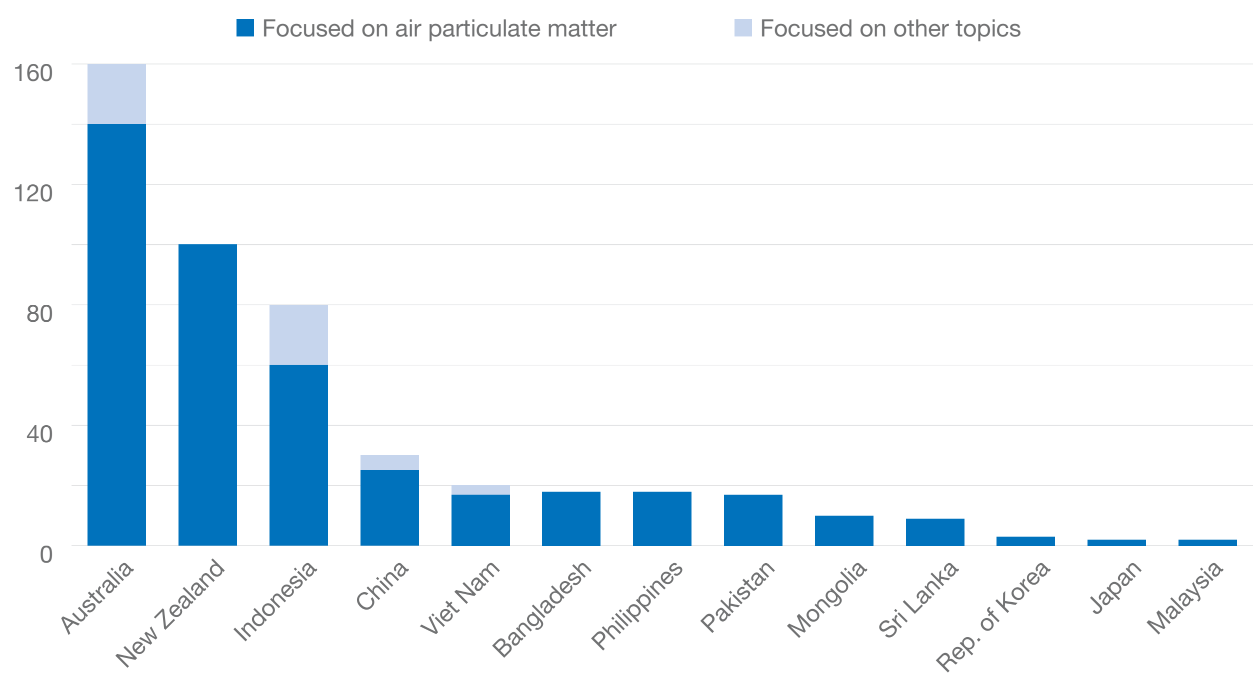
2.2. Improved national research and development capacity for air pollution monitoring

Overall, participation in the RCA AQM programme has resulted in improved national R&D capacity for air pollution monitoring for most SPs in three ways:

- Between 2000 and 2023, **464** publications (Fig. 2), mainly focused on air particulate matter, were developed across **13** countries through involvement in the RCA AQM programme.
- The programme has significantly contributed to developing approximately **98** regional research leaders.
- The RCA AQM programme has substantially enhanced the capacity of **14** countries across the region to maintain longer term, consistent AQM efforts.

Feedback from SPs highlighted the programme's significant contribution to enhancing research capabilities and outputs within the region, fostering expertise and advancing leadership in AQM. By cultivating a network of influential researchers, the programme enhanced the capacity for impactful research, drove innovation and strengthened regional and global collaboration in addressing air quality challenges. Furthermore, the RCA AQM has also been pivotal in developing and sustaining monitoring capabilities.

FIG. 2. Number of publications resulted from being part of the RCA AQM programme.



For example, in Indonesia, participation in the RCA AQM programme was fundamental to developing and disseminating research in the field of AQM by providing opportunities for collaborative research that would otherwise not have been available. The collaborative research environment accelerated research progress and enhanced the visibility of the research outcomes on AQM, leading to many publications (more than 80) and broad dissemination of knowledge.

While the degree of impact varied depending on national contexts and the level of engagement with the programme, feedback from SPs reflects a strong recognition of the RCA AQM programme's value and contribution to R&D capacity and its effectiveness.

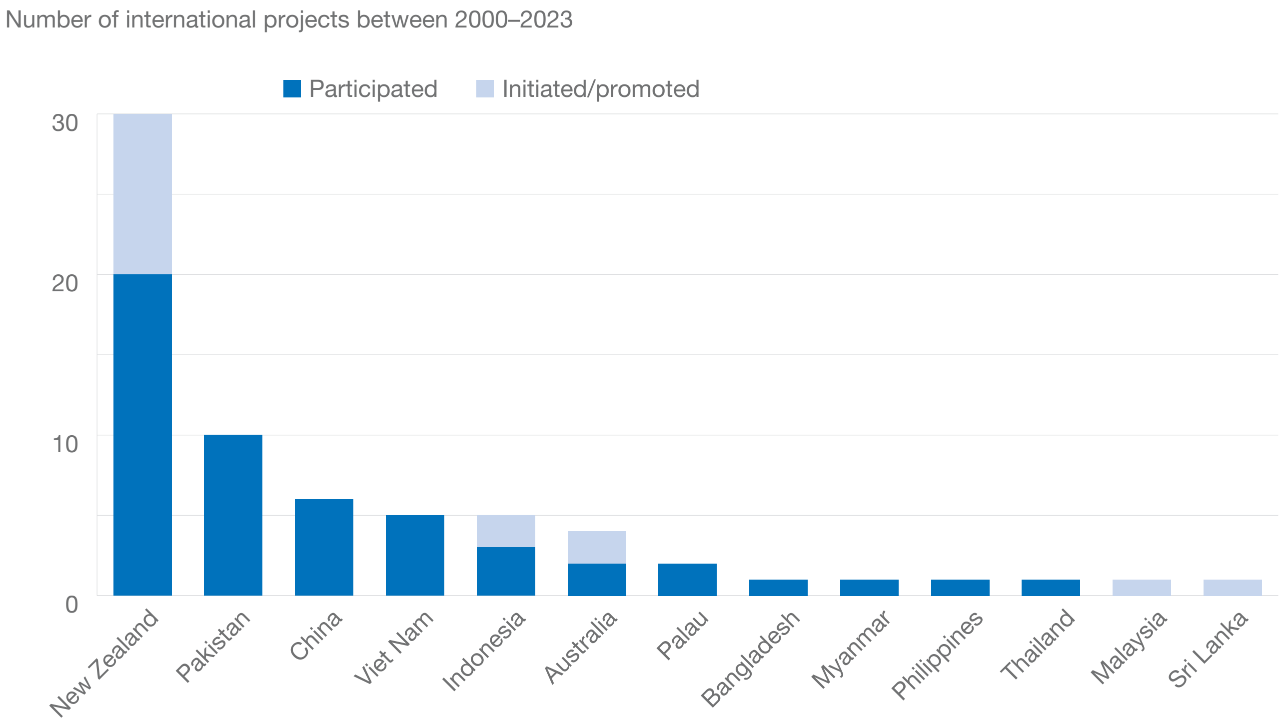
2.3. Strengthened information exchange in the region on transboundary air pollution monitoring and assessment

Participation in the RCA AQM programme strengthened information exchange in the region on transboundary air pollution monitoring and assessment. Between 2000 and 2023, information exchange occurred through:

- National personnel, **154**, from 13 countries collectively participated in **235** international conferences and workshops on transboundary air pollution monitoring and assessment, with RCA SPs organizing **52** of these events (Fig. 3).
- Engagement of 13 countries in **68** international projects. Five of these countries have also initiated or promoted international projects.
- Activities initiated by **16** countries aimed at increasing awareness among end users due to their participation in the RCA AQM programme. Three of these countries reported a significant increase in awareness.

These events facilitated sharing knowledge, coordinating strategies and fostering international collaboration to enhance cooperative efforts to address air quality challenges. For Indonesia, the structured framework for collaboration among participating countries enabled access to specialized facilities and equipment, as well as opportunities for sharing research and receiving feedback from international peers. These contributed to research and collaborative networks and allowed SPs to work together on the development of a regional database.

FIG. 3. International air pollution monitoring and assessment projects.



In addition, sharing information with end users about the significance of AQM and its impact on health, the environment and quality of life supports increased awareness of AQM and assessment and its importance and signifies high social impact.

2.4. Enhanced/established national and regional capacity for air pollution monitoring and assessment

Participation in the RCA AQM programme enhanced and/or established technical infrastructure and facilities for air pollution monitoring and assessment in participating countries. Areas of enhancement included:

- Technical infrastructure and facilities for air quality sampling and analysis;
- Contribution to the development of regional databases;
- Funding commitments by national EPAs for national air quality assessments.

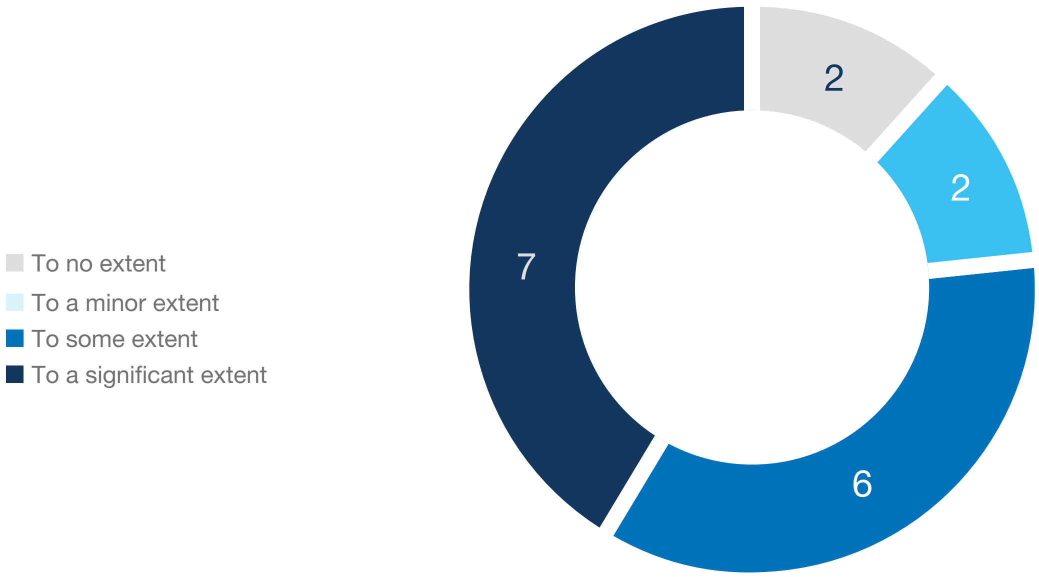
Nearly all (**17** out of **19**) participating countries possess the necessary technical infrastructure and facilities for air quality sampling and analysis. In addition, **14** of these also have the technical infrastructure and facilities for source apportionment.

For example, in Viet Nam, the equipment and technical support provided through the RCA AQM programme and targeted capacity building and data sharing opportunities have enabled the contribution of high-quality AQM data to national and regional databases. These databases have enhanced evidence-based decision-making and policy development for air quality management.

Nine RCA SPs have been actively contributing to regional air quality databases for over a decade. **Seven** of these report that the RCA AQM programme has significantly contributed to their ability to do this (Fig. 4).

FIG. 4. Perception of SPs on the extent of RCA contribution to technical infrastructure.

Perception of the SPs on the extent of the contribution between 2000–2023



Feedback from SPs indicated that funding commitments from the EPAs varied. Overall, just under half (**nine**) of the SPs had funding commitments that allowed them to sustain air quality assessment (**six** SPs) or lead and support others in national AQM (**three** SPs). However, **four** SPs believed their funding was only sufficient for some aspects of national AQM and there were no funding commitments in place for **six** SPs.

2.5. Influence on national and international health and environmental regulations, policy decisions and interventions, enforcement and behaviour change

State Parties reported that participation in the RCA AQM programme has had some influence on policy and behaviour change in the following areas (Fig. 5):

- New regulations or changes to existing regulations relating to air quality;
- Government policy decisions and interventions relating to air quality;
- Levels of enforcement of air quality standards or regulations;
- New air pollution programmes or changes to existing air pollution programs;
- Behaviour change relating to air quality.

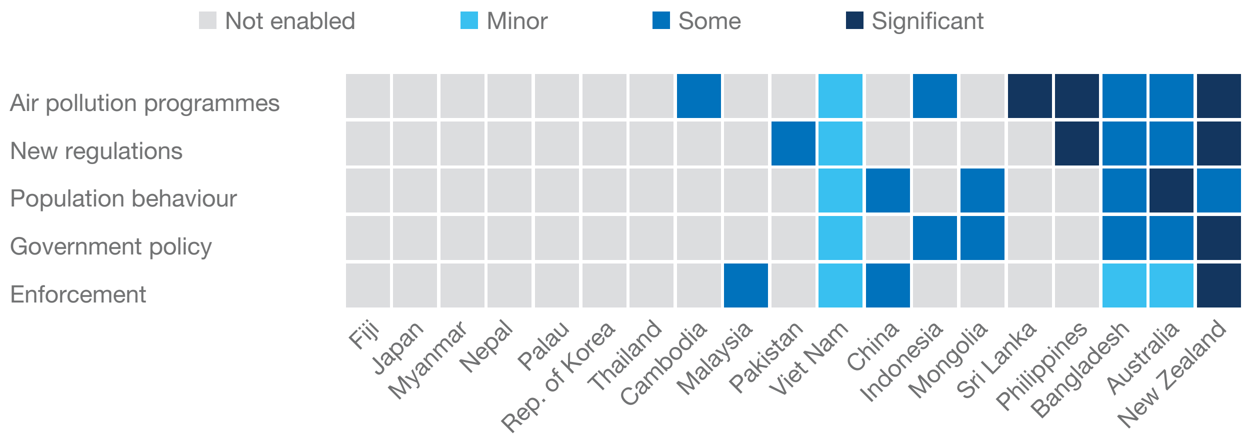
Overall, RCA AQM has made at least one contribution across these dimensions in **12** countries, indicating a broad influence on policy and behaviour. Furthermore, **four** of those countries noted that the RCA AQM had contributed to the change by a significant degree, and **six** countries mentioned that the programme contributed to some extent.

A key example for how the RCA AQM programme influenced the enactment of new regulations on air quality is New Zealand. Through particulate matter analysis and source apportionment, it was found that sulphur levels in automotive fuels significantly impact urban air quality, particularly in fine particle emissions. As a response, the country introduced new national regulations between 2007 and 2010 that were designed to reduce the allowable sulphur concentrations in fuels—from 500 ppm to 10 ppm for petrol and 3000 ppm to 10 ppm for diesel. Subsequent monitoring revealed a substantial decline in secondary sulphate aerosols linked to automotive emissions.

Another key example of the influence of the RCA AQM programme on policymaking deals with Bandung, Indonesia's third largest city. Based on the results obtained from using nuclear techniques to monitor the levels of PM10 and PM2.5, the city changed its bylaws regulating the burning of agricultural and household waste, as well as it introduced a series of education programmes to citizens about the harmful effects of burning their waste.

FIG. 5. Extent to which the RCA AQM has contributed to influence policy and behaviour.

Extent to which the RCA AQM has contributed between 2000–2023



Viet Nam has also been active across all policy and behaviour change dimensions, demonstrating the influence of AQM. The country has implemented government and industry regulations and programmes targeting major pollution sources. Outreach and educational campaigns have heightened public awareness about the consequences of air pollution, which has resulted in community led AQM efforts and empowered users to check air quality themselves through online, publicly-available air quality information.

Similarly, with support from the RCA AQM, the Nuclear Research Centre at the National University of Mongolia established an AQM lab, collecting and analyzing data for Ulaanbaatar's air quality administration. The results offer detailed insights into pollutants and their sources, which the centre shares with the public and other stakeholders. This outreach raises awareness of nuclear techniques in air pollution analysis and helps the public understand key pollutants.

2.6. Economic impacts[6]

A social cost-benefit analysis was conducted to estimate the economic impacts of the RCA AQM activities being evaluated. The analysis estimated the incremental (additional) costs of the RCA activities and compared these to the incremental benefits enabled by those activities. Compared to a hypothetical situation with no RCA, the estimates are of the benefits and costs associated with technical cooperation in AQM achieved under the RCA. Benefits that could be quantified were the social value of improvements in human health outcomes enabled by better AQM (see below for details).

[6] Due to using a similar framework to prior evaluations of RCA activities, this section includes similar text to prior publications including the Social and Economic Impact Assessment of the RCA Programme Non-destructive Testing Case Study [7].

The analysis used data from the expert survey, administrative and cost data provided by the IAEA, public data, and information from other sources. It estimated the costs and benefits that occurred between 1999 and 2021. Costs and benefits were analyzed as annual time series and adjusted for timing, using discounting to convert values occurring at different points in time into present values (based in 1999).

Benefits reflect the costs of air pollution avoided due to actions such as changes to air quality policy, regulations, standards and enforcement in RCA SPs enabled by the RCA AQM activities. Potential benefits include avoiding human health, environmental and other socio-economic costs associated with air pollution. In practice, only the benefits related to human health could be reliably estimated, so the benefits enabled by RCA activities have probably been underestimated in our analysis.

Costs represent the opportunity costs arising from committing resources of the IAEA and RCA SPs to RCA related activities. They include costs directly associated with RCA activities and non-monetary contributions of SPs to support RCA activities. Abatement costs associated with actions to improve air quality, such as investment in new clean technologies, were also considered in the analysis.

Due to the indirect relationship between AQM and changes in actual air quality that generate benefits, it is not possible to estimate a precise monetary value of the benefits associated with the RCA activities being evaluated. Instead, many scenarios, reflecting a range of assumptions about the impacts of the RCA activities, were analyzed to test how likely it was that these activities enabled benefits that exceeded their costs.

Results of the analysis indicate that the RCA delivered positive economic outcomes, with estimated benefits enabled by the AQM activities exceeding estimated costs in almost all (97%) scenarios that were tested, including under very conservative assumptions about impacts. Overall, there is strong evidence that the RCA activities contributed to changes in air quality policies, standards and enforcement, and these changes are likely to have improved air quality and reduced the associated costs of premature human mortality and morbidity, relative to estimated outcomes in the absence of the RCA.

This analysis of costs and benefits is retrospective and is based on actual outcomes under the RCA between 1999 and 2021 versus what was estimated to have happened in the absence of the RCA in that period. These results should not be used to make decisions about future activities under the RCA or to decide whether their scale needs to be increased or decreased. Full details of the economic analysis are provided in Annex VI.

2.7. Improved protection of human health and environment

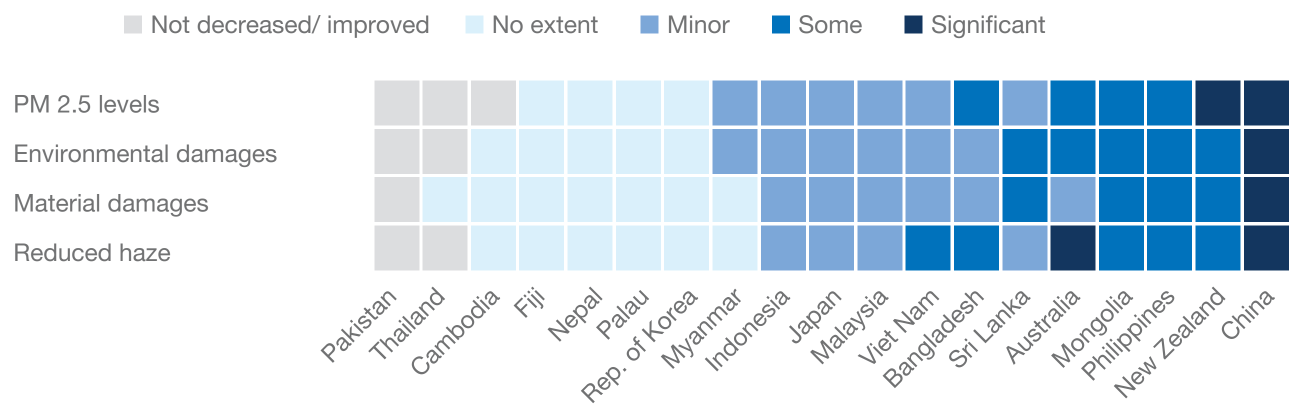
The ultimate aim of the RCA AQM programme is to strengthen the protection of human health and the environment. Participation in the RCA AQM programme has enabled a slight shift towards improved protection of human health and the environment in some countries through reduced exposure to air pollution. However, a complex interplay of factors has impacted health and the environment in the past twenty years.

PM2.5 air pollution is a significant concern for air quality and public health. It refers to fine particulate matter with a diameter of 2.5 µm or smaller. These tiny particles can be inhaled deep into the lungs, posing serious health risks such as respiratory and cardiovascular problems. PM2.5 pollution often comes from sources such as vehicle emissions, industrial processes and wildfires.

Reductions in exposure to air pollution vary greatly across the SPs (Fig. 6). Levels of PM2.5 decreased between 2000 and 2019 in **12** of **19** signatory countries. While the RCA programme is recognized for contributing to these reductions in several countries, its impact on PM2.5 levels is often part of a complex interplay of factors affecting air quality. State Parties' assessments indicated that the RCA contributed to these impacts, with **12** countries citing a low contribution (though nonetheless highly valued through the RCA's specific technical support, training opportunities and fostering of regional collaboration, all of which significantly enhanced overall monitoring capabilities), **five** countries citing a moderate contribution, and **one** country citing a high RCA contribution to this impact.

FIG. 6. Contribution of RCA to improvements in health and environment.

Extent to which the RCA AQM has contributed between 2000–2023



In China, the emission reduction measures implemented over the past decade have resulted in a decrease in PM2.5 levels across China, particularly since 2013. These initiatives have directly lowered the concentration of harmful pollutants in the air, thereby reducing the risk of respiratory and cardiovascular diseases, and consequently improving public health. Moreover, the decline in air pollution and smog has fostered a more favourable living environment, encouraging increased participation in outdoor activities, which has had a positive impact on both physical and mental well-being, while also enhancing overall life satisfaction. As air quality continues to improve, a noticeable downward trend in the incidence and mortality rates of related diseases has begun to emerge.

Another example is Australia, which is one of the global leaders in AQM. Since 2000, PM2.5 levels have dropped by around 25% per decade, and other key constituent pollutants have followed a similar downward trend. This decrease has been supported by reducing PM2.5 goals. In 2025, Australia will further reduce its annual goal of PM2.5 to 7 μg/m^3, with a daily maximum goal of 20 μg/m^3, making it one of the most stringent goals in the world.

Mountain landscape, Mongolia

3.

Conclusion

The RCA has supported significant gains for AQM in the Asia and Pacific region. This has led to increased research leadership, research outputs and contributions to national and regional databases. This information has been shared with EPAs to influence policy, regulation, interventions and enforcement changes, likely contributing to some behaviour changes. While there is a complex interplay of factors, the work of the RCA AQM has likely played a role in improvements in air quality in recent years. The social cost-benefit analysis estimated that the RCA very likely created more economic value than it consumed between 2000 and 2022.

Pre-defined performance criteria were agreed upon with IAEA and SP experts to provide an evaluative framework for the impact assessment (Tables VII–1 – VII–7, Annex VII). Based on the evidence provided by the IAEA and SPs, the RCA's impacts meet standards for **excellent performance** across two impact domains (nationally trained personnel and economic benefits). Furthermore, it achieved **good performance** across four impact domains (improved R&D capacity; strengthened information exchange; influence on national and international regulation, policy, interventions, enforcement and behaviour change; improved protection of human health and environment). Finally, the RCA AQM programme achieved **adequate performance** across one impact domain (enhanced/ established capacity for air pollution monitoring and assessment).

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Annex I: Air quality monitoring under RCA in Australia – case example

I–1. Background

Australia has monitored air quality since the 1960s, with different regions implementing varied approaches. For example, Sydney was among the early adopters of air pollution monitoring. By the early 1980s, the city was already publishing daily air quality reports for its most densely populated urban areas, focusing specifically on ozone concentrations and fine particulate matter.

However, it was not until 1991 that the Australian Nuclear Science and Technology Organisation (ANSTO) got involved in air quality monitoring (AQM) by introducing accelerator-based ion beam analysis (IBA) techniques to characterize fine particle air pollution. This was the start of the ANSTO Aerosol Sampling Program, which is still running today with over 20 functional sampling sites.

It was also in the 1990s that Australia joined the AQM programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA), which significantly advanced the country's expertise in air pollution monitoring. Through access to esteemed international experts and highly specialized training, Australia has positioned itself as a global leader in AQM.

I–2. Strengthened national capacity

One of the key achievements of the RCA AQM programme in Australia has been the significant development of the country's expertise in AQM. The programme provided access to internationally recognized experts specializing in sampling, advanced analysis and source apportionment while also enabling the participation of ANSTO staff and other end users, such as local industry and environmental protection authorities (EPAs), in specialized training workshops.[1]

These learning opportunities greatly enhanced Australia's national capacity in AQM. For instance, national experts, alongside their international counterparts, were introduced to positive matrix factorization (PMF) source apportionment techniques in 1996. These techniques were adopted in Australia within a year, positioning the country as a global leader in the application of PMF source apportionment methods for PM2.5 air pollution studies. Since then, the Centre for Accelerator Science at ANSTO has played a pivotal role in promoting these methodologies through national workshops and regional conferences. Today, these methods are widely accepted and used by local industry, mining operations and EPAs as the most effective means of quantifying pollution sources at receptor sampling sites.

[1] Under the RCA AQM programme, ANSTO staff have taken part in expert missions and trainings in a wide array of countries including Austria, China, Indonesia, Mongolia, Pakistan, Sri Lanka, Thailand and Viet Nam, among others.

The cooperative and knowledge exchange environment fostered by the programme also enabled the development of a national database of PM2.5 mass measurements and elemental concentrations. This comprehensive database encompasses data from 70 distinct sampling sites, covering the period from 1991 to the present, and is available publicly.

I–3. Enhanced infrastructure and adoption of technology

The Centre for Accelerator Science at ANSTO is now equipped with a comprehensive suite of PM2.5 sampling units to characterize air pollution, identify source fingerprints and trace pollution sources using wind-back trajectory methods. At the time of this publication, there were more than 20 fully operational sampling sites across Australia. During one week every month, the accelerator's capacity is dedicated to the analysis (IBA) of hundreds of filters from these sites, supporting both commercial and research purposes. Although this infrastructure has now become self-sustaining, it was initially established to meet the requirements of the RCA AQM programme.

I–4. Influence on policy and behaviour

Participation in the RCA AQM programme has significantly raised awareness about the potential adverse effects of air pollution on the environment and human health while also promoting the application of nuclear techniques for air pollution monitoring. Consequently, the knowledge and data generated by the programme have contributed, both directly and indirectly, to substantial policy development in Australia.

In the late 1990s, Australia introduced a PM2.5 goal of 15 $\mu g/m^3$ annual average and 35 $\mu g/m^3$ daily maximum. In 2015, this goal was reduced to 8 $\mu g/m^3$ annual average with 25 $\mu g/m^3$ daily maximum, and it is expected that this will be further reduced to 7 $\mu g/m^3$ and 20 $\mu g/m^3$, respectively, in 2025, making it one of the most stringent PM2.5 goals in the world. Furthermore, federal and state governments have acknowledged the importance of AQM and have taken subsequent measures as a response, including, for example, the funding of Cooperative Research Centres on air pollution, promoting EPAs to increase their numbers of sampling sites and the numbers of chemical species monitored and introducing a wide range of regulations regarding motor vehicles.

I–5. Social and economic effects

As a result of its participation in the RCA AQM programme, Australia has developed of its expertise in AQM and is currently one of the global leaders in the field. Participation in the RCA AQM programme, in combination with other enabling factors, is thought to have contributed to the decreasing trend of PM2.5 levels observed in the country in the past two decades. In fact, quantitative long term data obtained by ANSTO demonstrates that not only have PM2.5 levels dropped on average by approximately 25% per decade since 2000, but levels of key constituent pollutants (such as black carbon, sulphates, nitrates and organics) have also followed a similar trend. These results are particularly promising given the positive correlation between air pollution and mortality rates,[2] and are expected to have a positive effect on premature mortality rates.

Great Barrier Reef, Queensland, Australia

[2] According to the New South Wales Health Department, it is estimated that, even in a relatively clean air, approximately 420 people die prematurely from air pollution per year.

Annex II: Air quality monitoring under RCA in China – case example

II–1. Background

China's efforts to monitor air pollution date back to the 1970s. In 1973, the nation introduced their Environmental Protection Law of the People's Republic of China, marking the commencement of formal environmental protection initiatives. Building on this foundation, China began implementing air pollution monitoring in selected cities during the 1980s.

Prior to cooperation with the Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA), China's air quality monitoring (AQM) was limited to major urban areas and key pollutants, such as sulphur dioxide, nitrogen oxides and total suspended particulates. It was not until 2000, when China joined the AQM programme under the RCA, that the scale, scope and public disclosure of AQM was considerably expanded.

The RCA AQM programme offered numerous training opportunities in AQM, fostered international research cooperation and provided fundamental technological equipment, enabling China to stay updated on the latest AQM technologies. Additionally, the programme established a regional air quality database, which enabled the country to gain a deeper understanding of regional air quality, thereby enhancing the development of effective pollution prevention and control measures.

II–2. Strengthened national capacity

As a result of its involvement in the RCA AQM programme, China has benefitted from a wide range of training opportunities on AQM. Through participation in national and regional training courses, seminars and expert panels, Chinese personnel have acquired specialized knowledge and skills essential for effective AQM. In particular, the RCA AQM facilitated the training of a cohort of more than 40 national professionals and enhanced their capabilities in a variety of sampling, analysis and source apportionment techniques, including positive matrix factorization (PMF) and receptor models.

The programme also fostered international cooperation, allowing countries to share experiences and advancements and enabling China to further develop its domestic research and development on AQM. Additionally, China has also actively participated in the regional air quality sample database established under the RCA AQM programme, contributing monitoring data to be shared with other nations and using this data for analysis and research. Through its involvement in the data-sharing mechanism of the programme, China has established data exchange platforms with other countries and integrated the monitoring data acquired from the programme into its national air quality database.

II–3. Enhanced infrastructure and adoption of technology

Through the RCA AQM programme, China also acquired equipment and facilities for air sampling, analysis and source apportionment. This included items such as filter membranes, reference materials, GENT samplers, spare parts and static eliminators. These resources, together with the capacity building facilitated by the programme, enabled China to stay updated on the latest AQM technologies.

Four departments within China's Institute of Atomic Energy (CIAE) are currently responsible for AQM research, with more than ten professionals serving as core members. The team employs advanced analytical techniques using CIAE's primary instruments to analyze multi-component and isotope data from PM2.5 and PM10. With government support, the team has developed three key instruments for this purpose: total X ray fuorescence (TRFX) for multi-element analysis, a monotype accelerator mass spectrometer for $^{14}C/^{12}C$ ratio measurements, and laser induced plasma spectroscopy (LIPS) for onsite, online multi-element determination.

II–4. Influence on policy and behaviour

As a result of its participation in the RCA AQM programme (among other factors), China initiated pilot monitoring of PM2.5 levels in 2006 and has since then significantly expanded its AQM network. By 2012, PM2.5 was formally incorporated into the national AQM indicators and corresponding concentration limits were established to address this growing concern. These developments led to a more comprehensive and accurate monitoring of air quality, which helps detect and address pollution issues in a timely manner. Accurate monitoring data serves as a critical foundation for air pollution regulators, including environmental protection authorities (EPAs), in formulating policies and establishing standards aimed at addressing air pollution.

For example, in 2013, China launched the Air Pollution Prevention and Control Action Plan, which significantly intensified efforts to mitigate air pollution on a national scale through a series of measures such as industry emissions control, energy structure adjustment and vehicle exhaust treatment. Three years later, in 2016, China revised the Ambient Air Quality Standards, lowering the annual average concentration limit for PM2.5 from 35 $\mu g/m^3$ to 25 $\mu g/m^3$ daily maximum and underscoring the nation's increasing focus on public health and environmental protection.

Ultimately, the dissemination of AQM data has heightened public awareness of the adverse effects of air pollution. This increased awareness has prompted citizens to actively engage in efforts to improve air quality, thereby reinforcing the effectiveness of government-implemented emission reduction measures.

II–5. Social and economic effects

The emission reduction measures implemented over the past decade have resulted in a substantial decrease in PM2.5 levels across China, particularly since 2013. These initiatives have directly lowered the concentration of harmful pollutants in the air, thereby reducing the risk of respiratory and cardiovascular diseases, and consequently improving public health. Moreover, the decline in air pollution and smog has fostered a more favourable living environment, encouraging increased participation in outdoor activities, which has had a positive impact on both physical and mental well-being, while also enhancing overall life satisfaction. As air quality continues to improve, a noticeable downward trend in the incidence and mortality rates of related diseases has begun to emerge.

Moon Hill, Yangshuo, China

Annex III: Air quality monitoring under RCA in Indonesia – case example

III–1. Background

Prior to the 1990s, air quality monitoring (AQM) in Indonesia was limited in scope and frequency. Most efforts were concentrated in urban areas, and data collection was often sporadic and inconsistent. This absence of consistent air quality data translated into a poor understanding and low awareness of air pollution levels and their potential impact on health and the environment. In addition, the country also faced significant challenges in terms of technical limitations on the topic of AQM, such as inadequate technical equipment and limited human resources.

In 2000, Indonesia joined the AQM programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA), which improved the country's access to specialized infrastructure and training and ultimately enabled the establishment of a comprehensive AQM network. Since joining the RCA, AQM has gained momentum in the country due to an enhanced understanding of air pollution levels and growing concerns about its impact on public health.

III–2. Strengthened national capacity

The RCA AQM programme played a pivotal role in enhancing Indonesia's AQM capabilities. First, the programme provided specialized courses and hands-on training on the topic of AQM, thus equipping local personnel with specific skills in the areas of air quality sampling, analysis and source apportionment.

Furthermore, the RCA AQM programme was fundamental for the development and dissemination of research in the field of AQM. By providing a structured framework for collaboration among participating countries, the RCA AQM programme facilitated access to specialized facilities and equipment, the sharing of expertise among local and regional researchers, and their collaboration for the establishment of standardized protocols and guidelines on AQM. The various workshops and conferences organized by the programme allowed local researchers to present their research findings, receive feedback from their international peers and collaborate on joint research projects. Furthermore, the standardized methodologies developed under the RCA AQM framework helped ensure that research outputs were consistent, comparable and of high quality, which significantly contributed to the credibility and impact of the published research.

Overall, the RCA AQM programme generated a collaborative research environment that would have been otherwise not available for national researchers or institutions. The synergy created through international collaboration under the RCA accelerated research progress and enhanced the visibility of the research outcomes on AQM, leading to a higher number of publications and broader dissemination of knowledge on the topic. In fact, it is estimated that participation in the RCA AQM programme has contributed to the development and dissemination of more than 80 research publications on AQM.

As a result of enhancing the capabilities of national researchers and institutions, the RCA AQM programme also improved Indonesia's ability to provide AQM data for national and regional databases. The programme has established collaborative networks among participant countries, fostering mutual support for both data collection and analysis tasks. The RCA AQM has established a data-sharing mechanism among countries, allowing State Parties (SPs) to work together on completing a regional database while keeping oversight to ensure the quality of the data.

III–3. Enhanced infrastructure and adoption of technology

In the initial years after joining the RCA AQM programme, Indonesia received essential equipment for air quality sampling, analysis and source apportionment. Additionally, the programme provided access to international facilities and technologies that would have been challenging to obtain independently. This support in acquiring equipment was crucial for establishing a robust, national AQM infrastructure. In fact, because of this support, Indonesia expanded its sampling sites from 2 to 17, significantly enhancing the country's capacity to collect and analyze air quality samples.

III–4. Influence policy and behaviour

Joining the RCA AQM programme strengthened Indonesia's AQM network and analytical capabilities, which resulted in increased accuracy and reliability of air quality data in the country. This improved data provided a scientific foundation for assessing pollutants and identifying levels of heavy metals in the air, serving as a scientific reference for enacting government policies regarding air quality standards. Additionally, the data offers valuable insights into the main contributing pollutants, serving as a reference for policymakers to design and implement effective action plans to mitigate the impact of air pollution in the region.

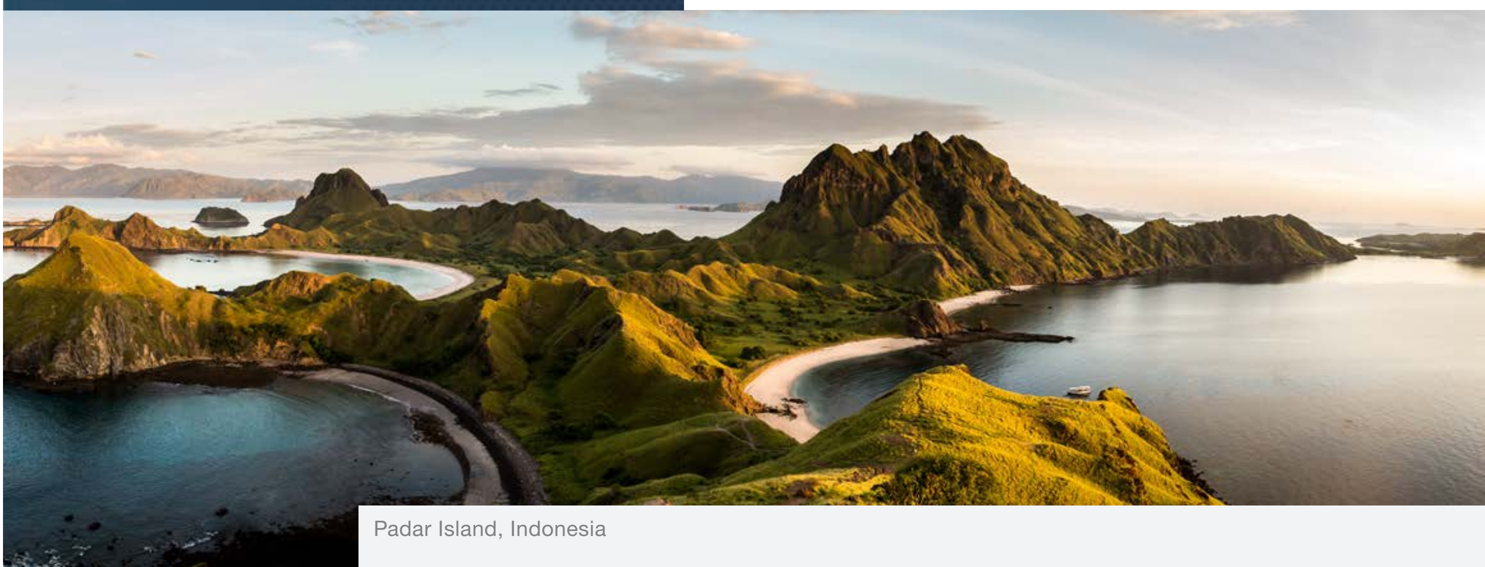
Indonesia has implemented several initiatives, such as workshops and seminars on AQM, to raise awareness among end users about the relevance of AQM and assessment. Findings related to heavy metal pollution in ambient air are disseminated regularly, increasing awareness of the health impacts associated with air pollution among citizens. As end users have become more knowledgeable about AQM, Indonesia has experienced an increase in the demand for air quality data. This has led to a more widespread use of data in decision making processes, both at the government and community levels, resulting in more targeted and effective air quality management strategies.

A key example of the influence of the RCA AQM programme on policymaking is its effects in Bandung, the country's third largest city. Based on the results obtained from using nuclear techniques to monitor the levels of PM10 and PM2.5 in the city, the local authorities changed its bylaws regulating the burning of agricultural and household waste, as well as introducing a series of education programmes for citizens about the harmful effects of burning their waste.

III–5. Social and economic effects

As a result of its participation in the RCA AQM programme, Indonesia acquired specialized infrastructure and enhanced the skills of national experts and institutions on air quality sampling, analysis and source apportionment. Furthermore, the collaborative framework generated by the RCA facilitated the development of research and knowledge sharing on AQM, which ultimately enabled the establishment and development of a comprehensive AQM network in the country. Improved AQM resulted in high quality and accurate data on air pollution, which constituted the basis for the development of new governmental policies and programmes on air quality standards.

These advances, in combination with other contributing factors such as economic changes and other environmental initiatives, are considered to have contributed to the decreasing trend of PM2.5 levels observed in Indonesia in the past two decades. Reflecting this promising path is the city of Bandung, which won the title of ASEAN Environmentally Sustainable City in 2017.



Padar Island, Indonesia

Annex IV: Air quality monitoring under RCA in Viet Nam – case example

IV–1. Background

Viet Nam started monitoring air pollution in the 1990s, focusing its efforts on major cities such as Hanoi and Ho Chi Minh City. During those early years, air quality monitoring (AQM) faced several challenges, including i) infrastructure and technology limitations, ii) incomplete air pollution data, iii) regulatory compliance uncertainties and inconsistent enforcement, iv) insufficient expert personnel and v) overall resource constraints.

In 2000, Viet Nam joined the AQM programme under the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA), which contributed to tackling these challenges by promoting regional cooperation on knowledge sharing and capacity building, as well as the investment on technologies for enhancing AQM practices towards sustainable initiatives for pollution management.

Since then, a more comprehensive and systematic approach to AQM has been implemented in the country in response to widespread concerns about pollution and the importance of safeguarding public health and the environment.

IV–2. Strengthened national capacity

The RCA AQM programme has significantly enhanced Viet Nam's capacity in AQM along three separate dimensions: human capital and leadership development, research advancement and data collection and management. In particular, the RCA AQM programme enabled the participation of national experts in international workshops and seminars, as well as expert missions, contributing to their expertise in the areas of air quality sampling, analysis and source apportionment. These initiatives also nurtured the growth of national researchers in the field of AQM, shaping the research landscape in Viet Nam and contributing partly to regional advancements in air quality management.

Furthermore, by fostering research collaboration and creating appropriate space for knowledge and data exchange, it is estimated that participation in the RCA AQM programme has contributed to the development and dissemination of around 20 research publications on AQM.

Finally, by providing equipment and other technical support, as well as targeted capacity building and data sharing opportunities, the RCA AQM programme has also improved Viet Nam's ability to provide AQM data for national and regional databases. These contributions have been instrumental in enhancing evidence-based decision-making and policy development related to air quality management.

IV–3. Enhanced infrastructure and adoption of technology

Under the RCA AQM programme, Viet Nam received some essential equipment for sample analysis, including fine and coarse nuclepore filters, reference materials in filter media, a Gent type sampler and related spare parts, and a static eliminator device, among others. Moreover, the programme has supported the introduction and adoption of advanced technologies for air quality analysis and source apportionment, including the use of satellite data and modelling techniques. These technological advances enable the systematic collection, processing and analysis of air quality data and provide a comprehensive understanding of pollution sources and trends.

IV–4. Influence on policy and behaviour

Participation in the RCA AQM programme has influenced the formulation of new regulations by the Vietnamese authorities aimed at controlling air pollution[1], as well as governmental policies encouraging industry regulation. The programme has also contributed to the development of several national and local air quality management programmes targeting major pollution sources such as transportation, industry and biomass burning.

In addition, RCA AQM's outreach activities and educational campaigns have contributed to a heightened public awareness of air quality and the consequences of air pollution on health, particularly respiratory issues and other chronic diseases. These initiatives have led to behaviour change among the population, including increased public demand for cleaner air initiatives and greater participation in community led AQM efforts. The establishment of AQM stations and widespread dissemination of real-time air pollution data through online platforms and mobile applications have empowered users to check air quality directly.

IV–5. Social and economic effects

Enhanced AQM through participation in the RCA AQM programme has enabled the Government of Viet Nam to implement more effective environmental regulations and policies, thus attracting foreign investment that is increasingly prioritizing sustainability. Furthermore, the rising need for AQM has stimulated the development of related technologies, encouraging growth in sectors such as environmental engineering and sensor manufacturing.

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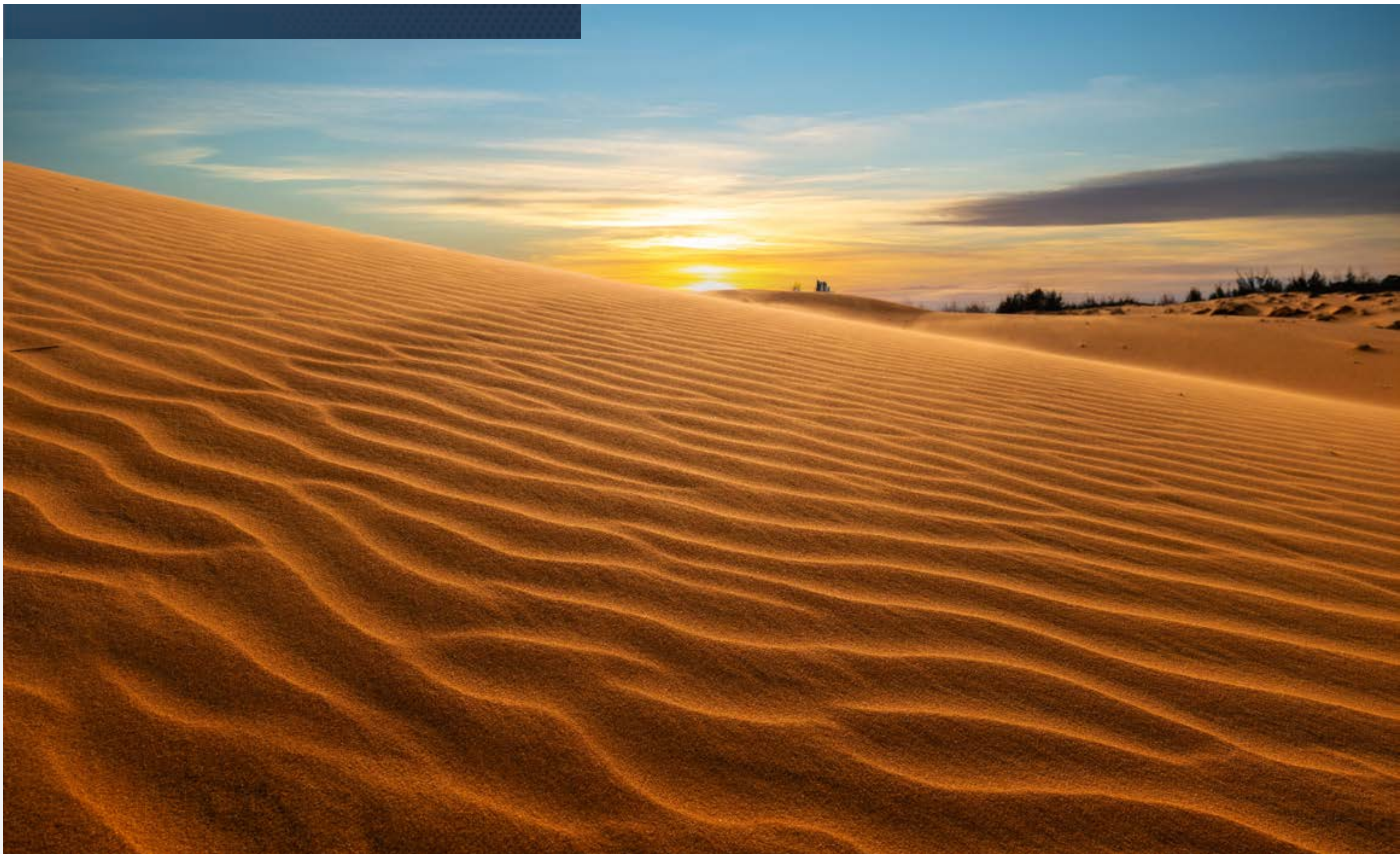
[1] For example, the banning of non-lead petrol starting from July 1, 2001 (Directive 24/2000/CT-TTg on the use of non-lead petrol in Viet Nam); or the replacement and elimination of the use of beehive coal fuel in Hanoi City (Directive 15CT-UBND of the Hanoi City People's Committee dated October 30, 2019).

Improvements in air quality monitoring have also enabled the implementation of targeted and more effective interventions, such as traffic management and industrial emission control, leading to an overall reduction in PM2.5 levels. As PM2.5 levels have decreased, there has been a corresponding decline in health issues associated with air pollution among the Vietnamese population, including respiratory diseases, cardiovascular problems and other related conditions.

Finally, improved AQM has translated into a better understanding of the sources and effects of air pollution on the environment, enabling industries and the State to implement prevention and mitigating measures as required.



Sand dunes at Mũi Né, Viet Nam

Annex V: Survey analysis

V–1. Introduction

This annex presents the findings of the Social and Economic Impact Assessment of the Air Quality Monitoring (AQM) programme of the Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA). The data that informs the analysis was collected through an online survey that was designed and piloted during May 2024 and deployed between June and August 2024. The respondents to the survey were national experts in the field of AQM. They provided relevant information about the capacity of trained personnel to carry out consistent air quality sampling, analysis and source apportionment; improvements in research and development (R&D); the extent to which information on transboundary air pollution monitoring is exchanged across the region; the influence on policy regulations; and the overall health and environmental benefits that the RCA programme has contributed to achieving in their countries.

Out of the 22 countries that are part of the RCA, the report focuses on the 19 countries that participated in IAEA's AQM online survey: Australia, Bangladesh, Cambodia, China, Fiji, Indonesia, Japan, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, Palau, the Philippines, the Republic of Korea, Sri Lanka, Thailand and Viet Nam[1].

The analysis presents the outcomes from the 19 countries that participated in the survey. However, it is essential to acknowledge that four of these countries —Cambodia, Fiji, Nepal, and Palau— while being signatories to the RCA, have not been extensively engaged in the activities of the RCA AQM programme. Consequently, the programme's impact on these countries' accomplishments across all evaluation metrics could be limited. It is therefore recommended that the findings in this report be interpreted with this in mind.

The assessment of the social and economic impacts of the RCA AQM programme involved pre-defining agreed performance criteria (aspects of social and economic impacts that were the focus of the evaluation) and standards (narratives describing four levels of performance — excellent, good, adequate and minor). These criteria and standards (detailed in Tables VII–1 – VII–7, Annex VII) provided a transparent and robust framework for rating the impact of the RCA AQM programme.

In particular, to understand the contribution of the RCA AQM programme on social and economic indicators, the study analyzes the extent to which being part of the programme has enabled State Parties (SPs) to meet the following performance criteria (Table V–1).

[1] Singapore and India did not participate in the online survey and Lao People's Democratic Republic did not complete it (only one answer was provided).

TABLE V–1: Criteria for AQM explored in the survey.

Criterion	Description
Nationally trained personnel able to carry out consistent air quality sampling, analysis and source apportionment	As a result of RCA, in-country personnel are trained to carry out consistent, high quality, and synchronized air quality sampling, analysis and source apportionment.
Improved national R&D capacity for air pollution monitoring	As a result of RCA projects, SPs have: ▸ Published research on AQM, specifically, on air particulate matter; ▸ Generated research leadership on AQM; ▸ Contributed monitoring data to national databases.
Strengthened information exchange in the region on transboundary air pollution monitoring and assessment	As a result of RCA, there is an increase in: ▸ International cooperation and information exchange in air pollution monitoring (e.g. increased number of engagements, workshops and collaborations); ▸ End users' awareness about the importance of air quality assessment.
Enhanced/established national and regional capacity for air pollution monitoring and assessment	As a result of RCA projects, SPs have: ▸ Obtained the necessary technical infrastructure and facilities for air quality sampling, analysis and source apportionment; ▸ Contributed to the development of a regional database of air quality samples; ▸ Obtained the funding commitments by national environmental protection authorities (EPAs) and other end users to national air quality assessment.
Influence on national and international health and environmental regulations, policy decisions and interventions, enforcement and behaviour change	RCA influences: ▸ New regulations and changes to existing regulations relating to air quality; ▸ Policy decisions and interventions relating to air quality; ▸ Levels of enforcement of air quality standards and regulations; ▸ New air pollution programmes or changes to existing air pollution programmes; ▸ Population behaviour change relating to air quality.
Improved protection of human health and environment	RCA influences reductions in exposure to air pollution, which contributes to reduced mortality, morbidity, and environmental and material damages and improved visibility.

V–2. Summary and discussion

The assessment of the RCA AQM programme's social and economic impacts involved pre-defining agreed-upon performance criteria (aspects of social and economic impacts that were the focus of the evaluation) and standards (narratives describing four levels of performance—excellent, good, adequate and minor). These criteria and standards provided a transparent and robust framework for rating the programme's impact.

Figure V–1 summarizes the performance of the programme in each country against the defined criteria and standards.

The RCA AQM programme's strongest performance was in New Zealand, where all criteria met excellent standards (Fig. V–1). This was followed by Australia and Sri Lanka, where four criteria achieved excellence. A group of countries, including the Philippines, Indonesia, China, Bangladesh and Viet Nam, also saw the RCA AQM programme perform excellently in at least two criteria. As mentioned earlier, Cambodia, Fiji, and Nepal met only minor standards in most criteria, which was expected given their limited engagement in the RCA AQM programme despite being signatories. Consequently, the impact of the RCA AQM programme on these countries' accomplishments across all evaluation metrics was limited. However, even with limited engagement, Palau perceived that the RCA AQM programme contributed positively by training personnel and facilitating regional information exchange.

FIG. V–1. Performance of the programme in each country against the defined criteria and standards.

Extent to which the RCA AQM has contributed between 2000–2023

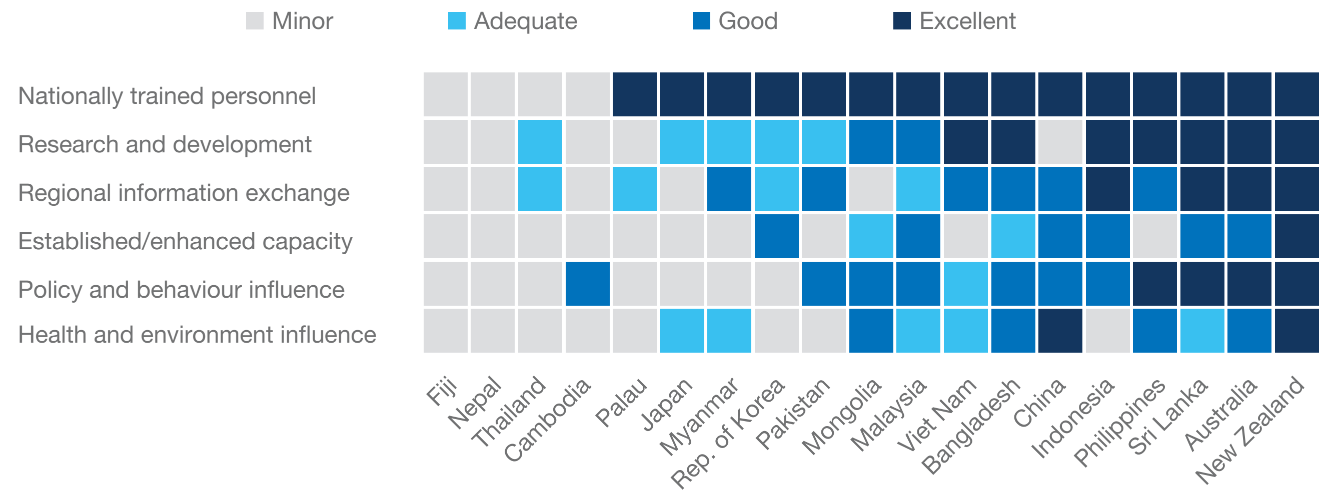


Figure V–1 highlights that **the RCA AQM programme was most effective in training national personnel, rated an excellent in 15 countries.** It also made significant contributions to supporting and enhancing R&D across participant countries, promoting the development of publications and research leaders, with seven countries providing a rating of excellent, two of good, and six a rating of adequate in this criterion. The RCA AQM programme also performed well in influencing policy and behaviour, with four countries rating it as excellent, seven rating as good, and one as adequate, underscoring its importance in this area.

The criteria with the lowest performance were related to the establishment and enhancement of capacity, which includes infrastructure and facilities for sampling analysis, source apportionment, development of regional databases and securing funding commitments. Only New Zealand rated this as excellent in this dimension, while nine countries rated it as minor. Regarding its influence on human health and environment, specifically in reducing PM2.5 levels, two countries rated this as excellent, four as good, and six as adequate, indicating that while the RCA AQM contributes, other factors are likely to also play a significant role in these outcomes.

V–2.1. State Parties' perception: contribution of the IAEA and the RCA in achieving objectives

This section presents the perceptions of SPs regarding the impact of the RCA AQM programme on the AQM sector in their respective countries, and its broader socio-economic benefits through AQM activities between 2000 and 2023. The experts were asked to estimate the proportion of total activity in the AQM sector in their countries that could be attributed to the RCA AQM programme. The responses varied, reflecting different levels of engagement and dependency on the programme across countries, suggesting air quality management needs differ across the Asia and Pacific region (Fig. V–2).

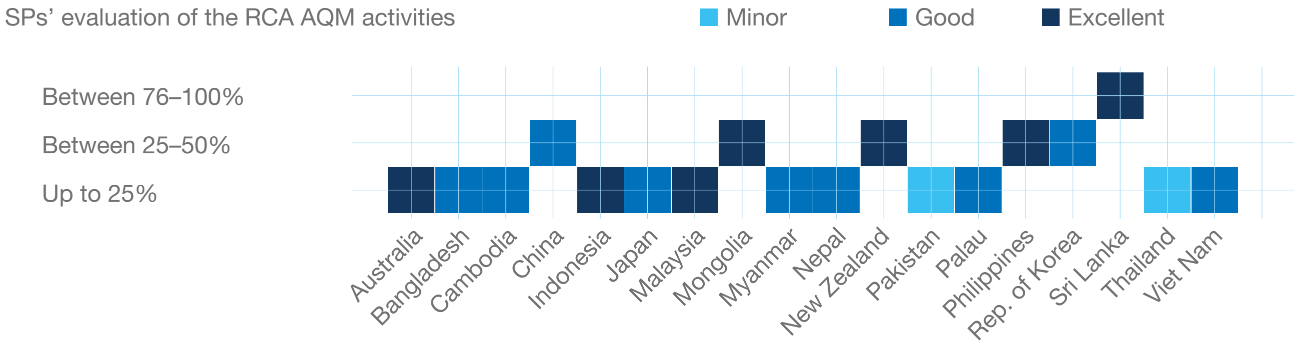
High contribution: Sri Lanka reported that a significant portion of their AQM activities—ranging from 76% to 100%—could be directly attributed to the RCA AQM programme. This high level of attribution highlights the critical role that the RCA AQM programme has played in advancing AQM in Sri Lanka. This perception is supported by the findings of the assessment that demonstrated excellent standards of the programme in Sri Lanka across four out of six key criteria: nationally trained personnel, R&D, regional information exchange, and policy and behaviour influence. The programme's substantial contribution has been instrumental in establishing and strengthening AQM infrastructure, developing local expertise, and influencing environmental policy (through air pollution programmes).

Moderate contribution: China, Mongolia, New Zealand, the Philippines and the Republic of Korea reported a moderate contribution from the RCA programme, estimating that 25% to 50% of their AQM activities were influenced by the programme. These countries typically had some pre-existing infrastructure and expertise but benefited significantly from the additional resources, training and knowledge sharing facilitated by the RCA programme.

- **New Zealand:** The RCA AQM programme was rated excellent across all six assessment criteria, including nationally trained personnel, R&D, regional information exchange, established/enhanced capacity, policy and behaviour influence, and human health and environment influence. New Zealand also evaluated the role of the IAEA and the RCA activities as excellent in achieving the general objectives and socio-economic benefits through AQM.
- **Philippines:** The programme was rated excellent in three criteria—nationally trained personnel, R&D, and policy and behaviour influence—and was rated good in two others (regional information exchange and human health and environment influence). The Philippines rated the roles of the IAEA and the RCA as excellent in achieving its objectives and socio-economic benefits.
- **China:** The programme was rated excellent in two criteria (nationally trained personnel and human health and environment influence) and was rated good in three other criteria (policy and behaviour influence, established/enhanced capacity and regional information exchange). China evaluated the roles of the IAEA and the RCA as good in contributing to the broader socio-economic objectives through AQM.
- **Mongolia:** The programme was rated excellent in the criterion of nationally trained personnel and was rated good in R&D, policy and behaviour influence, and human health and environmental influence. However, the programme had only a minor impact on regional information exchange in Mongolia. Despite this, Mongolia evaluated the roles of the IAEA and the RCA as excellent, indicating the value placed on the programme's strategic contribution to enhancing national capacities and influencing policy and behaviour.
- **Republic of Korea:** The RCA AQM programme was rated excellent in nationally trained personnel, was rated good in established/enhanced capacity, and was rated adequate in R&D and regional information exchange. The Republic of Korea evaluated the roles of the IAEA and the RCA as good in achieving the general objectives and socio-economic benefits through AQM.

Out of the SPs that considered the programme to have made a moderate contribution, three rated the roles of the IAEA and the RCA in achieving general objectives and socio-economic benefits through AQM as excellent. This indicates a strong appreciation for the programme, even if its overall contribution to their AQM activities was moderate. These findings suggest that the programme's contributions effectively complemented other efforts by local, regional and international stakeholders, creating valuable synergies in AQM.

FIG. V–2. Proportion of total activity in AQM sector attributed to the RCA AQM programme.



Low contribution: Australia, Bangladesh, Cambodia, Indonesia, Japan, Malaysia, Myanmar, Nepal, Pakistan, Palau, Thailand and Viet Nam perceived the RCA AQM programme as contributing up to 25% of their total AQM activities. Despite this relatively low contribution, the programme was highly valued for its specific technical support, training opportunities and the fostering of regional collaboration, all of which significantly enhanced their overall monitoring capabilities. Depending on each country's context, such as their levels of development and technological resources, the programme's contribution can be seen as equally relevant to those countries reporting a higher impact. In these cases, even a modest contribution could have provided essential resources and expertise, making a difference in advancing their AQM efforts.

- Australia, Indonesia and Malaysia evaluated the roles of the IAEA and the RCA activities in achieving the general objectives and socio-economic benefits through AQM as excellent. This evaluation reflects the countries' appreciation of the programme's targeted contributions, such as advanced technical training and strategic regional collaboration, even if the programme's overall influence on their monitoring activities was limited.
- Bangladesh, Cambodia, Japan, Myanmar, Nepal, Palau and Viet Nam evaluated the role of the programme as good. These countries recognized the value of the RCA programme in providing foundational support and resources that complemented their existing AQM efforts.
- Pakistan and Thailand evaluated the role of the programme as minor, indicating that the RCA AQM programme had minimal impact on their AQM activities or socio-economic outcomes.

V–2.2. Consistency of perceptions with programme performance

The perceptions of the programme's contribution and effectiveness align with the performance of the RCA AQM programme based on the criteria and standards previously reported:

Excellent perception: In countries such as Australia, Indonesia and Malaysia, where SPs rated the RCA AQM programme as excellent in achieving socio-economic impacts, the programme's targeted interventions—such as high-quality technical training, effective capacity building and strategic collaboration—have effectively compensated for its limited overall contribution to national monitoring activities. Additionally, in Sri Lanka, where experts also evaluated the programme's role as excellent, and the proportion of activities attributed to the RCA is high, the positive perception of the SPs aligns with the evaluation results, as Sri Lanka was rated excellent in four out of the six criteria. This consistency underscores the programme's significant and well recognized impact in the country.

Good perception: Countries that rated the programme as good, despite its relatively low contribution, could have benefited from specific aspects such as regional information exchange and policy influence, which helped to enhance their existing AQM frameworks. This is evident in the cases of Bangladesh, Cambodia, Japan, Myanmar, Nepal, Palau and Viet Nam. For China and the Republic of Korea, where the programme was also rated as good and was reported to contribute between 20% to 25% of total activities, there appears to be an opportunity to further increase the efficiency and impact of the programme's actions. Despite its contributions, these countries could benefit from additional efforts to strengthen the programme's role within their national monitoring activities.

Poor perception: The poor evaluation from Pakistan and Thailand could indicate challenges in programme implementation, relevance or resource allocation that limited its impact.

V–3. Criterion 1: nationally trained personnel on air quality monitoring

This section presents the results of the assessment on the extent to which the support of the RCA AQM programme has enabled SPs to train national personnel in carrying out consistent sampling, analysis and source apportionment.

The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in the SP providing training to in-country personnel to carry out consistent sampling, analysis and source apportionment.
- **Good:** Participation in the RCA AQM programme results in the SP providing training to in-country personnel to carry out consistent sampling and analysis.
- **Adequate:** Participation in the RCA AQM programme results in the SP providing training to in-country personnel to carry out consistent sampling.
- **Minor:** Standard for adequate not met.

V–3.1. Nationally trained personnel

Nationally trained personnel in AQM refers to individuals who have received specialized training in AQM through various national and regional programmes. These trainings are designed to equip participants with the knowledge and skills necessary to monitor, analyze and manage air quality using advanced scientific techniques and tools. The trainings focus on various aspects of AQM, including data validation, receptor modelling, source apportionment and the use of advanced analytical techniques.

The trainings include[2]:

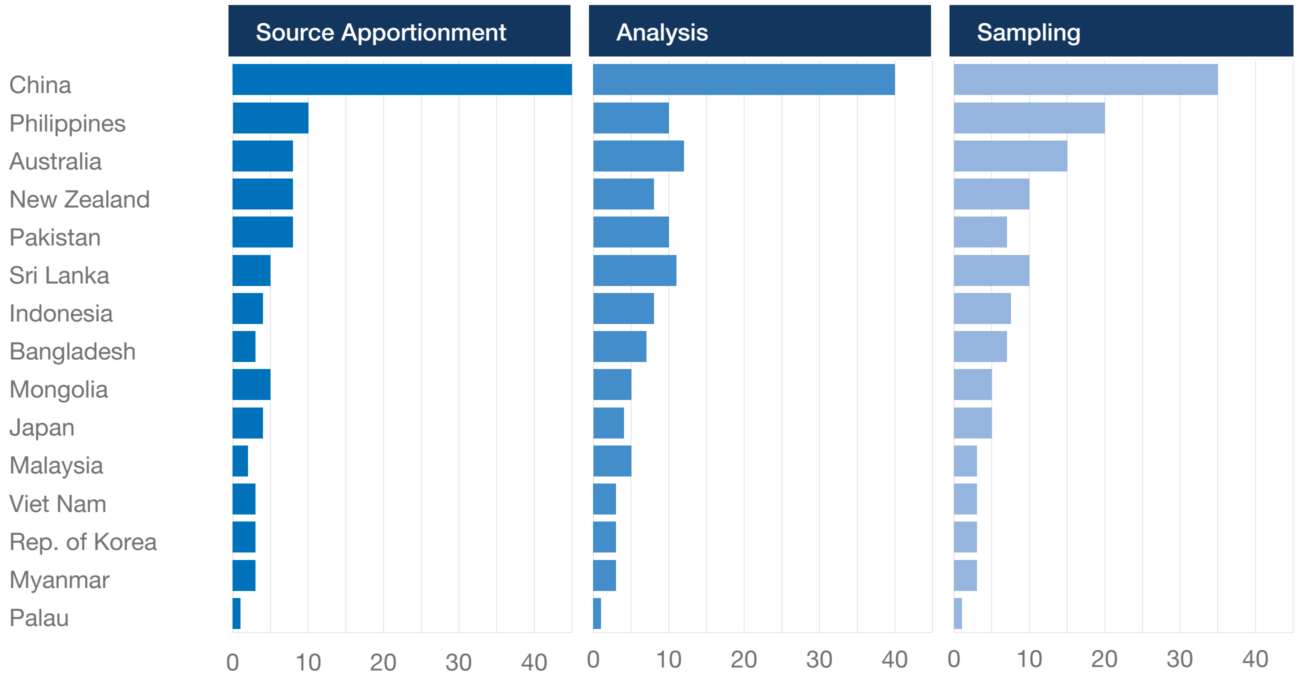
- **IAEA RCA Regional Training Workshop on Data Validation for Airborne Particulate Data:** Focuses on methods for ensuring the accuracy and reliability of airborne particulate data.
- **National Seminar on Improved Information of Urban Air Quality Management and Consultancy on Application of HYSPLIT:** Provides training on using hybrid single-particle Lagrangian integrated trajectory (HYSPLIT) for modelling air quality in urban environments.
- **IAEA RCA Regional Training Course on the Use of Receptor Models in Development of Air Quality Management Strategies:** Teaches the application of receptor models for developing effective AQM strategies.

[2] The description and names of the trainings were obtained from the Full Project Status Reports provided by IAEA.

- **IAEA RCA RTC on PMF Apportionment Applied to Regional Data:** Covers methods such as positive matrix factorization (PMF) for apportioning sources of pollution, including the analysis of key transboundary pollution events.
- **IAEA RCA Regional Training Course on HYSPLIT Back Trajectory Techniques Applied to Regional Data and Key Transboundary Events:** Focuses on using back trajectory analysis for understanding pollution transport.
- **IAEA RCA Regional Training Course on Harmonization of Data and Source Components:** Emphasizes standardizing data and source components for consistent air quality assessments.
- **IAEA RCA Regional Training Course on Source Components and Visibility and Introduction to Back Trajectories:** Addresses the relationship between pollution sources and visibility, along with back trajectory analysis.
- **IAEA RCA Regional Training Course on Using Back Trajectory Schemes to Link Pollution Transport Across the Region and Beyond:** Trains participants on linking pollution sources to regional and long range transport.
- **Regional Training Course on Quality Assurance of Fingerprint and Source Apportionment Data:** Ensures the quality and reliability of data used for identifying pollution sources.
- **Regional Training Course on QA Source Apportionment to Complete Data for Fingerprint Database:** Focuses on completing and ensuring the accuracy of fingerprint databases used in source apportionment.
- **Regional Group Training on the Effective Utilization of XRF Spectrometers for Optimized and Accurate Air Particulate Matter (APM) Analysis:** Trains participants on the use of X ray fluorescence (XRF) for analyzing particulate matter.
- **Regional Group Training on the Utilization of Synchrotron Radiation Techniques for Advanced Analytical Studies on Air Pollution:** Introduces advanced synchrotron radiation techniques for detailed air pollution analysis.
- **Regional Training Course on Quality Assurance of Fingerprint and Source Apportionment of Air Particulate Matter (APM):** Focuses on maintaining the quality of data used in source apportionment of APM.
- **Training on Neutron Activation Analysis (NAA) and XRF Techniques:** Provides knowledge on using NAA and XRF for analyzing air quality.
- **Regional Training Workshop on Atmospheric Chemistry and Transport:** Covers the chemical processes in the atmosphere and their roles in pollution transport.
- **RCA Regional Training Workshop on The Application of Advanced Data Analysis Methods to Ambient Aerosol Compositional Data:** Teaches advanced data analysis methods for understanding the composition of ambient aerosols.

Figure V-3 illustrates the total number of national personnel trained by the RCA AQM programme from 2000 to 2023, categorized by type of training: sampling, analysis and source apportionment. Among the 19 countries involved, only Cambodia, Thailand, Fiji and Nepal reported that they had not trained national personnel under the RCA programme for consistent air quality sampling, analysis or source apportionment during this period.

FIG. V–3. Number of nationally trained personnel between 2000 and 2023.



Conversely, the remaining 15 countries—Malaysia, Viet Nam, Bangladesh, Myanmar, Philippines, Indonesia, Mongolia, the Republic of Korea, New Zealand, Palau, Pakistan, Sri Lanka, China, Australia and Japan—meet the excellent criteria. These countries reported that their participation in the RCA AQM programme has enabled them to train in-country personnel effectively to carry out consistent air quality sampling, analysis and source apportionment.

Figure V–3 indicates that China, the Philippines and Australia have had the highest number of national personnel trained by the RCA AQM programme between 2000 and 2023. Specifically:

- **China** has the most personnel trained, with a total of 35 trained in sampling, 40 in analysis and 45 in source apportionment.
- **The Philippines** follows with 20 personnel trained in sampling, 10 in analysis and 10 in source apportionment.
- **Australia** has trained 15 personnel trained in sampling, 15 in analysis and 8 in source apportionment.

These numbers demonstrate the investment in capacity building through the RCA AQM programme. Particularly, it shows that there has been a balanced focus on training personnel across all three areas: sampling, analysis and source apportionment. This suggests a comprehensive approach to developing air quality management expertise within the region.

V–4. Criterion 2: improved national research and development on air quality monitoring

This section presents the findings on the contribution of the RCA AQM programme to improving national R&D on AQM. The section assesses the extent to which, as a result of the RCA, SPs have:

- Published research on AQM, specifically on air particulate matter.
- Generated research leadership on AQM.
- Contributed monitoring data to national databases.

The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in research outputs and publications on AQM, and specifically on air particulate matter; and research leaders on the topic at the national and international levels; and contributing monitoring data to national databases for ten or more years.
- **Good:** Participation in the RCA AQM programme results in research outputs and publications on AQM, and specifically on air particulate matter; and research leaders on the topic at the national; and contributing monitoring data to national databases for 8–10 years.
- **Adequate:** Participation in the RCA AQM programme results in research outputs and publications on AQM, and specifically on air particulate matter; or research leaders on the topic at the national level; or contributing monitoring data to national databases.
- **Minor:** Standard for adequate not met.

V–4.1. Overall contribution of the RCA AQM programme

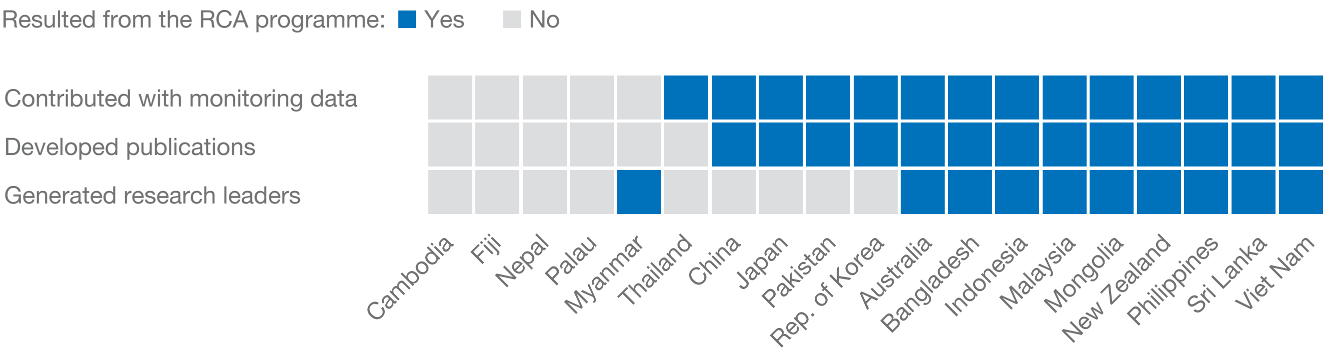
The SPs were asked whether, as a result of their participation in the RCA AQM programme, their countries have developed research outputs and publications on AQM, generated research leaders in AQM or contributed with monitoring data to national databases. Figure V–4 shows the perception that the SPs have on the role that the programme has had in each of these dimensions.

As can be seen in Fig. V–4, all countries actively engaged with the programme[3], except for Myanmar, consider that as a result of the RCA AQM programme, their countries have been able to contribute monitoring data to national databases. Furthermore, only Myanmar and Thailand consider that their participation in the RCA programme has not resulted in their capacity to develop research outputs

[3] Cambodia, Fiji, Nepal and Palau while being signatories to the RCA, they have not been extensively engaged in the activities of the RCA AQM programme.

on AQM. With respect to the contribution that the RCA programme has made to the generation of research leaders, only Thailand, China, Japan, Pakistan and the Republic of Korea consider that the programme did not contribute to that field.

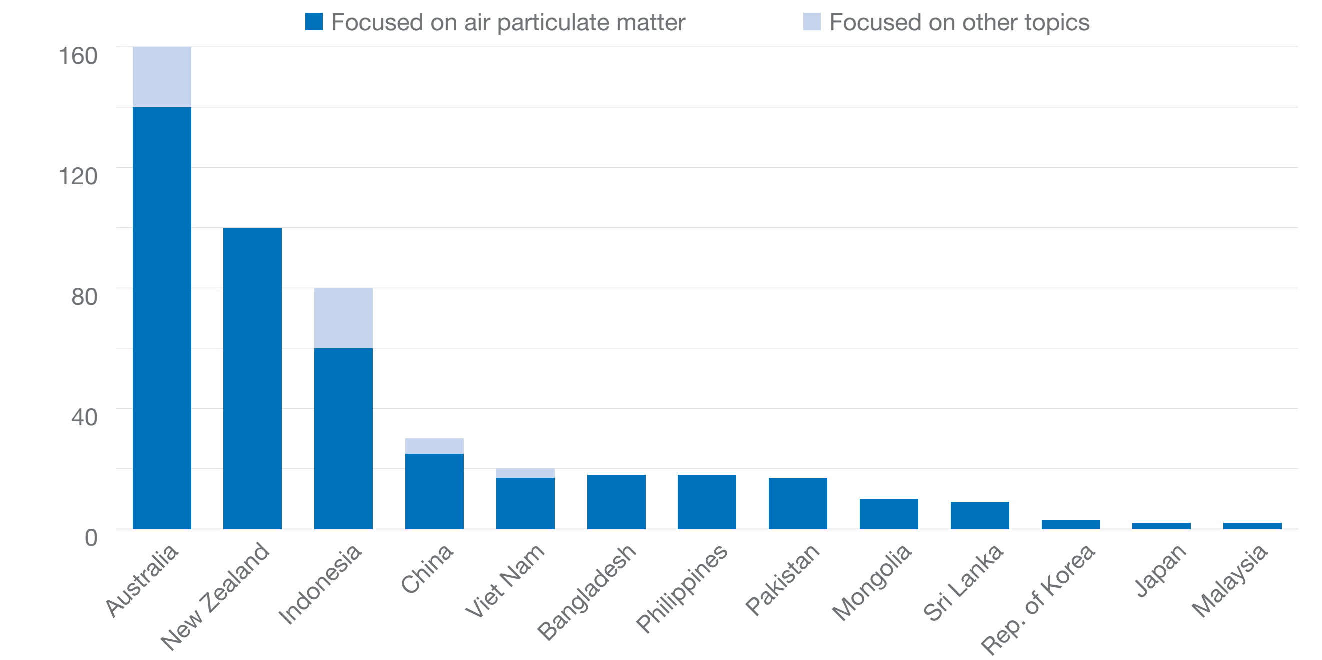
FIG. V–4. Contribution of the RCA to national R&D on AQM.



V–4.2. Research outputs and publications

Figure V–5 illustrates the number of research outputs and publications produced between 2000 and 2023 in each country supported by the RCA AQM programme. It also indicates which of these research outputs and publications specifically focused on the topic of air particulate matter.

FIG. V–5. Number of publications and research outputs resulted from being part of the RCA AQM programme.



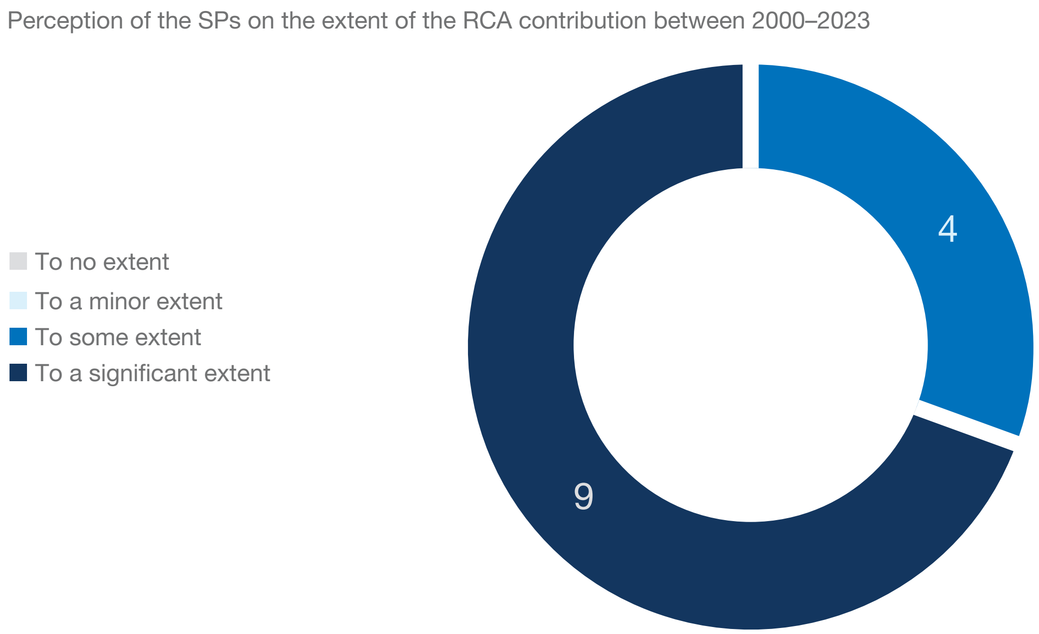
Australia reported that a total of 160 publications (140 of them focusing on air particulate matter) were developed as a direct result of participation in the RCA AQM programme. New Zealand similarly reported 100 publications resulting from the programme's support. Overall, a total of 464 publications were developed across 13 countries in the region as a result of involvement in the RCA AQM programme between 2000 and 2023, highlighting its significant contribution to research in this area (Fig. V–5).

V–4.2.1. Contribution of the RCA AQM programme to research outputs and publications

The SPs from the 13 countries where the RCA AQM programme has contributed to the development of research outputs were asked to evaluate the extent of this contribution between 2000 and 2023 (Fig. V–6). Nine SPs reported that the programme contributed to a significant extent, while four indicated that it contributed to some extent.

This distribution of responses implies the RCA AQM programme's role in advancing research and publications across the region. The majority view, which recognizes a significant contribution, suggests that the programme has played a major role in fostering research and generating valuable outputs. The

FIG. V–6. Perception of SPs on the extent of the RCA contribution to research outputs.



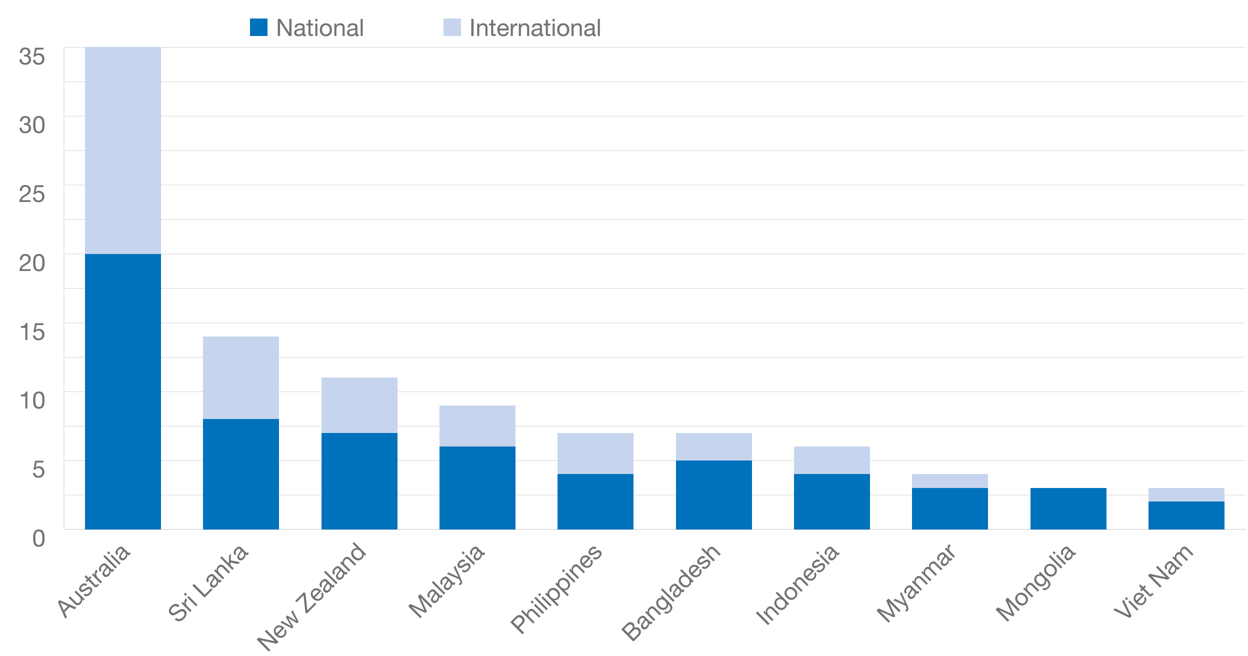
responses from the remaining SPs, who saw the contribution as more moderate, indicate that while the programme's impact is appreciated, it may vary depending on the specific contexts and engagement levels of different countries. Overall, this feedback reflects a strong recognition of the programme's effectiveness in enhancing research capabilities and outputs within the region, even as the degree of impact could differ across various contexts.

V–4.3. Research leaders

Figure V–7 illustrates the number of research leaders generated in each country as a result of participating in the RCA AQM programme between 2000 and 2023. It highlights the researchers who have become prominent figures at both national and international levels in AQM.

The programme has significantly contributed to the development of approximately 98 research leaders across the region, including 62 national and 36 international leaders. Australia stands out with the highest number of research leaders in AQM, totalling 35, followed by Sri Lanka and New Zealand, with 12 and 11 research leaders, respectively.

FIG. V–7. Number of research leaders resulted from being part of the RCA AQM programme.



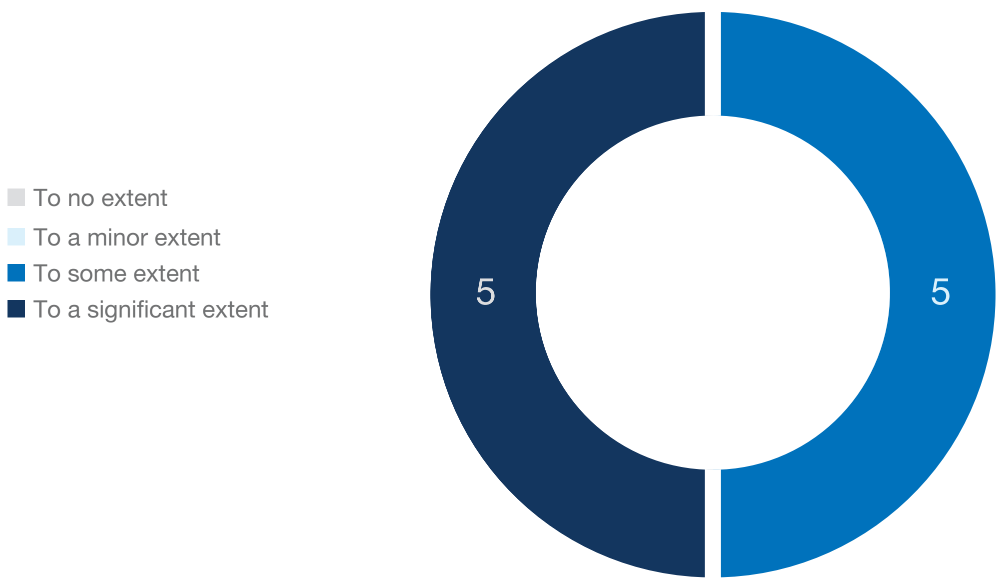
This achievement underscores the RCA AQM programme's role in fostering expertise and advancing leadership in AQM. By cultivating a network of influential researchers, the programme enhances the capacity for impactful research, drives innovation, and strengthens regional and global collaboration in addressing air quality challenges.

V–4.3.1. Contribution of the RCA AQM programme to research leaders

SPs from the ten countries where the RCA AQM programme contributed to the generation of research leaders were asked to evaluate the extent of this contribution between 2000 and 2023 (Fig. V–8). Five SPs reported that the programme contributed to a significant extent, while the remaining five indicated that it contributed to some extent.

These responses suggest a broadly positive assessment of the RCA AQM programme's impact on developing research leaders in AQM. The fact that half of the SPs view the contribution as significant highlights the programme's substantial role in advancing expertise and leadership in the field. Meanwhile, the other half acknowledging a contribution to some extent indicates that while the programme's impact is recognized, there could be variability in the degree to which it has influenced the development of research leaders across different countries. Overall, these responses reflect the programme's effectiveness in fostering a network of research leaders, though the impact could vary depending on national contexts and the level of engagement with the programme.

FIG. V–8. Perception of SPs on the extent of the RCA contribution to research leaders between 2000–2023.



V–4.4. Monitoring data for national databases

Contributing to monitoring data on air quality for national databases refers to the process of providing and integrating air quality data collected through monitoring efforts into national databases. This contribution involves data collection, data reporting, data integration and data utilization. By contributing to national databases, this process supports the creation of a centralized repository of air quality information that can be accessed and utilized for improving air quality management and public health outcomes.

Table V–2 illustrates the duration for which each country has been contributing monitoring data on air quality to national databases, alongside the extent of the RCA AQM programme's contribution to their capacity for this data provision. Notably, ten countries have been contributing AQM data for more than ten years. Among these, six countries acknowledge that the RCA AQM programme has significantly contributed to their ability to provide this data.

This information indicates that the RCA AQM programme has played a substantial role in enhancing the capacity of these countries to maintain long term, consistent AQM efforts. The fact that a majority of these long term contributors recognize the programme's significant contribution suggests that the support provided by the RCA AQM programme has been pivotal in developing and sustaining their monitoring capabilities.

TABLE V–2. Duration for which each country has been contributing monitoring data on air quality to national databases.

Country	Time contributing	RCA contribution
Australia	More than 10 years	To a significant extent
China	More than 10 years	To a significant extent
New Zealand	More than 10 years	To a significant extent
Philippines	More than 10 years	To a significant extent
Sri Lanka	More than 10 years	To a significant extent
Viet Nam	More than 10 years	To a significant extent
Bangladesh	More than 10 years	To some extent
Indonesia	More than 10 years	To some extent
Mongolia	More than 10 years	To some extent
Republic of Korea	More than 10 years	To some extent
Pakistan	Between 8 and 10 years	To a significant extent
Malaysia	Between 8 and 10 years	To some extent
Japan	Less than 8 years	To a minor extent
Thailand	Less than 8 years	To a minor extent
Cambodia	Does not contribute	N/A
Fiji	Does not contribute	N/A
Myanmar	Does not contribute	N/A
Nepal	Does not contribute	N/A
Palau	Does not contribute	N/A

V–5. Criterion 3: strengthened information exchange in the region on transboundary air pollution monitoring and assessment

This section presents the findings on the contribution of the RCA AQM programme to strengthening information exchange in the region on transboundary air pollution monitoring and assessment. This section assesses the extent to which, as a result of the RCA, there is an increase in:

- International cooperation and information exchange in air pollution monitoring (e.g. increased number of engagements, workshops and collaborations);
- End users' awareness about the importance of air quality assessment.

The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in the SP organizing international conferences and/or workshops on transboundary air pollution monitoring and assessment; and the SP promoting the implementation of international projects on air pollution monitoring and assessment; and end users becoming aware of the importance of air quality monitoring and assessment.
- **Good:** Participation in the RCA AQM programme results in the SP participating in international conferences and/or workshops on transboundary air pollution monitoring and assessment; and the SP participating in international projects on air pollution monitoring and assessment; and the SP initiating activities to create awareness among end users on the importance of air quality monitoring and assessment.
- **Adequate:** Participation in the RCA AQM programme results in the SP participating in international conferences and/or workshops on transboundary air pollution monitoring and assessment; or the SP participating in international projects on air pollution monitoring and assessment.
- **Minor:** Standard for adequate not met.

V–5.1. International conferences on transboundary air pollution monitoring and assessment

Figure V–9 presents the involvement of SPs in international conferences and workshops on transboundary air pollution monitoring and assessment as a result of their participation in the RCA AQM programme between 2000 and 2023. The 13 countries that have participated in conferences have collectively participated in approximately 235 such conferences, with RCA members organizing a total of 52 of these events.

New Zealand led participation with 50 conferences, including 19 that they organized. China followed with 45 conferences, 30 of which were organized by them. Myanmar also played a significant role, participating in 27 conferences. This active engagement highlights the importance of addressing transboundary air pollution, as these conferences and workshops provide platforms for sharing knowledge, coordinating strategies and fostering international collaboration.

By engaging in and hosting these events, they contribute to the advancement of transboundary air pollution monitoring, facilitate the exchange of best practices and enhance cooperative efforts to address air quality challenges that cross national borders.

FIG. V–9. Number of international conferences on transboundary AQM between 2000 and 2023.

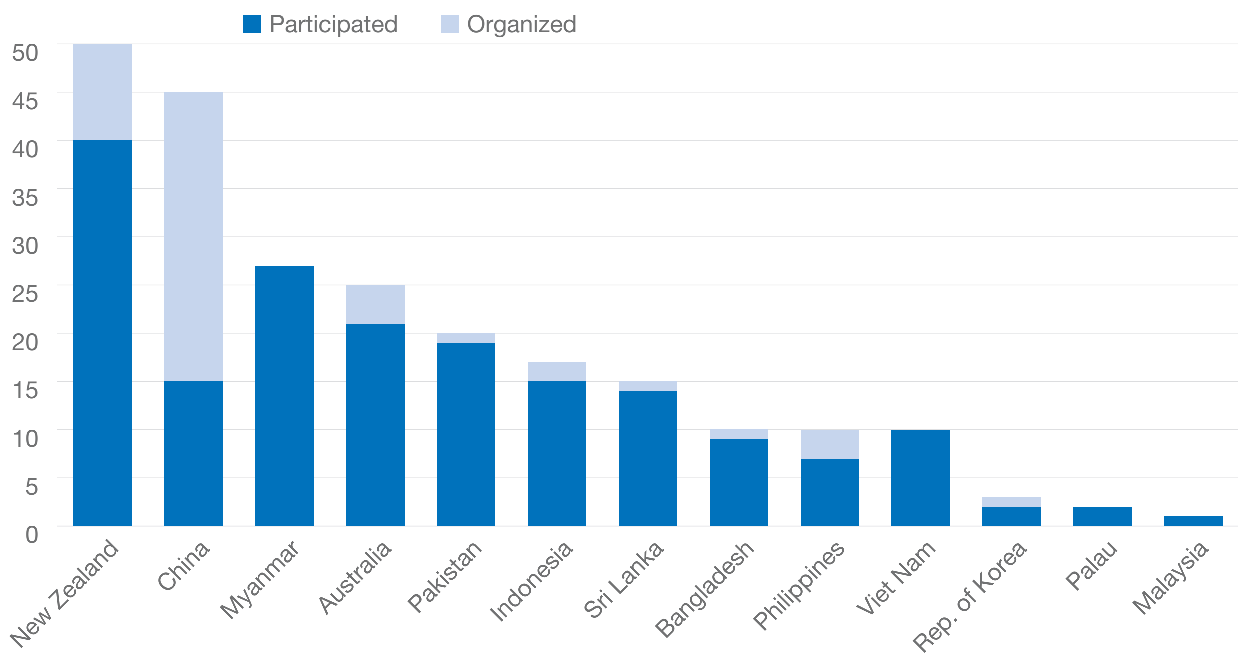


Table V–3. Participation of countries in international conferences and workshops on transboundary air pollution monitoring and assessment.

Country	Participated	Organized	Personnel
New Zealand	50	10	15
China	45	30	60
Myanmar	27	0	10
Australia	25	3	15
Pakistan	20	1	9
Indonesia	17	2	4
Sri Lanka	15	1	12
Viet Nam	10	0	8
Bangladesh	10	1	5
Philippines	10	3	10
Republic of Korea	3	1	3
Palau	2	0	2
Malaysia	1	0	1

Table V–3 details the participation of countries in international conferences and workshops on transboundary air pollution monitoring and assessment, including the number of conferences attended and organized and the number of national personnel involved. Between 2000 and 2023, a total of 154 national personnel from these countries took part in conferences as a result of their involvement in the RCA AQM programme. This participation highlights the programme's role in enhancing expertise and fostering international collaboration to address transboundary air pollution issues.

V–5.2. International projects in air pollution monitoring and assessment

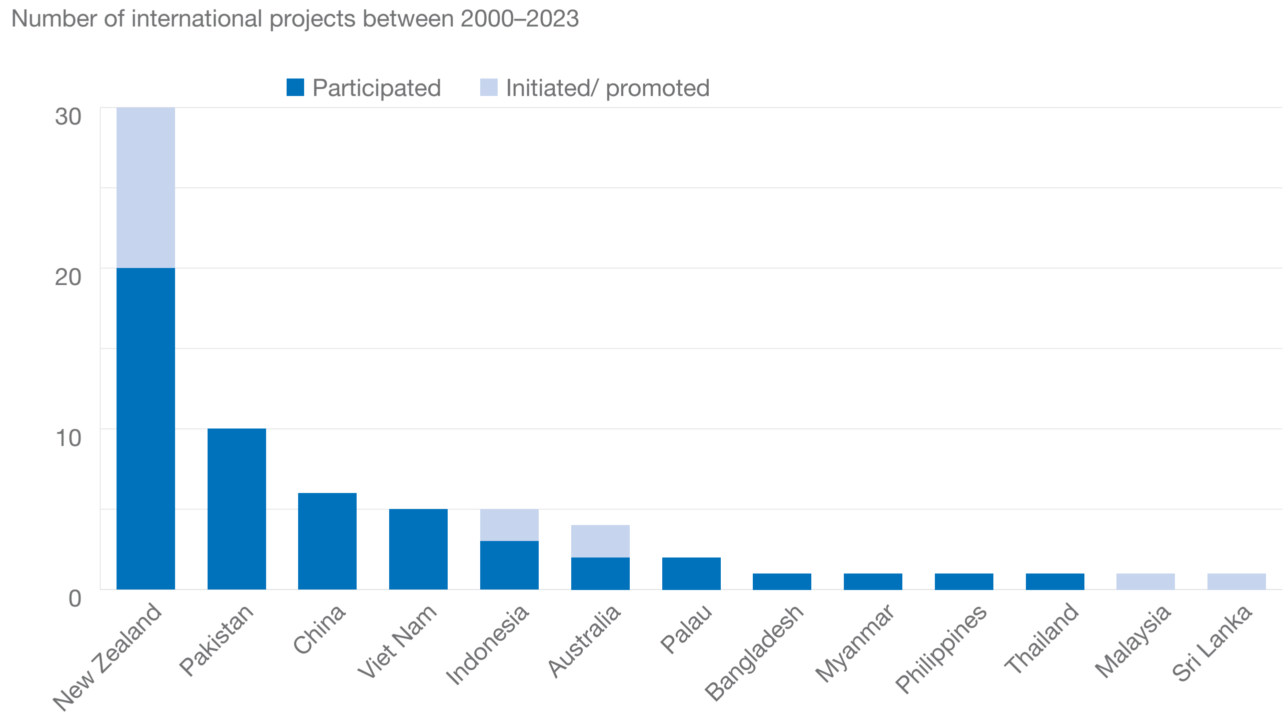
International projects in air pollution monitoring and assessment refer to collaborative efforts between countries or international organizations aimed at addressing air pollution on a global or regional scale. Overall, these projects aim to tackle air quality challenges that transcend national borders, leveraging collective expertise and resources to improve air quality and public health on a broader scale.

Figure V–10 provides an overview of the participation of SPs in international projects related to air pollution monitoring and assessment as a result of their involvement in the RCA AQM programme between 2000 and 2023. It also highlights the number of projects that each country has initiated or promoted.

A total of 13 RCA signatory countries have engaged in international projects, collectively participating in 68 projects during this period. New Zealand leads with participation in 30 projects, demonstrating its commitment to addressing transboundary air pollution. Pakistan and China are involved in ten and seven projects, respectively. Notably, Australia, New Zealand, Indonesia, Malaysia and Sri Lanka have not only participated in these projects but have also initiated or promoted several, further enhancing their contributions to regional and global air quality efforts.

This distribution reflects the engagement by these countries in collaborative efforts to tackle air pollution. New Zealand's prominent role in both participation and promotion of projects underscores its leadership and proactive approach in advancing international air quality initiatives. The involvement of other countries such as Indonesia, Malaysia, and Sri Lanka in initiating projects highlights the broader impact of the RCA AQM programme in fostering international collaboration and leadership in air pollution monitoring and assessment.

FIG. V–10. Number of international projects in AQM.



V–5.3. Awareness among end users on the importance of AQM

Awareness among end users on the importance of AQM refers to the understanding and recognition by individuals, communities or governments of the significance of monitoring air quality and its impact on human health, the environment and overall quality of life. This awareness typically encompasses several key aspects: health implications, environmental impact, data utilization, policy regulation, community engagement, technology and tools. In essence, increasing awareness among end users helps promote proactive engagement in AQM and management, leading to better health outcomes, more effective environmental protection and stronger community involvement in addressing air pollution.

Table V–4 outlines the perceived impact of the RCA AQM programme in terms of raising awareness among end users about the importance of air quality monitoring and assessment between 2000 and 2023. Out of the 19 countries involved in the study, 16 reported initiating activities aimed at increasing awareness as a result of their participation in the RCA AQM programme.

Among these 16 countries, the Philippines, New Zealand and Sri Lanka considered that the level of awareness among end users has significantly improved. In contrast, nine countries observed a moderate increase in awareness, while four countries reported only a minor change.

This distribution highlights the RCA AQM programme’s effectiveness in promoting awareness about air quality issues, though the extent of impact varies. The substantial improvements reported by the Philippines, New Zealand and Sri Lanka suggest that targeted awareness initiatives in these countries have been particularly successful. Meanwhile, the varying degrees of awareness change across other countries indicate that while many have made progress, there is still room for further enhancement in raising awareness and engaging end users in air quality monitoring and assessment.

Table V–4. Impact of the RCA AQM programme on raising awareness among end users about importance of air quality monitoring and assessment between 2000 and 2023.

Country	Activities to create awareness	Extent to which awareness has changed among end users
New Zealand	Yes	To a large extent
Philippines	Yes	To a large extent
Sri Lanka	Yes	To a large extent
Bangladesh	Yes	To a moderate extent
Cambodia	Yes	To a moderate extent
China	Yes	To a moderate extent
Indonesia	Yes	To a moderate extent
Mongolia	Yes	To a moderate extent
Myanmar	Yes	To a moderate extent
Nepal	Yes	To a moderate extent
Pakistan	Yes	To a moderate extent
Viet Nam	Yes	To a moderate extent
Australia	Yes	To a minor extent
Japan	Yes	To a minor extent
Republic of Korea	Yes	To a minor extent
Thailand	Yes	To a minor extent
Fiji	No	N/A
Malaysia	No	N/A
Palau	No	N/A

V–6. Criterion 4: enhanced/established national and regional capacity for air pollution monitoring and assessment

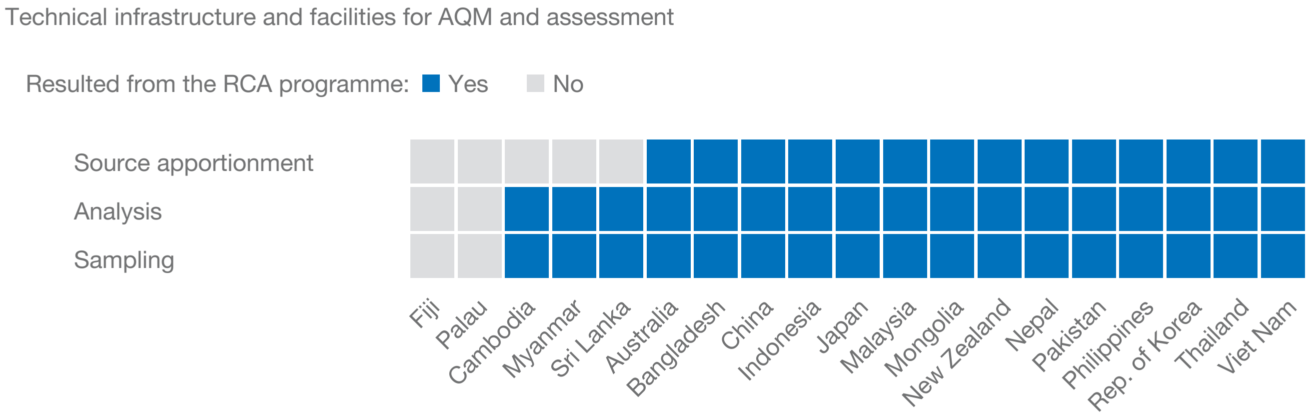
This section presents the findings on the contribution of the RCA AQM programme to enhancing/establishing national and regional capacities for air pollution monitoring and assessment. It assesses the extent to which, as a result of RCA projects, SPs have:

- Obtained the necessary technical infrastructure and facilities for air quality sampling, analysis and source apportionment;
- Contributed to the development of a regional database of air quality samples;
- Obtained the funding commitments by national environmental protection authorities (EPAs) and other end users to national air quality assessment.

The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in the SP having the technical infrastructure and facilities for air quality sampling, analysis and source apportionment; and the SP having contributed to the development of a regional database of air quality samples for more than 10 years; and there are funding commitments by national EPAs and other end users to lead and support others in national air quality assessment.
- **Good:** Participation in the RCA AQM programme results in the SP having the technical infrastructure and facilities for air quality sampling and analysis, but requires external support for source apportionment; and the SP having contributed to the development of a regional database of air quality samples for 8–10 years; and there are funding commitments by national EPAs and other end users to sustain national air quality assessment.
- **Adequate:** Participation in the RCA AQM programme results in the SP having the technical infrastructure and facilities for air quality sampling, but requires external support for analysis and source apportionment; and the SP having contributed to the development of a regional database of air quality samples; and there are funding commitments by national EPAs and other end users to undertake some national air quality assessment.
- **Minor:** Standard for adequate not met.

FIG. V–11. Availability of technical infrastructure and facilities among SPs for conducting air quality sampling, analysis and source apportionment.



V–6.1. Technical infrastructure and facilities

Technical infrastructure and facilities to conduct air quality sampling, analysis and source apportionment refer to the physical and technical resources required to effectively monitor, measure and understand air quality. This encompasses a range of equipment, systems and facilities necessary for comprehensive air quality management: sampling equipment, monitoring stations, laboratories, analytical instruments, source identification tools and emission inventories, among others. Overall, having robust technical infrastructure and facilities is crucial for effective AQM, enabling precise measurement, detailed analysis and informed decision-making to manage and mitigate air pollution.

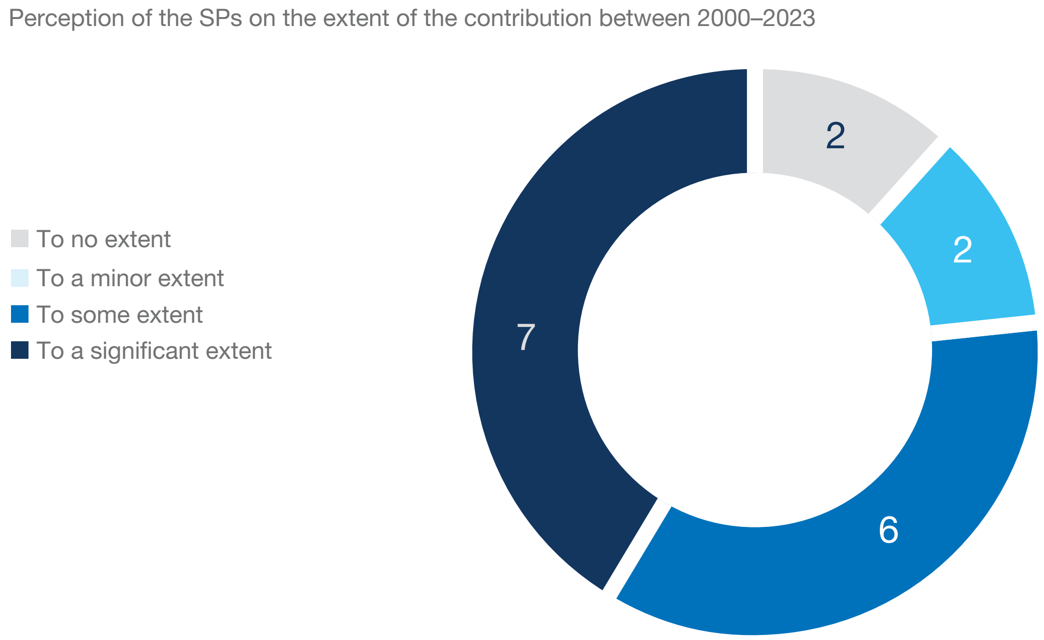
Figure V–11 illustrates the availability of technical infrastructure and facilities among SPs for conducting air quality sampling, analysis and source apportionment. According to the chart, all countries except Fiji and Palau possess the necessary technical infrastructure and facilities for air quality sampling and analysis. Additionally, 14 out of the 19 countries have the technical resources required for source apportionment. This indicates that while most countries are equipped to carry out comprehensive AQM and analysis, there is a notable gap in source apportionment capabilities for some, underscoring areas where further development could enhance overall air quality management.

V–6.1.1. Contribution of the RCA AQM programme to the development of technical infrastructure

Figure V–12 provides insights into the impact of the RCA AQM programme on the development of technical infrastructure and facilities for air quality monitoring and assessment from 2000 to 2023. Among the 17 countries with existing technical infrastructure, seven report that the RCA AQM programme contributed significantly to the development of these facilities. Additionally, six countries acknowledge a moderate contribution, while two countries recognize a minor impact, and two countries report no contribution from the RCA AQM programme.

This distribution highlights that the role that the RCA AQM programme has played in enhancing technical infrastructure for many countries, with a notable number recognizing its substantial impact. The variation in reported contributions suggests that while the programme has made significant strides in some areas, there is variability in its effectiveness across different countries. This underscores both the successes of the programme in advancing AQM capabilities and the need for targeted efforts to address gaps in support for other countries.

FIG. V–12. Perception of SPs on the extent of the RCA contribution to technical infrastructure.



V–6.2. Regional databases of air quality samples

A regional database of air quality samples is a comprehensive, organized collection of data on air quality measurements gathered from multiple locations within a specific region. This database typically includes information on various air pollutants and is used to track, analyze and manage air quality over a broader geographic area. A regional database of air quality samples is a crucial tool for effective air quality management, providing valuable insights for policymakers, researchers and the public to address and mitigate air pollution issues on a regional scale.

Table V–5 provides an overview of the duration each country has been contributing to the development of regional databases for air quality samples, as well as the extent to which the RCA AQM programme has enhanced their capacity to do so between 2000 and 2023.

As indicated, nine countries have been actively contributing to regional air quality databases for over a decade. Of these, seven countries report that the RCA AQM programme has made a significant contribution to their capacity to support these databases. This suggests that the RCA AQM programme has played a crucial role in strengthening the technical and logistical abilities of these countries, enabling them to maintain and enhance their contributions to regional AQM efforts. The sustained involvement of these countries highlights the programme's effectiveness in fostering long term commitment to regional data sharing and air quality management.

Table V–5. Duration that each country has been contributing to the development of regional databases for air quality samples.

Country	Time contributing	RCA contribution
Australia	More than 10 years	To a significant extent
Bangladesh	More than 10 years	To some extent
China	More than 10 years	To a significant extent
Indonesia	More than 10 years	To a significant extent
New Zealand	More than 10 years	To a significant extent
Philippines	More than 10 years	To a significant extent
Republic of Korea	More than 10 years	To a significant extent
Sri Lanka	More than 10 years	To a significant extent
Viet Nam	More than 10 years	To some extent
Malaysia	Between 8 and 10 years	To a significant extent
Pakistan	Between 8 and 10 years	To a significant extent
Mongolia	Between 8 and 10 years	To some extent
Palau	Less than 8 years	N/A
Cambodia	Does not contribute	To a minor extent
Japan	Does not contribute	To no extent
Myanmar	Does not contribute	To no extent
Nepal	Does not contribute	To no extent
Thailand	Does not contribute	To no extent
Fiji	Does not contribute	N/A

V–6.3. Funding commitments by national environmental protection authorities

Table V–6 presents the perceptions of SPs regarding the adequacy of funding commitments by national EPAs and other end users for air quality assessment activities. According to the table, three countries (Cambodia, Malaysia and New Zealand) believe that their funding commitments are sufficient to both lead and support others in national air quality assessment efforts. Meanwhile, six countries (Australia, China, Indonesia, Nepal, the Republic of Korea and Sri Lanka) feel that their funding is adequate to sustain ongoing air quality assessment activities. In contrast, four countries view their funding as sufficient only for undertaking some aspects of national air quality assessment, and six countries report a lack of funding commitments altogether.

Table V–6. Perceptions SPs regarding the adequacy of funding commitments by national EPAs.

Country	The funding commitments by national EPAs is enough:
Cambodia	To lead and support others in national air quality assessment
Malaysia	To lead and support others in national air quality assessment
New Zealand	To lead and support others in national air quality assessment
Australia	To sustain air quality assessment
China	To sustain air quality assessment
Indonesia	To sustain air quality assessment
Nepal	To sustain air quality assessment
Republic of Korea	To sustain air quality assessment
Sri Lanka	To sustain air quality assessment
Bangladesh	To undertake some national air quality assessment
Mongolia	To undertake some national air quality assessment
Philippines	To undertake some national air quality assessment
Thailand	To undertake some national air quality assessment
Fiji	There are no funding commitments
Japan	There are no funding commitments
Myanmar	There are no funding commitments
Pakistan	There are no funding commitments
Palau	There are no funding commitments
Viet Nam	There are no funding commitments

V–7. Criterion 5: influence on policy and behaviour change

This section presents the findings about the contribution of the RCA AQM programme to influencing human health and environmental regulations, policy decisions and interventions, enforcement and behaviour change. It assesses the extent to which RCA has influenced:

- New regulations and changes to existing regulations relating to air quality;
- Policy decisions and interventions relating to air quality;
- Levels of enforcement of air quality standards and regulations;
- New air pollution programmes or changes to existing air pollution programmes;
- Population behaviour change relating to air quality.

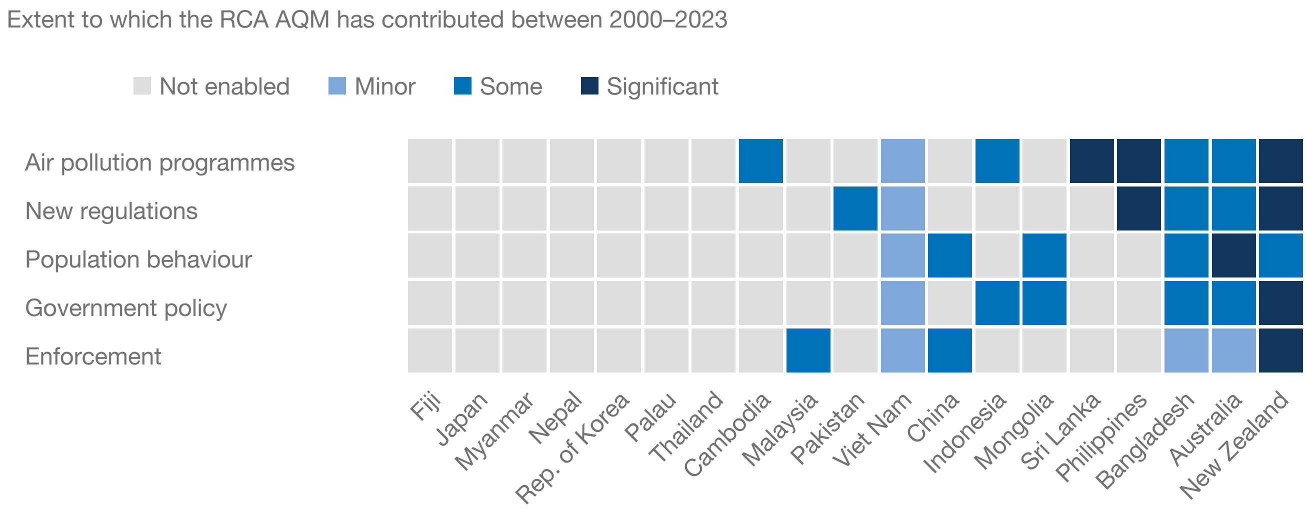
The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in a significant increase in new regulations or changes to existing regulations; or policy decisions and interventions; or levels of enforcement; or number of pollution programmes; or evidence of population-level behaviour change.
- **Good:** Participation in the RCA AQM programme results in some increase in new regulations or changes to existing regulations; or policy decisions and interventions; or levels of enforcement; or number of pollution programmes; or evidence of population-level behaviour change.
- **Adequate:** Participation in the RCA AQM programme results in any increase in new regulations or changes to existing regulations; or policy decisions and interventions; or levels of enforcement; or number of pollution programmes; or evidence of population-level behaviour change.
- **Minor:** No material increase in any of new regulations or changes to existing regulations, policy decisions and interventions, levels of enforcement, number of pollutions programmes, or evidence of population-level behaviour change.

V–7.1. Influence on policy behaviour

Influence on policy and people’s behaviour refers to the role that the RCA AQM has in contributing to governmental regulations and individual actions. This assessment aims to understand how RCA AQM’s activities—such as training personnel, facilitating critical air quality data and enhancing international cooperation—drive legislation creation, inform urban planning and support public health policies aimed at reducing pollution. Additionally, it evaluates whether these activities increase awareness and promote sustainable lifestyle choices among individuals.

FIG. V–13. Extent to which the RCA AQM has contributed to influence policy and behaviour.



To assess this impact, SPs were asked whether their countries' participation in the RCA AQM programme from 2000 to 2023 resulted in, or enabled, any of the outcomes listed above and to what extent.

As shown in Fig. V–13, RCA AQM has contributed to the creation or modification of air pollution programmes in eight countries (Australia, Bangladesh, Cambodia, Indonesia, New Zealand, Philippines, Sri Lanka and Viet Nam). In New Zealand, the Philippines and Sri Lanka, RCA AQM significantly influenced the creation of these programmes. Additionally, it contributed to the establishment or modification of air quality regulations in six countries (Australia, Bangladesh, New Zealand, Pakistan and the Philippines).

Overall, RCA AQM has made at least one contribution across these dimensions in 12 countries, indicating a broad influence on both policy and behaviour. All details regarding the RCA AQM's impact on these dimensions can be explored in Fig. V–13.

Table V–7 provides further explanations from SPs on the policy and behaviour change resulting from participation in the RCA AQM programme between 2000 and 2023.

Table V–7. Detailed explanations from SPs on the policy and behaviour change resulting from participation in the RCA AQM programme between 2000 and 2023.

Country	Dimension	SP explanation
Australia	New regulations	Australia has reduced its national PM2.5 annual and daily goals from 15 µg /m^3 and 35 µg /m^3 to 8 µg /m^3 and 25 µg /m^3 over the period 2000–2023. New South Wales (NSW) Health Dept has now commenced regular modelling using PM2.5 data to estimate 420 people a year die prematurely from air pollution in the State of NSW alone.
Australia	Government policy	Data from the RCA programme was used in Royal Commission and Senate enquires into Australian major bushfire events and what can be done in the future.
Australia	New regulations	New lower national environmental protection goals (national environment protection measures or NEPMs) for industry were introduced over the period for industry, were reviewed and lowered systematically over the study period and will continue to be reassessed and lowered in 2025.
Australia	Air pollution programmes	Databases and end user programmes over the study period highlighted the need for source apportionment studies to better determine what source were contributing to PM2.5 pollution. For example, industrial ammonium nitrate manufacturers in Newcastle, NSW spent an extra $35M on their Prill Plant to reduce their ammonium sulphate emissions as a consequence of data obtained within the RCA programme.
Australia	Population behaviour	The RCA programme provided several datasets to community action groups, local councils in rural NSW and in industrial areas in Newcastle.
Bangladesh	New regulations	Between 2000 and 2023, Bangladesh implemented several new regulations and amendments to existing laws aimed at improving air quality and journal publication from the outcome of RCA AQM programme are useful information for the policy makers. Key developments include 1) Air Pollution Control Rules 2021: introduced during March 2022, new air pollution control rules, which set emission standards. 2) Vehicle Emission Standards: lifetime of buses and trucks to 20 and 25 years. 3) Brick Kiln Regulations: phase out traditional clay brick kilns by 2028, which is a major contributor to air pollution. 4) Environmental Conservation Rules 2023: address industrial emissions and managing waste to minimize environmental impact.
Bangladesh	Government policy	Between 2000 and 2023, Bangladesh implemented several new regulations and amendments to existing laws aimed at improving air quality. Also, journal publications from the outcome of RCA AQM programme are useful information for the policy makers. Key developments include Air Pollution Control Rules 2021: introduced during March 2022, new air pollution control rules which set emission standards. Vehicle Emission Standards: lifetime of buses and trucks to 20 and 25 years. Brick Kiln Regulations: phase out traditional clay brick kilns by 2028, which is a major contributor to air pollution. Environmental Conservation Rules 2023: address industrial emissions and managing waste to minimize environmental impact.
Bangladesh	New regulations	Bangladesh's participation in the RCA AQM programme between 2000 and 2023 led to several improvements in the enforcement of air quality. Development and Implementation of Regulations: The RCA AQM programme facilitated the creation and enhancement of air quality regulations in Bangladesh, including the Air Pollution Control Rules of 2021 and the Environmental Conservation Rules of 2023. Monitoring, Reporting & Awareness: The programme emphasized the importance of monitoring air quality data on PM2.5 and PM10. This led to improved capacity within the Department of Environment (DoE) for AQM, including the installation of AQM stations across major cities as well as focused on raising public awareness.

Country	Dimension	SP explanation
Bangladesh	Air pollution programmes	The RCA AQM programme significantly contributed to the development and enhancement of air pollution control efforts in Bangladesh between 2000 and 2023. By providing technical assistance, funding and capacity building support, the RCA AQM programme facilitated the creation of new regulations such as the Air Pollution Control Rules of 2021 and the Environmental Conservation Rules of 2023. These regulations established comprehensive emission standards and monitoring protocols for both mobile and stationary sources. The programme also helped improve AQM infrastructure, leading to better data collection and reporting. Despite these advancements, enforcement remains a challenge, highlighting the need for ongoing support.
Bangladesh	Population behaviour	The RCA AQM programme played a notable role in influencing population behaviour regarding air quality in Bangladesh between 2000 and 2023. Through awareness campaigns and educational initiatives, the programme raised public consciousness about the health impacts of air pollution and the importance of adhering to air quality regulations. These efforts included community engagement activities, media outreach and stakeholder workshops. Subsequently using the RCA AQM data, a significant number of journal publications on pollution assessment, source identification and impact of pollution on human health have been published in high impact factor journals, which might have significant impact on the population behaviour change relating to air quality.
China	New regulations	The results obtained from these projects provided an essential basis to pollution regulators, such as the EPAs, for developing policies and standards in relation to air pollution.
China	Population behaviour	People reduce the utilization of cars that run on fossil fuels instead they prefer to drive electric cars.
Indonesia	Government policy	The AQM project, which focuses on APM characterization and source apportionment, has provided important data on the chemical species of APM in Indonesia, including high levels of heavy metal contamination at several sampling sites that are hazardous to public health. These findings have prompted the Ministry of Environment (MoE) and the Local Environmental Protection Agency (EPA) to conduct regular monitoring during 2012–2018, including the impact of heavy metals on human health and the environment and an inventory of industrial emissions. They are also conducting outreach to industrial workers, especially those involved in heavy metal smelting in both formal and non-formal industries, to improve the safety and health of workers and the environment.
Indonesia	Air pollution programmes	Through regional AQM and reinforced by national projects, Indonesia, which previously had no data on PM2.5, has been able to establish a database on PM2.5 and PM10. Sampling has been extended to 16 sites in collaboration with the MoE, local EPAs and universities. Human resource development has been carried out through workshops and training on sampling, source apportionment and long range transport during 2012 – 2018. Achievements of the project include the successful identification of air quality problems, the effectiveness of government policy on unleaded petrol, and the identification of the source of Pb pollution in South Tangerang. It was found to be caused by the smelting industry and not the Siwabessy nuclear reactor, which had previously been blamed.
Malaysia	New regulations	The yearly Malaysian Ambient Air Quality Standard (MAAQS - 2020 interim) for PM2.5 and PM10 was changed to 15 µg /m^3 and 40 µg /m^3, respectively.

Country	Dimension	SP explanation
Mongolia	Government policy	As part of the fight against air pollution, the Ulaanbaatar city administration has been taking measures to increase the city's lawn, tree planting and car air pollution tariffs. The Government has been taking measures to expand urbanization through the expansion of construction and apartments to reduce emissions of Ger area and building new energy and heat sources. There are some positive changes in fighting air pollution in urban areas, especially in winter, when emissions from the Ger areas are reduced.
Mongolia	Population behaviour	In the framework of RCA contribution, Mongolia introduced AQM tools based on nuclear techniques. With the support of the RCA and regional projects, the Nuclear Research Centre of the National University of Mongolia established an AQM laboratory and has been sampling, analyzing data and providing the results to the air quality administration of Ulaanbaatar city. The results are more comprehensive and detailed in terms of air pollutants and source identification. The Centre also publishes and promotes its results of analysis of air pollution to the public and other stakeholders. Therefore, the public is aware of the nuclear techniques that analyze air pollution and make them understand the key pollutants.
New Zealand	New regulations	As a result of particulate matter composition analysis and source apportionment, it was identified that the levels of sulphur in automotive fuels were having a disproportionate impact on urban air quality with respect to fine particle emissions. From 2007 – 2010, new national regulations were introduced to reduce the allowable sulphur concentrations in automotive fuels from 500 ppm to 10 ppm for petrol and 3000 ppm to 10 ppm for diesel products (Petroleum Products Specifications Regulations 2007, https://www.legislation.govt.nz/regulation/public/2007/0088/latest/whole.html). Subsequent monitoring has shown the dramatic decrease in secondary sulphate aerosol associated with automotive emissions.
New Zealand	Government policy	From the observation that there were high levels of arsenic associated with particulate matter during the winter in New Zealand urban environments, it was concluded that this was the result of contaminated fuels being used in solid fuel fires for domestic space heating. In 2004 regulations were introduced banning the burning of treated timber products that contained arsenic and other heavy metal contaminants (Resource Management National Environmental Standards for Air Quality Regulations 2004, https://www.legislation.govt.nz/regulation/public/2004/0309/latest/DLM286835.html).
New Zealand	New regulations	The New Zealand National Environmental Standards for Air Quality were introduced in 2004. The standards impose restrictions on airsheds that exceed concentrations of criteria pollutants and regulatory authorities must manage air quality and emission sources to ensure compliance. The AQM and source apportionment work instituted under the RCA AQM programme has been instrumental in identifying the sources of pollution and their contributions to peak concentrations so the air quality can be managed effectively. The introduction of various regulatory (e.g. wood burner standards) and incentivized programmes has led to a downward trend in urban air pollution.
New Zealand	Air pollution programmes	In 2004 an air particulate matter monitoring and speciation network was established across five sites in New Zealand's largest city (Auckland) to monitor air quality and associated toxic contaminants and identify the contributing sources. The monitoring network is still in operation and has significantly influenced the management or urban air quality in Auckland and provided data on the long term trends for key sources that inform air quality management for all New Zealand urban centres. Additionally, the monitoring has allowed the identification of sources contributing to peak events that were outside of regulatory authority control and therefore exempt from National Environmental Standards for Air Quality.

Country	Dimension	SP explanation
New Zealand	Population behaviour	Extensive surveys and social media campaigns have been undertaken to improve urban air quality by encouraging switching to cleaner residential space heating and avoiding the use of contaminated fuels in solid fuel fires. This has driven down peak winter pollution levels in many urban centres but the use of contaminated fuels still poses a challenge for the release of toxic contaminants such as lead and arsenic.
Pakistan	New regulations	Between 1998 and 2001, Pakistan carried out analysis of air particulate samples collected during Pakistan Environmental Protection Agency (PAK-EPA) and JICA joint studies on the air quality of major cities of Pakistan (Lahore, Rawalpindi, Faisalabad etc.). Moreover, they collected and analyzed air particulate samples at a site in Islamabad from 2001 to 2011. Sharing the results with PAK EPA led to changes in National Environmental Quality Standards in January 2012. Collaboration with PAK-EPA is still on-going and sampling was carried out at an industrial site in Islamabad in 2023 with the assistance of PAK-EPA. However, due to increasing population and industrialization the air quality of Islamabad has not improved.
Philippines	New regulations	The RCA AQM programme influenced the adoption of the interim guideline values for PM2.5, which then necessitated the Philippines local Environmental Management Bureau (EMB) to have more PM2.5 monitoring stations in place. The Philippines were part of the Technical Working Group (TWG).
Philippines	Air pollution programmes	The Philippines had air pollution source apportionment studies funded by the local EMB, also submitted to an international funding agency and to the National Research Council of the Philippines. Recently, EMB has been commissioning studies on air pollution source apportionment, not exactly to The Philippine Nuclear Research Institute (PNRI) but to a consultant who also learned this technique from PNRI.
Viet Nam	New regulations	1) The Prime Minister decided to deploy the use of unleaded gasoline starting from 1 July 2001 throughout the territory of Viet Nam (Directive 24/2000/CT-TTg of the PM). 2) Directive No. 15/CT-UBND of the Hanoi City People's Committee dated 30 October 2019 on replacing and eliminating all honeycomb charcoal stoves as fuel in daily life, business and services. 3) Directive No. 03/CT-TTg dated 18 January 2021 on strengthening control of air pollution; Technical guidance of the MONRE in document No. 3051/BTNMT-TCMT dated 7 June 2021. National technical regulation on Air Quality: QCVN 05: 2023 (Circular No. 01/2023/TT-BTNMT dated 13 March 2023): the 24-hour average PM2.5 concentration will be 45 $\mu g/m^3$ and will be applied from 1 January 2026.
Viet Nam	Government policy	Directive No. 03/CT-TTg dated 18 January 2021 of the Prime Minister on strengthening control of air pollution.
Viet Nam	New regulations	National Technical Regulation on Air Quality: QCVN 05: 2023 (Circular No.01/2023/TT-BTNMT dated 13 March 2023): the maximum limit value of 24-hour average PM2.5 concentration will be 45 $\mu g/m^3$ and will be applied from 1 January 2026 (currently 50 $\mu g/m^3$ according to QCVN 05:2013).
Viet Nam	Air pollution programmes	Technical guidance on developing air environment quality management plans in provinces and centrally run cities (provincial level) according to the provisions of the Law on Environmental Protection dated 17 November 2020 and Decision No. 985a /QD-TTg dated 1 June 2016 of the Prime Minister on approving the National Action Plan on Air Quality Management to 2020, vision to 2025.
Viet Nam	Population behaviour	People are gradually changing their awareness, habits and lifestyle, sharing information and acting together to protect the environment.

V–8. Criterion 7: Improved protection of human health and environment[4]

This section presents the findings on the contribution of the RCA AQM programme to improved protection of human health and environment. It assesses the extent to which RCA has contributed to reductions in exposure to air pollution (thus contributing to reduced mortality, morbidity and environmental and material damages) and improved visibility.

The standards (levels of performance) for the fulfilment of this criterion are the following:

- **Excellent:** Participation in the RCA AQM programme results in a significant reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity and environmental and material damages, and improvement in visibility);
- **Good:** Participation in the RCA AQM programme results in some reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity and environmental and material damages, and improvement in visibility);
- **Adequate:** Participation in the RCA AQM programme results in any reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity and environmental and material damages, and improvement in visibility);
- **Minor:** No material reduction in exposure to air pollution (and consequently, no reductions in mortality, morbidity and environmental and material damages, and no improvement in visibility).

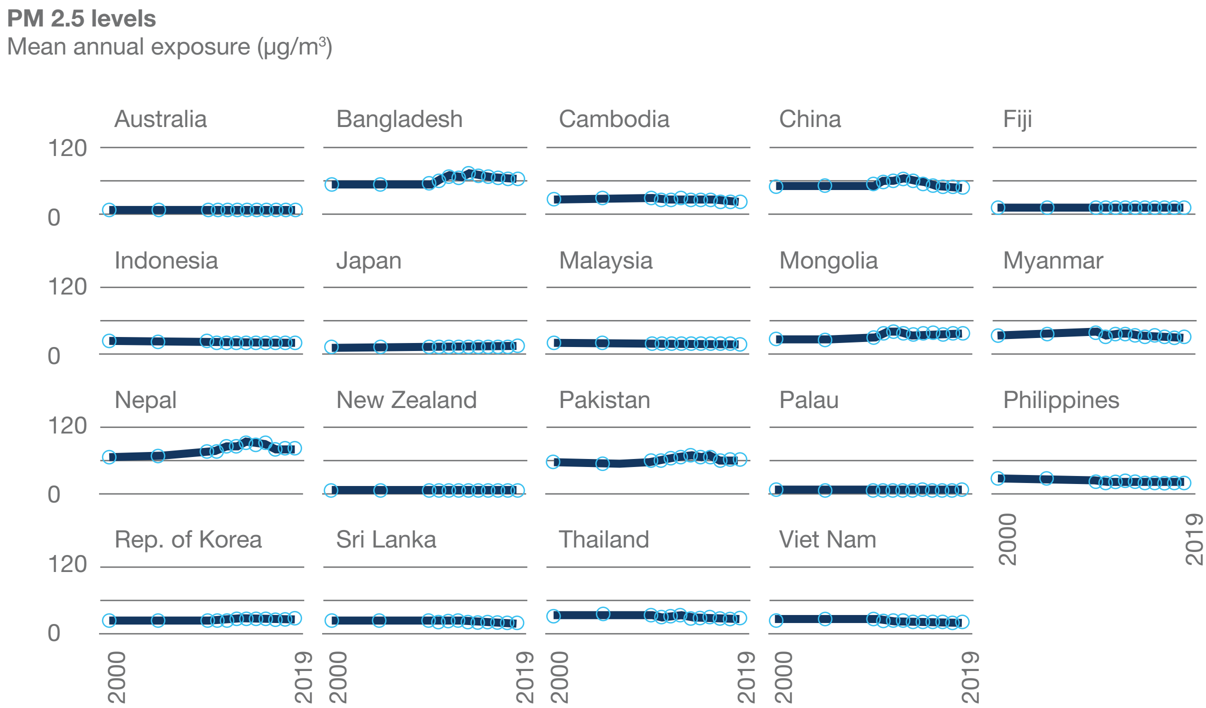
V–8.1. Evolution of PM 2.5 levels over time

Air pollution, PM2.5, refers to fine particulate matter with a diameter of 2.5 μm or smaller. These tiny particles can be inhaled deep into the lungs, posing serious health risks such as respiratory and cardiovascular problems. Pollution (PM2.5) often comes from sources such as vehicle emissions, industrial processes and wildfires and is a significant concern for air quality and public health [1].

To evaluate the effectiveness of air quality management and the progress in reducing exposure to PM2.5, data on mean annual PM2.5 levels (measured in micrograms per cubic meter) were analyzed over time. The analysis covers the period from 2000 to 2019 and beyond, offering insights into the trends across different countries; key findings are (Fig. V–14):

[4] Criterion 6 is discussed in Annex VI.

FIG. V-14. Evolution of PM 2.5 levels (mean annual exposure) over time (Courtesy of World Bank Group) [V–2].



1. **Decreasing PM2.5 levels (2000–2019):** In 11 countries, including Australia, Cambodia, China, Indonesia, Malaysia, Myanmar, New Zealand, the Philippines, Sri Lanka, Thailand and Viet Nam, PM2.5 levels have decreased over the period from 2000 to 2019.

2. **Recent decrease in selected countries:** In Bangladesh, Nepal, Pakistan and Palau, despite an overall increase in PM2.5 levels from 2000 to 2023, there was a reduction in 2019 compared to 2015.

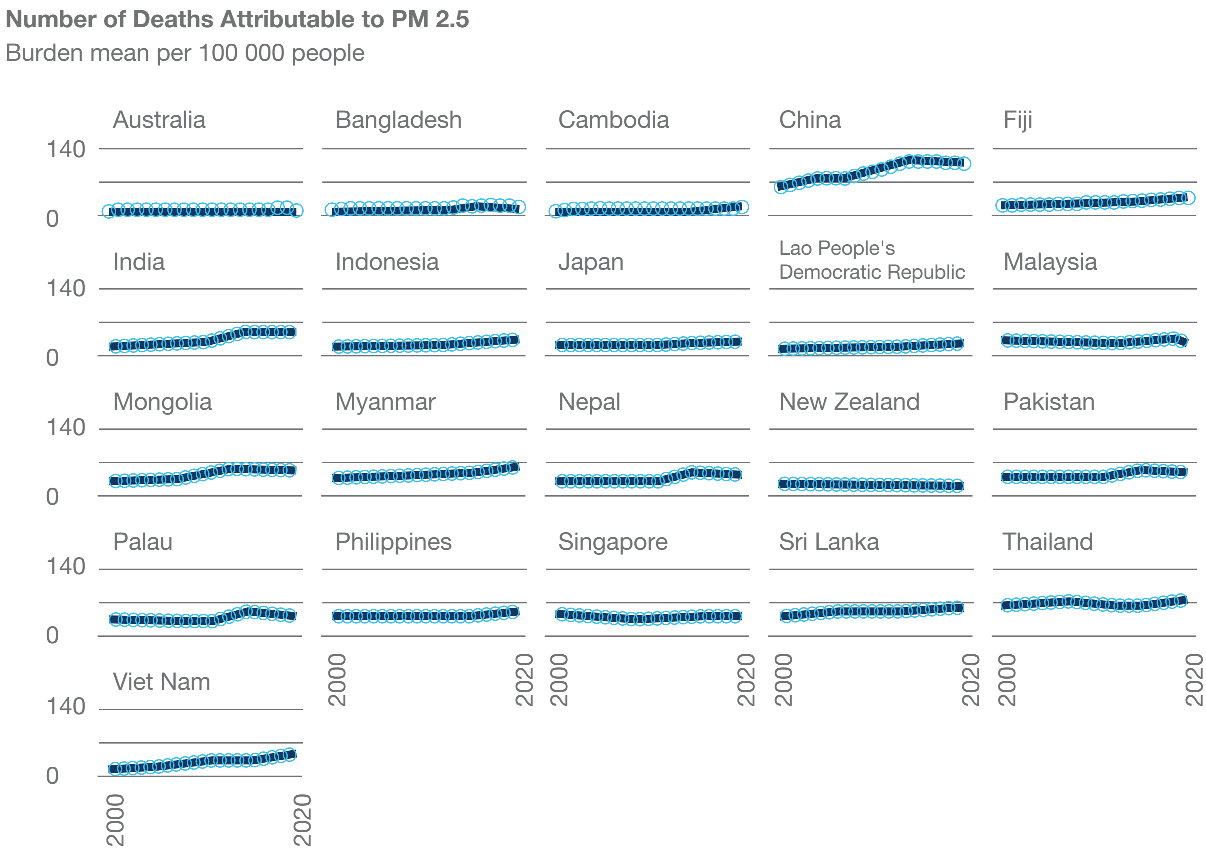
3. **Deceleration in PM2.5 trends:** Japan and the Republic of Korea experienced higher PM2.5 levels in 2019 compared to 2015, but the trend has shown deceleration compared to the more rapid increase observed from 2011 to 2015.

4. **Stable or increasing trends:** In Mongolia and Fiji, the PM2.5 trend has not shown a decrease or deceleration. This analysis highlights the varied progress across countries in managing PM2.5 pollution and the impact of air quality interventions over time.

V–8.1.1. Evolution of the number of deaths attributable to PM 2.5 over time

Long term exposure to high levels of PM2.5 is associated with increased mortality rates due to conditions such as heart attacks, strokes and chronic respiratory diseases [V–3, V–4]. Fig. V–15 illustrates the evolution of the number of deaths attributable to PM2.5 pollution over time, expressed as deaths per 100 000 people [V–5].

FIG. V–15. Evolution of the number of deaths attributable to PM 2.5 over time [V–5].



Using deaths per 100 000 people, rather than aggregate figures, allows for a more accurate comparison of PM2.5 related mortality across different regions and over time, regardless of population size. Aggregate death figures can be misleading, as larger populations will naturally have more deaths, even if the air quality is similar. By normalizing the data to a fixed population size, this measure accounts for population growth and provides a clearer understanding of the relative health impact of pollution in different contexts.

However, it is important to note that changes in the number of deaths attributable to PM2.5 over time are influenced by many factors outside the RCA's control. It is not possible to accurately measure the RCA's impact without a clear comparison of what the death rate would have been without their AQM efforts.

Additionally, modelling this impact would be problematic because the uncertainty in the estimated yearly death from PM2.5 likely outweighs the size of the RCAs contributions to reducing those deaths. Therefore, though the number of deaths is of interest to the RCA, it does not contribute towards judgements about the RCA's performance and value.

Key observations are:

1. **Overall trend (2000–2020):** The death burden from PM2.5 has increased in all countries analyzed except for New Zealand and Singapore. Trends in the number of deaths are at least partially driven by population growth and demographic shifts such as ageing over the period.

2. **Decreases in specific countries:** For nine countries— Bangladesh, China, India, Japan, Malaysia, Mongolia, Nepal, Pakistan and Palau —the estimated deaths caused by PM2.5 pollution decreased in 2020 compared to 2015. This analysis highlights varying trends in PM2.5 related mortality across different countries, reflecting both the progress made in some areas and ongoing challenges in others.

V–8.2. Contribution of the RCA AQM programme to human health and environment

Fig. V–16 shows the perception of the SPs about the extent to which the RCA AQM programme has contributed to the following:

- Decrease/deceleration in PM 2.5 levels;
- Reduction in environmental damages (caused by air pollution);
- Reduction in material damages (caused by air pollution);
- Improvement in visibility (reduced haze).

Perceived significant contributions:

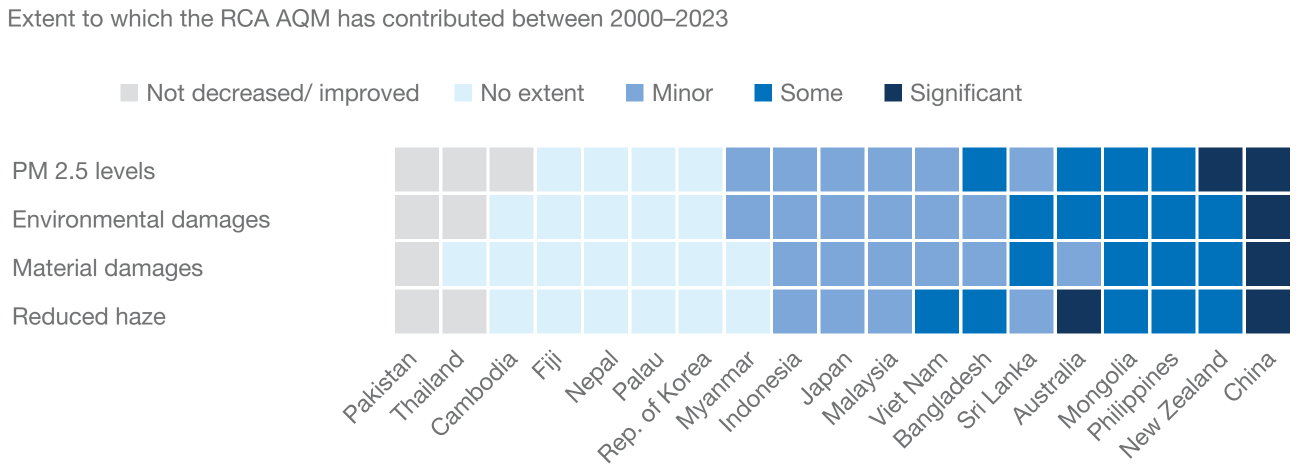
Countries such as Australia, China, Mongolia, New Zealand, the Philippines and Viet Nam report that the RCA AQM programme has contributed to a significant or some extent to reducing PM2.5 levels. This perception aligns with the observed data showing that PM2.5 levels have decreased in these countries from 2000 to 2019 (except for Mongolia, where PM2.5 levels have increased). Similarly, Australia, New Zealand and Viet Nam show trends of decreasing PM2.5 levels, suggesting that the RCA AQM programme's interventions might be positively influencing these trends.

Perceived minor contributions:

In contrast, countries such as Indonesia, Japan, Malaysia, Myanmar, the Republic of Korea and Sri Lanka perceive the RCA AQM programme as having only a minor contribution to reducing or decelerating PM2.5 levels (Fig. V–16). This perception is supported by data indicating that while these countries have seen some improvements in air quality, these changes might be influenced by a range of factors, with the RCA AQM programme being one among several contributing elements. For example, Japan has experienced improvements in air quality, but these trends could also be due to other factors or policies beyond the RCA AQM programme. Similarly, in Indonesia, Myanmar, Malaysia and Sri Lanka, the observed improvements might be incremental and influenced by a combination of factors, including local regulations, economic changes and other environmental initiatives.

These findings underscore that while the RCA AQM programme is recognized for its contributions in several countries, its impact on PM2.5 levels is often part of a complex interplay of factors affecting air quality.

FIG. V–16. Extent to which the RCA AQM programme has contributed to improvements in health and environment.



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Annex VI: Economic analysis

VI–1. Summary and discussion

An economic framework was developed to estimate economic benefits *enabled by* the the Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA) air quality monitoring (AQM) activities being evaluated, for comparison with the costs of those activities. The objective was to assess whether it is likely that the RCA activities generated enough benefits to justify the associated costs.

The benefits enabled by the RCA AQM activities come from avoided costs of ambient air pollution, compared to what would have occurred in the absence of the RCA activities. Due to the indirect nature of the impacts of RCA activities on actual air quality and substantial uncertainties about the size of these impacts, it is not possible to precisely calculate the value of benefits of the RCA activities. Instead, the economic analysis aims to assess how likely it is that the benefits enabled by the RCA activities exceeded the costs of those activities.

Benefits include all potential sources of social and economic value that are affected by ambient air pollution, but in practice only impacts on human health could be quantified. This means that the benefits enabled by the RCA activities are probably under estimated, as air pollution also has other social and environmental costs that could not be estimated.

The analysis is based on estimates of the premature mortality and morbidity costs of ambient air pollution produced by the World Bank Group [VI–1], and the impacts of the RCA activities on air quality policy, regulations, and enforcement using information from the survey of experts described in Annex V. Direct and indirect costs of the relevant RCA activities were also estimated for comparison with costs. Benefits and costs were assessed over the period from 1999 to 2021.

The analysis suggests that it is very likely that the RCA activities being evaluated enabled more benefits than the costs of the programme by enabling other actions that led to improvements in ambient air quality relative to what would have occurred in the absence of the RCA activities. Across a wide range of assumptions, including highly conservative assumptions, benefits enabled by the RCA activities exceeded costs in 97% of the scenarios tested.

There is strong evidence that the RCA activities contributed to changes in air quality policies, standards and enforcement in some RCA countries, and these changes are likely to have improved air quality and reduced the associated costs of mortality and morbidity, relative to outcomes in the absence of the RCA. The human health costs of ambient air pollution in RCA countries are very large, and even a small contribution to mitigating these costs is a significant benefit. However, as changes in actual air quality also depend on other factors such as political support, investment by governments and businesses and behaviour change, it is not possible to directly attribute the estimated benefits to the RCA activities.

VI–2. Overview of the economic framework

VI–2.1. Objectives of the economic analysis

The economic framework seeks to evaluate the RCA AQM activities relative to the standards for the economic impact criterion that were developed for this evaluation:

- **Excellent (exceeding expectations):** Economic analysis suggests with a high level of certainty that the investment created more value than it consumed. Break-even is likely in nearly all scenarios (even under conservative assumptions used in the sensitivity analysis).
- **Good (meeting expectations):** Economic analysis suggests more likely than not, the investment created more value than it consumed. Break-even is likely in over half the range of scenarios (and under realistic mid-range assumptions used in the sensitivity analysis).
- **Adequate (meeting bottom-line expectations):** Economic analysis suggests that under some scenarios, the investment created more value than it consumed. Break-even is possible (under plausible assumptions used in the sensitivity analysis).
- **Inadequate (not meeting expectations):** Break-even is unlikely (or only possible under optimistic assumptions used in the sensitivity analysis).

These standards focus on the overall contribution of the RCA AQM activities to the creation of value in RCA countries. In this context, value is all potential sources of social value, including impacts on human health and the environment, although, in practice, only the health impacts can be quantified with currently available information.

The economic framework described below is designed to support the evaluation of these criteria and standards. It supports a broad assessment of whether the benefits enabled by RCA activities are likely to exceed the costs of those activities. It is not possible to estimate precisely the benefits associated with the RCA AQM activities being evaluated due to the indirect link between AQM and actual air quality. Given the substantial uncertainty about impacts, the framework focuses on assessing the strength of evidence for economic impacts and the likelihood that the value created exceeds costs.

VI–2.2. Relevant RCA activities to be evaluated

The five RCA projects being evaluated were undertaken between 1999 and 2021 and received total nominal direct funding from the IAEA of approximately €3.3 million over this period (Table VI–1). These activities promoted training, research, collaboration and knowledge transfer relating to AQM techniques among the 22 State Parties (SPs) to the RCA. The combined impacts of the five projects are evaluated, and the contributions of the individual projects are not assessed.

The relevant RCA activities included a programme of air quality sampling and analysis, which led to the creation of a database of air quality measurements. A total of around 18 000 air quality samples were collected and analyzed across sites in 14 countries that participated in the sampling programme as part of the RCA activities.

There were some differences in the extent to which the 22 SPs participated in the relevant RCA activities. This was taken into account in the analysis of impacts (see below for details).

Table VI–1. Summary of relevant RCA activities being evaluated.

Project	Objectives	Direct funding
RAS8082 (1999–2004)	To assess and compare air pollution levels in strategically chosen areas in the East Asia and the Pacific region through nuclear and complementary analytical techniques; to identify and quantify critical air pollution sources; and to accumulate accurate air pollution data for future work on transboundary movement of airborne particulate matter (APM).	€1.2m
RAS7013 (2003–2008)	To obtain a sufficiently large set of high-quality regional data characterizing fine and coarse breathable APM for (i) development of a regional database; (ii) employment of advanced models to provide a more detailed and accurate descriptions of the types and locations of pollution sources; and (iii) assessment of the effectiveness of actions taken by participating countries to reduce concentrations and impact of particulate pollution.	€0.8m
RAS7015 (2007–2012)	Contribute to the improvement of air quality in the RCA region by applying advanced nuclear analytical techniques to the assessment of APM pollution. The specific objectives are 1) to obtain sufficient long term data on fine and coarse APM to identify the anthropogenic and natural pollution sources and to assess the extent of their impact; 2) to obtain sufficient high quality data from a sufficient number of SPs within the region covering the same time frame to facilitate a study of larger-scale transboundary pollution and transportation sources; and 3) to create a reliable high quality regionwide database that will enable government air-quality managers to make informed decisions on pollution abatement and control strategies.	€0.6m
RAS7023 (2012–2016)	To enhance regional capabilities in source apportionment and fingerprinting of air particulate matter pollution in urban areas of RCA SPs through the use of nuclear analytical techniques.	€0.3m
RAS7029 (2016–2021)	To enhance capacity using nuclear analytical techniques in assessing the impact of fine particulate matter on human health, visibility and historic monuments.	€0.4m

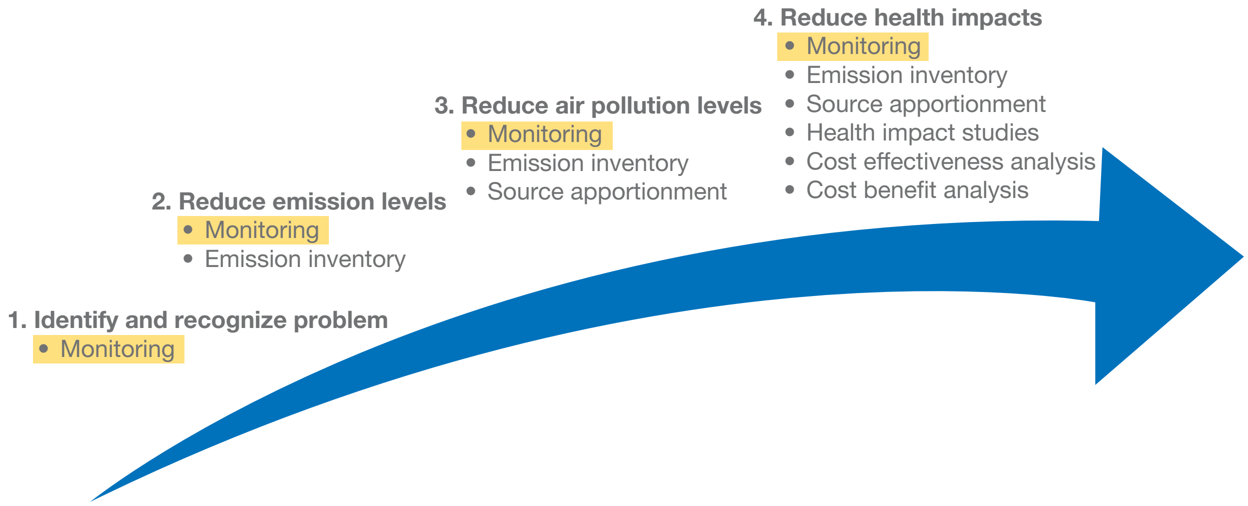
VI–2.3. Benefits enabled by RCA activities

Air quality monitoring has been identified as a critical activity to improve air quality. The United Nations Environment Programme (UNEP) included monitoring as a key activity in all stages of the process to improve air quality and reduce the health impacts of air pollution (Fig. VI–1). The benefits enabled by RCA AQM activities are the costs of ambient air pollution avoided due to changes in air quality policy, standards and enforcement in RCA countries that were enabled by the RCA activities.

Costs of air pollution that can potentially be avoided by improving air quality include [VI–3]:

- **Premature deaths (mortality):** There is a strong link between exposure to fine particulates and reduced life expectancy. Lost life-years can be valued by estimating willingness to pay to avoid premature death or by the value of lost labour output.
- **Costs of illnesses (morbidity):** Illnesses caused by exposure to air pollution create medical treatment costs and lost labour output. People may also be willing to pay to avoid illness.
- **Productivity impacts:** There is some evidence that exposure to air pollution reduces productivity even among generally healthy people due to reduced cognitive and physical capacity.
- **Quality of life (well-being):** People may choose not to do outdoor activities when air pollution levels are high and may forego the well-being value of those activities. Visible air pollution could also reduce people's enjoyment of outdoor activities.
- **Environmental impacts:** Air pollution can lead to reduced crop yields, health impacts for livestock, damage to waterways and reduced biodiversity and can contribute to climate change.
- **Other socio-economic impacts:** High levels of air pollution could reduce tourism activity and lead to a loss of associated economic activity. Over time, air pollution can also cause physical damage to cultural and heritage sites that people value.

FIG. VI–1. Roles of monitoring in improving air quality (Courtesy of the UNEP) [VI-2].



There are many existing studies of the costs of air pollution in individual countries and globally. These studies typically focus on human health costs in the form of premature mortality and excess morbidity caused by exposure to particulates and certain chemicals such as ozone. This is partly because these costs are very large and can be directly linked to air quality. There is also generally better data and evidence to estimate mortality and morbidity costs of air pollution than for other types of costs.

Due to a lack of information to enable reliable quantification of other costs, the economic framework described below focuses on human health costs only, acknowledging that this may be an under-estimate of the benefits enabled by the RCA activities being evaluated if some of the other costs described above are also relevant.

The most significant impacts on human health are from ambient (outdoor) air pollution from sources such as industrial processes, transport, energy, agriculture and natural sources. In some countries, indoor air pollution from cooking and heating is also significant, but this was not considered in the economic evaluation as the RCA activities focussed on measuring ambient air quality only.

The model of benefits enabled by the RCA activities described below uses existing estimates of these costs between 1999 and 2021 as measures of the actual outcomes that occurred under the RCA. While there are many studies of the human health costs of air pollution, a series of studies by the World Bank Group (2016, 2020 and 2021) are among the most comprehensive, robust and credible according to the authors of this report [VI–3, VI–4]. These estimates include the costs of premature mortality and excess morbidity from ambient PM2.5 exposure.[1] The World Bank's 2021 study provides estimates for individual countries, including all 22 RCA SPs [VI–1].

The 2021 World Bank study estimated total annual costs in the RCA SPs of ambient PM2.5 exposure in 2019 of US$2.1 trillion. For countries in South Asia, this cost was estimated as 5.9% of the gross domestic product (GDP), while for East Asia and the Pacific region, the estimated cost was 7.3% of the GDP.

In the economic model used for this evaluation, the estimated benefits enabled by RCA AQM activities are the difference between estimates of actual costs of ambient air pollution and what the costs of ambient air pollution would have been in the absence of the RCA. To calculate this difference, a model was developed to estimate what the costs of air pollution would have been in RCA countries between 1999 and 2021 in the absence of the RCA (the counterfactual scenario). These estimates are compared to the actual costs of air pollution over this period

[1] Exposure to other types of airborne pollutants such as ozone and nitrogen oxides also have health and environmental effects but there is less data on exposure to these pollutants compared to PM2.5. It is plausible that exposure to these other pollutants will be correlated with PM2.5 exposure as there is some overlap in sources of these pollutants.

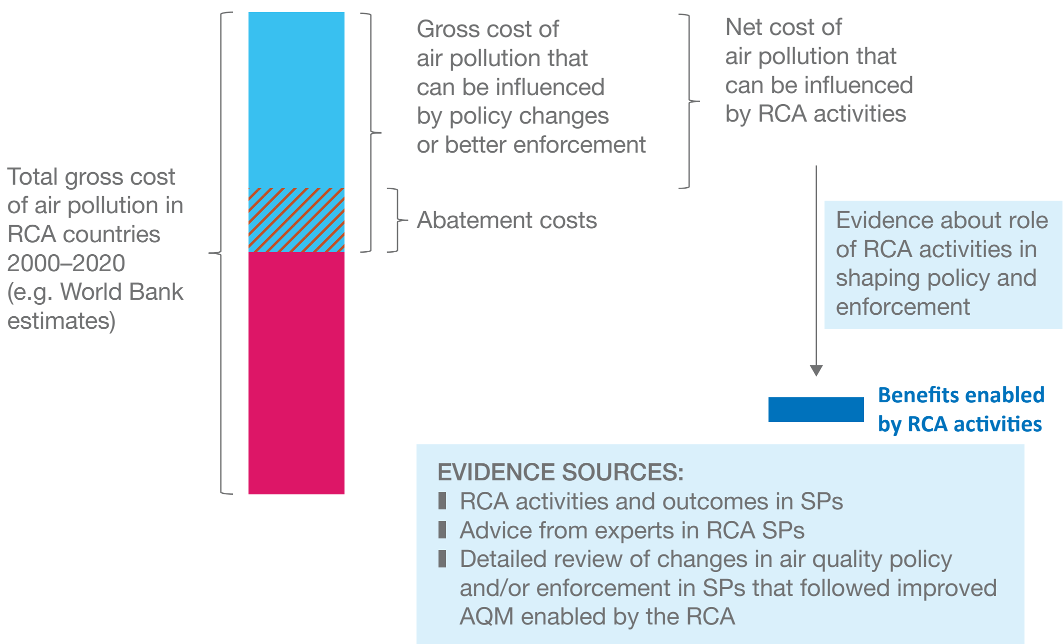
to calculate the avoided costs of air pollution enabled by RCA activities (i.e. the benefits enabled by the RCA activities) as the difference between the two estimates for each year.

Policies and other interventions designed to reduce ambient air pollution are likely to have abatement costs, due to additional investments in new technology and/or changes in commercial activity that are necessary to improve air quality. The benefits enabled by RCA activities are estimated net of abatement costs.

The overall approach to estimating benefits enabled by the RCA activities is summarized in Fig. VI–2. This considers the extent to which policy changes and enforcement can affect costs of air pollution, the extent to which those changes were enabled by the RCA activities. Abatement costs are also considered. This leads to an estimate of benefits enabled by RCA activities, net of abatement costs, that is, some fraction of the costs of ambient air pollution in RCA countries.

The key step in the analysis is translating participation in RCA activities and the information provided by experts in RCA member countries about the impacts of the RCA activities into changes in air pollution costs enabled by the RCA. This is done by applying an impact model (described below) to the survey data collected for this evaluation that was described in Annex V. As there is substantial uncertainty in estimating impacts on air pollution from the survey results, the impact model is designed to be conservative, and a range of alternative assumptions are tested.

FIG. VI–2. Overview of the approach to estimating benefits enabled by RCA AQM activities.



VI–2.4. Costs of RCA activities

Costs of the RCA AQM activities being evaluated include:

- Direct funding is provided by the IAEA (see Table VI–1).
- The opportunity costs of time associated with participation in these activities by experts and others in RCA SPs.
- Costs associated with collecting and analyzing air quality samples that were done as part of the RCA activities.

Direct costs are based on information provided by the IAEA about funding approvals for the relevant RCA projects. Other costs are estimated based on records of activity provided by the IAEA for these projects, including participation in relevant meetings and workshops and the volume of air quality samples that were taken.

Downstream costs associated with investments in new clean technologies and other changes made to improve air quality resulting from the RCA activities are not modelled directly but are included in the estimates of benefits as abatement costs, as described above.

VI–2.5. Comparing benefits and costs

Benefits and costs associated with RCA activities are compared by calculating the present value of real benefits and costs over the period from 1999 to 2021. All benefits and costs are expressed in real 1999 Euro and are discounted back to 1999 using an average real discount rate for RCA countries (see below). The present value calculation accounts for the fact that benefits and costs that occur later in time are less valuable than those that occurred earlier. Benefits and costs are discounted back to 1999 to give a comparison of benefits and costs as at the beginning of the RCA programme for AQM.[2]

The net present value of economic benefits enabled by RCA activities is the estimated difference between the present value of benefits and the present value of costs over the evaluation period from 1999 to 2021. If the net present value is positive, the RCA activities enabled more benefits than the associated costs during this period.

Extensive sensitivity testing was done to estimate and compare benefits and costs under alternative parameter values to account for the uncertainty associated with the model inputs and assumptions. This involved defining alternative low and

[2] Discounting benefits and costs back to the start of the relevant activities (1999) makes the methodology used for this evaluation consistent with what would have been done in a forward-looking assessment of expected future benefits and costs of the RCA activities at that time. As most of the benefits enabled by the RCA activities occur at the end of the evaluation period, this is a conservative assumption that tends to reduce the estimated net benefits. An alternative approach of inflating past values forward to the end of the evaluation period would produce larger estimates of net benefits.

high values of each parameter of the economic model around a baseline value. Results were generated for all possible combinations of low, baseline and high assumptions for all parameters of the model (2187 scenarios in total).[3]

The sensitivity analysis was summarized by calculating the proportion of scenarios in which estimated benefits enabled by the RCA activities were greater than costs and by calculating the distribution of net present value across the scenarios. This is designed to assess the standards for the economic impact criterion described above (i.e. to test how likely it is that benefits enabled by the RCA activities exceeded their costs).

VI–2.6. Discount rate

The discount rate used in the analysis reflects the time value of money. For example, costs incurred in the early years of the evaluation period could have been invested in alternative activities that would have generated a return on investment over time. The magnitude of the discount rate reflects the extent to which benefits and costs occurring later in time have lower value than those occurring earlier in time.

The baseline discount rate used in this analysis was set by assigning the RCA SPs to low, medium and high risk categories and assuming discount rates of 5%, 10%, and 15% for these categories, respectively. Averaging across countries gives the baseline discount rate of 10.2%. In sensitivity analysis, alternatives of 5.2% and 15.2% were tested.

VI–2.7. Limitations of the economic analysis

Given the uncertainties associated with assessing the causal impacts of the RCA activities on costs of ambient air pollution, the evaluation focuses on assessing how likely it is that these activities enabled benefits that are greater than their costs. It is not possible to say that the RCA AQM activities directly generated some dollar value of benefits. Instead, the estimated benefits were enabled by RCA activities but also required significant additional actions and/or commitments of resources by RCA SPs to achieve. It is not possible to separate the contribution of the RCA activities from other such factors.

[3] This is equivalent to assuming that the low, baseline and high values are equally likely for each parameter and that the parameter values are all independent of each other.

VI–3. Estimated benefits enabled by RCA air quality monitoring activities

VI–3.1. Overview of the benefits model

The RCA activities being evaluated aimed to improve the state of AQM in RCA countries. In turn, this could have improved actual air quality and reduced costs of air pollution by supporting the development of policies, standards and interventions relating to air quality in these countries (see Fig. VI–1). Improved monitoring could also have helped countries to better enforce air quality standards and could have provided information to the public to help them make choices to reduce their exposure to air pollution.

The benefits model is designed to estimate the difference between the actual costs of ambient air pollution in RCA SPs and counterfactual costs of ambient air pollution in the absence of the RCA projects being evaluated. Actual costs of ambient air pollution are based on the World Bank estimates described above. The model estimates counterfactual costs of air pollution by making assumptions about the extent to which RCA activities enabled air pollution costs to be avoided. The benefit enabled by the RCA activities is the difference between the actual and counterfactual estimates for costs of air pollution.

The counterfactual costs of ambient air pollution ($CF_{i,t}$) in a given RCA country *i* and year *t* were modelled as depending on:

- The actual costs of air pollution in that country and year ($C_{i,t}$). This reflects actual outcomes that occurred during the evaluation period. These costs are estimated from actual data for RCA countries using a method described below.
- The proportion of costs of air pollution that can potentially be affected by air quality policy initiatives and related public sector interventions (*P*).
- The estimated contribution of RCA activities (p_i) in country *i* in enabling those potential policy-related contributions to reduce the cost of air pollution.
- The proportion of any reduction in air pollution costs that is offset by abatement costs (*a*).

In particular, the change in costs of ambient air pollution in country *i* and in year *t* that was enabled by RCA activities, net of abatement costs, is modelled as:

$$CF_{i,t} - C_{i,t} = P \times p_i \times CF_{i,t} - a\left(CF_{i,t} - C_{i,t}\right) \quad \textbf{VI-1}$$

where $P \times p_i \times CF_{i,t}$ is the proportion of counterfactual costs of air pollution that can be avoided by RCA activities, and $a\left(CF_{i,t} - C_{i,t}\right)$ is the abatement costs that offset any reduction in air pollution costs.

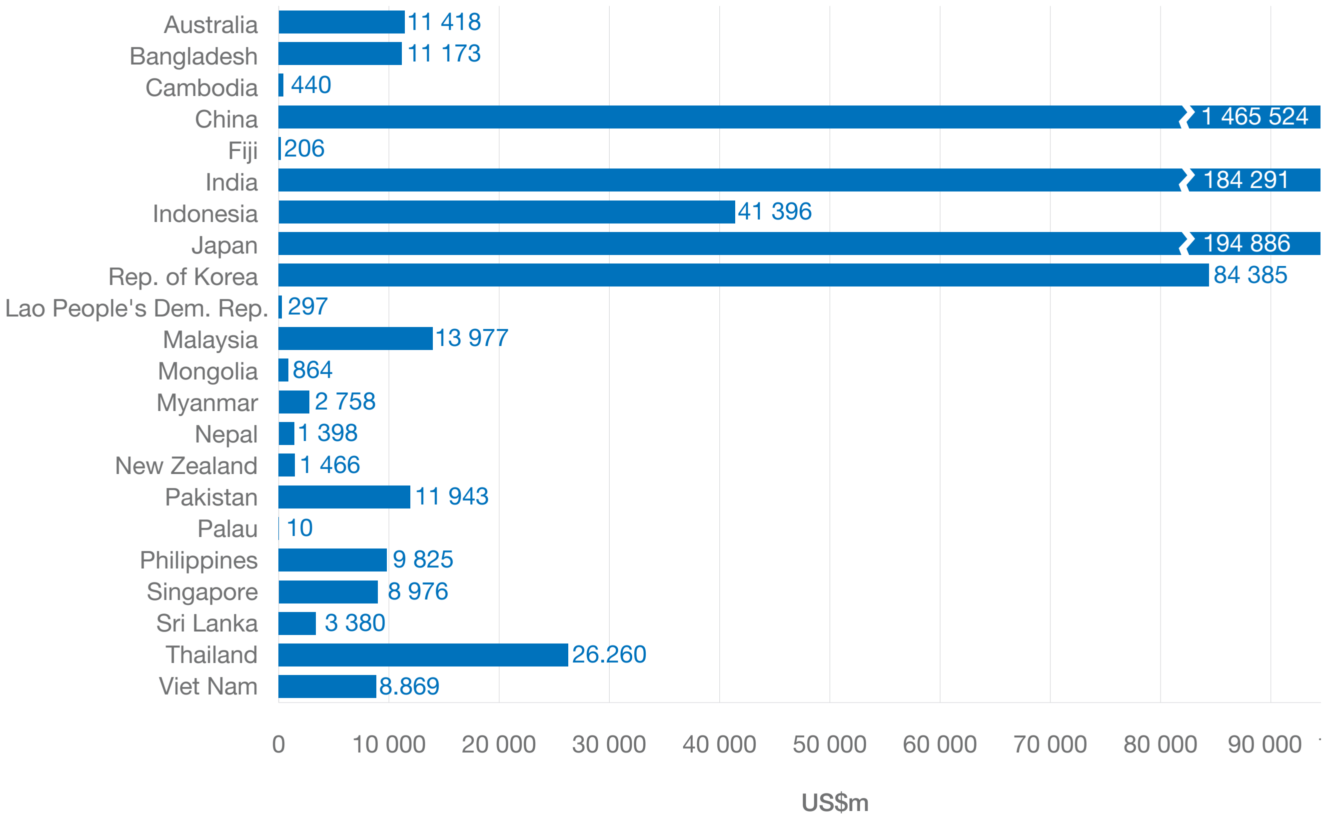
Rearranging for the unknown counterfactual cost of ambient air pollution in country *i* and in year *t* gives an expression that can be used to calculate this cost, given assumptions about the three parameters and the estimated actual cost of air pollution:

$$CF_{i,t} = \frac{(1+a)C_{i,t}}{1 - P \times p_i + a} \quad \textbf{VI-2}$$

The parameters *P*, p_i, and *a* are all numbers between 0 and 1 that were estimated as follows:

- UNEP studied potential clean air measures in Asia and the Pacific region and estimated that feasible solutions could reduce exposure to air pollution by around 15–30% depending on the types of solutions applied. Since the costs of air pollution vary in proportion to pollution levels, this also implies that 15–30% of the costs of pollution can feasibly be mitigated by policy interventions. Given, this the potential policy impact parameter *P* was assigned a baseline value of 20%, with a sensitivity range from 10%–30% [VI–2].
- The United States Environmental Protection Agency estimated that the benefits of the United States Clean Air Act from 1990 to 2020 exceeded costs of compliance or abatement by a ratio of 32:1 in its central scenario. This implies abatement costs were around 3% of the gross benefits. In sensitivity testing, the ratio of abatement costs to gross benefits varied between 1% and 25% [VI–5]. Gao et al (2016) estimated costs of reducing air pollution in China between 2013 and 2017 as around 16% of the gross benefits [VI–6]. Given this, the abatement cost parameter a was assigned a baseline value of 20%, with a sensitivity range from 10% to 30%.
- The RCA contribution for each country (p_i) was estimated using an impact model calibrated from a survey of air quality experts in RCA countries (described below). Baseline values for this parameter range from 0.0% (no impact) to around 0.2% across countries.

FIG. VI–3. Estimated cost of ambient PM2.5 exposure in RCA countries in 2019 [VI–1].



VI–3.2. Estimated actual costs of ambient air pollution in RCA countries

Estimates of the costs of ambient (outdoor) PM2.5 exposure for individual countries in 2019 were published by the World Bank Group [VI–1, VI–7].[4] These reflect costs associated with premature deaths (mortality) and health conditions (morbidity) that can be attributed to ambient air pollution (Fig. VI–3). The differences in costs across countries come from differences in ambient PM2.5 exposure, population sizes and structures, and values of premature mortalities and morbidities. The World Bank estimates that around 85% of the costs of ambient PM2.5 exposure are due to premature mortality, with the remainder due to morbidity.

Annual costs of air pollution from 1999 to 2021 were estimated for each RCA country by scaling the World Bank cost estimate for 2019 by the number of deaths attributable to ambient PM2.5 exposure in each year relative to the number of such deaths in 2019. These costs were also scaled by the ratio of GDP per capita in each year relative to GDP per capita in 2019.

[4] Details of the specific assumptions used to calculate these costs are provided in the World Bank's report [VI–1]. The underlying estimates of the burden of disease associated with ambient PM2.5 exposure are based on the 2019 Global Burden of Disease study [VI–8.]

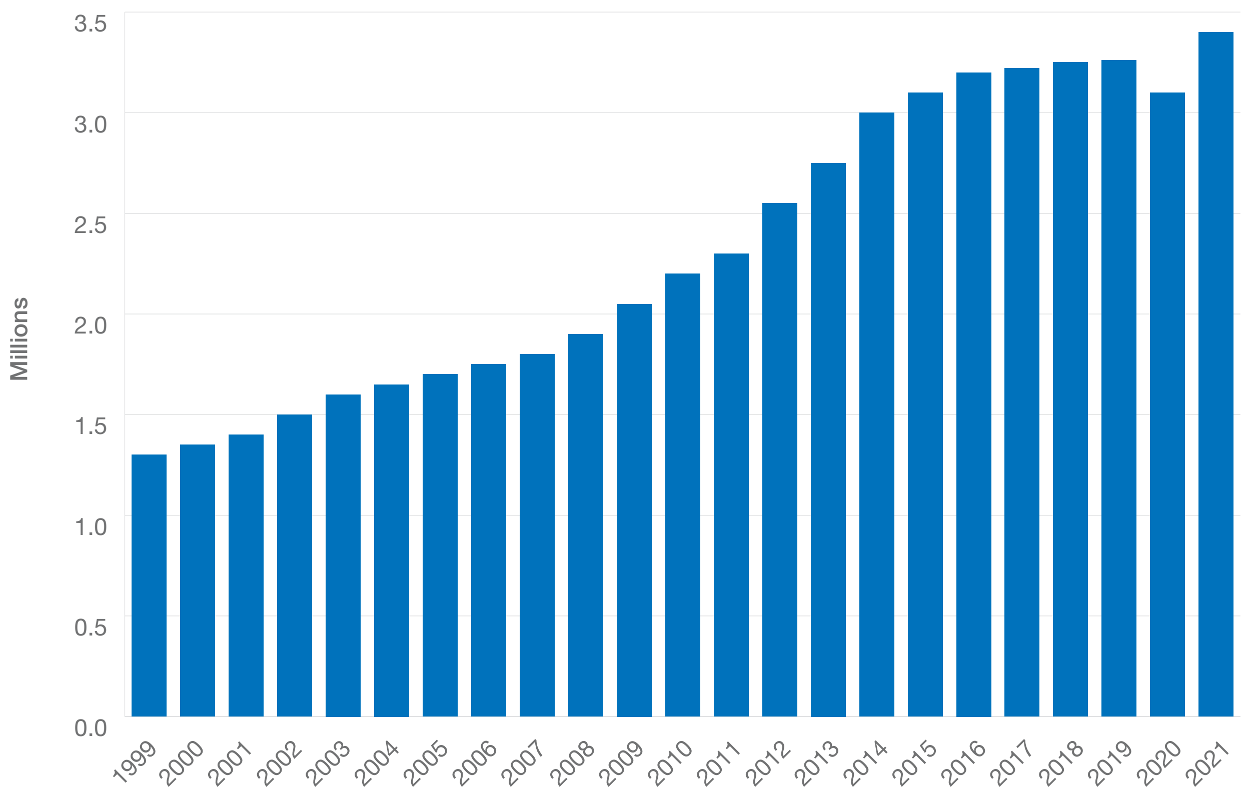
Specifically, the cost of ambient PM2.5 exposure in country *i* and in year *t* was estimated based on deaths attributable to ambient PM2.5 exposure in that year ($D_{i,t}$) and GDP per capita in that year ($G_{i,t}$), relative to values in 2019:

$$C_{i,t} = C_{i,2019} \times \frac{D_{i,t}}{D_{i,2019}} \times \frac{G_{i,t}}{G_{i,2019}} \quad \text{VI-3}$$

Estimates of total annual deaths attributable to ambient PM2.5 exposure in RCA countries have generally increased over time, although the rate of increase appears to have slowed after 2014 (Fig. VI–4). In total, between 1999 and 2021, around 53.5 million premature deaths occurred in RCA countries that could be attributed to ambient PM2.5 exposure.

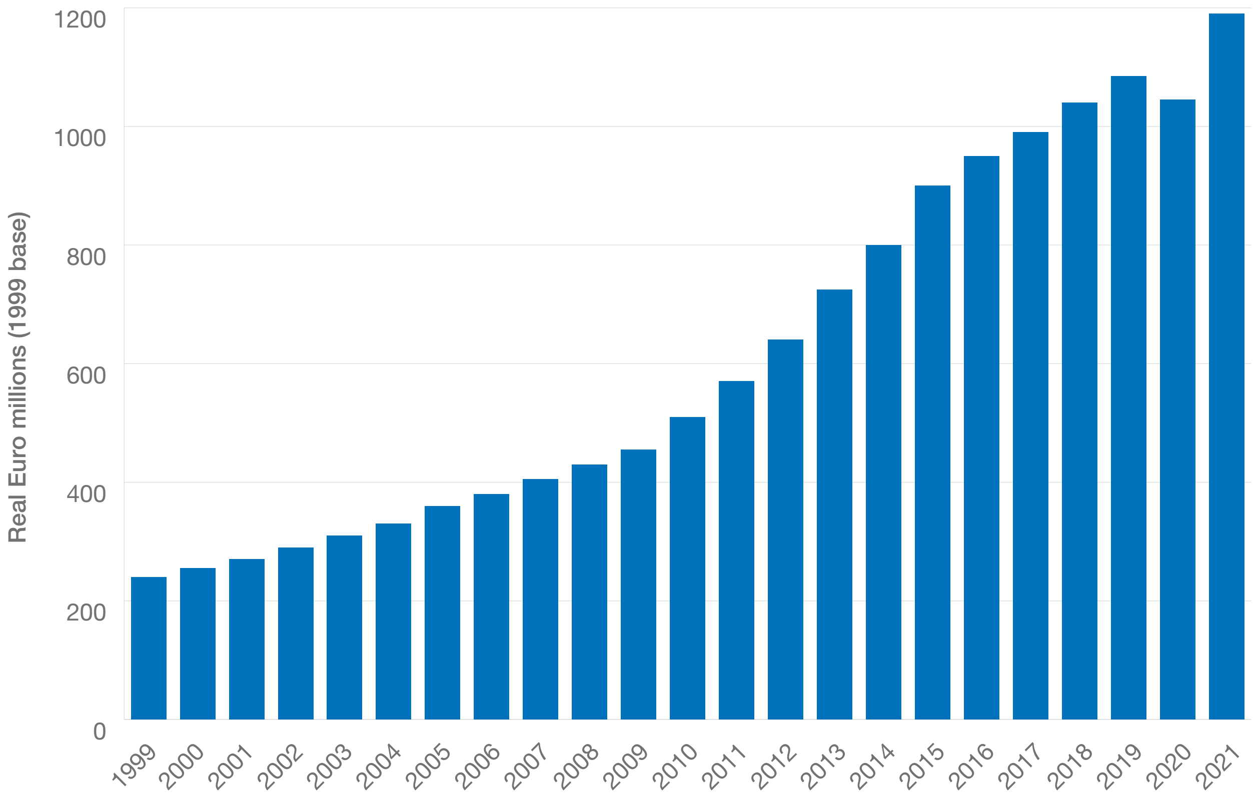
Applying the formula above across all RCA countries and summing these estimates for the evaluation period from 1999 to 2021 gives an estimated total real cost of €14.1 trillion (1999 base), or €4.3 trillion in present value terms (discounted back to 1999 at a discount rate of 10.2%, as explained above). Figure VI–5 shows the total estimated annual real cost of ambient PM2.5 exposure in RCA countries before the present value conversion.[5] These estimates generally increase over time following the increase in deaths attributable to ambient PM2.5 exposure and growth in GDP per capita at the same time.

FIG. VI–4. Estimated total annual deaths attributable to ambient PM2.5 exposure in RCA countries [VI–8].



[5] Nominal values were converted to real values using GDP deflator data for each country from the World Bank World Development Indicators database [VI–12]. Local currencies for RCA countries were converted to Euro using exchange rate data from the IMF International Financial Statistics database [VI–13].

FIG. VI–5. Estimated real annual costs of ambient PM2.5 exposure in RCA countries [VI–1, VI–8 – VI–10].



VI–3.3. Impact model for RCA activities

To assess the extent to which RCA AQM activities enabled costs of ambient air pollution to be avoided, air quality experts from RCA SPs were surveyed about the impacts across five domains (see Annex V):

- New regulations or changes to existing regulations relating to air quality;
- Government policy decisions and interventions relating to air quality;
- Levels of enforcement of air quality standards or regulations;
- New air pollution programmes or changes to existing air pollution programmes;
- Population behaviour change relating to air quality.

For each of these five domains, experts were asked to rate the impact of RCA activities as not enabled, minor impact, some impact or significant impact. Experts were also asked to rate the impact of RCA activities on actual ambient PM2.5 levels in their country. They were asked to assess the extent to which these activities had contributed to a decrease or deceleration (slower rate of increase) of ambient PM2.5 levels. Responses to the relevant survey questions are summarized in Fig. V–16 in Annex V.

Respondents to the expert survey also provided qualitative information about the practical impacts of RCA activities on air pollution policy, standards and enforcement in their country. The responses provided (see Table V–7 in Annex V) were reviewed and rated according to the strength of the evidence provided. This assessment found strong evidence in one case (Bangladesh), some evidence in three cases (Australia, New Zealand and Viet Nam), weak evidence in six cases (China, Indonesia, Malaysia, Mongolia, Pakistan and the Philippines), and no evidence in the remaining countries.

As described in Annex V, four SPs were assessed as having relatively low levels of participation in the RCA AQM activities being evaluated, and impacts were not modelled for those parties (Cambodia, Fiji, Nepal and Palau). In addition, experts from three SPs did not respond to the survey, and impacts were also not modelled (India, Lao People's Democratic Republic and Singapore).[6]

Survey responses were also used to estimate the first year that RCA activities were assumed to have impacts on actual air quality (if any), and therefore, on the costs of air pollution in each SP. In most cases, this was assumed to be in 2018, when the RCA activities were largely completed. In some cases, other dates are used based on information provided by survey respondents about when air quality policy changes occurred (2022 for Bangladesh, 2020 for Malaysia and 2021 for Thailand).

For modelling purposes, the survey responses and qualitative evidence assessment shown above were translated into estimated values of the RCA impact parameter p_i for each country in the model described above:

- Impact factors were assigned to the impacts of RCA activities across the five domains of change rated by experts responding to the survey, ranging from 0% for not enabled, low participation and no response, to 10% for significant impacts.
- The five impact factors were averaged to calculate an initial RCA impact score between 0% and 10% for each SP.
- The initial score was multiplied by a scalar based on the survey response for the impact of the RCA programme on PM2.5 levels, ranging from 0 for non-responses and no significant impacts to 0.25 for significant impacts.
- The score was again by a scalar based on the qualitative evidence assessment, ranging from 0 for no evidence to 0.75 for strong evidence.

[6] Costs for these countries were included in the cost side of the analysis.

FIG. VI–6. Overview of the RCA impact model.

AVERAGE OF IMPACT FACTORS FOR:

- New regulations or changes to existing regulations relating to air quality
- Government policy decisions and interventions relating to air quality
- Levels of enforcement of air quality standards or regulations
- New air pollution programmes or changes to existing air pollution programmes
- Population behaviour change relating to air quality

x

Adjustment for RCA impact on actual PM2.5 levels

x

Adjustment for strength of qualitative evidence

=

Proportion of potential air quality benefits enabled by RCA activities

This structure for the RCA impact model (Fig. VI–6) emphasizes the importance of actual air quality outcomes and the strength of qualitative evidence as key factors for establishing a relationship between the RCA activities and changes in costs associated with air pollution in RCA countries. Sensitivity tests were performed by assuming lower and higher values of the impact factors and scalars described above. The assumptions used in the RCA impact model are summarized in Table VI–2.

Figure VI–7 summarizes the baseline estimates of potential proportions of the costs of air pollution that were enabled to be avoided by RCA activities in each country (the values for the p_i parameter in the model described above). Across RCA countries, under the baseline assumptions, it is estimated that RCA activities enabled up to around 0.2% of the costs of ambient air pollution in a year to be avoided.[7] Based on the evidence provided by experts in RCA SPs, RCA activities enabled a reduction in the costs of air pollution in 9 out of the 22 RCA countries. This may underestimate the impacts of the RCA as three countries had effective participation in RCA activities but did not respond to the survey for this evaluation (India, Lao People's Democratic Republic and Singapore).

[7] The relatively high result for New Zealand reflects the survey response that the RCA activities had significant impacts across four out of the five domains described above. Due to the relatively low costs of air pollution in New Zealand compared to most other RCA SPs, this has a minimal impact on the overall estimate of the benefits enabled by the RCA activities.

TABLE VI–2. Summary of RCA impact model assumptions.

Response	Low	Baseline	High
RCA contribution to five domains of change			
No response	0.0%	0.0%	0.0%
Low RCA participation	0.0%	0.0%	0.0%
Not enabled	0.0%	0.0%	0.0%
Minor impact	0.5%	1.0%	1.5%
Some impact	2.5%	5.0%	7.5%
Significant impact	5.0%	10.0%	15.0%
RCA impact on actual PM2.5 levels			
No response	0.000	0.000	0.000
Low participation	0.000	0.000	0.000
No decrease or deceleration	0.000	0.000	0.000
To no extent	0.000	0.000	0.000
To a minor extent	0.025	0.050	0.075
To some extent	0.050	0.100	0.150
To a significant extent	0.125	0.250	0.375
Qualitative evidence assessment			
No evidence	0.000	0.000	0.000
Weak evidence	0.125	0.250	0.375
Some evidence	0.250	0.500	0.750
Strong evidence	0.500	0.750	1.000

FIG. VI–7. Baseline estimates of the potential proportion of air pollution costs that RCA activities enabled to be avoided (countries with no percentages listed have estimates of 0%).

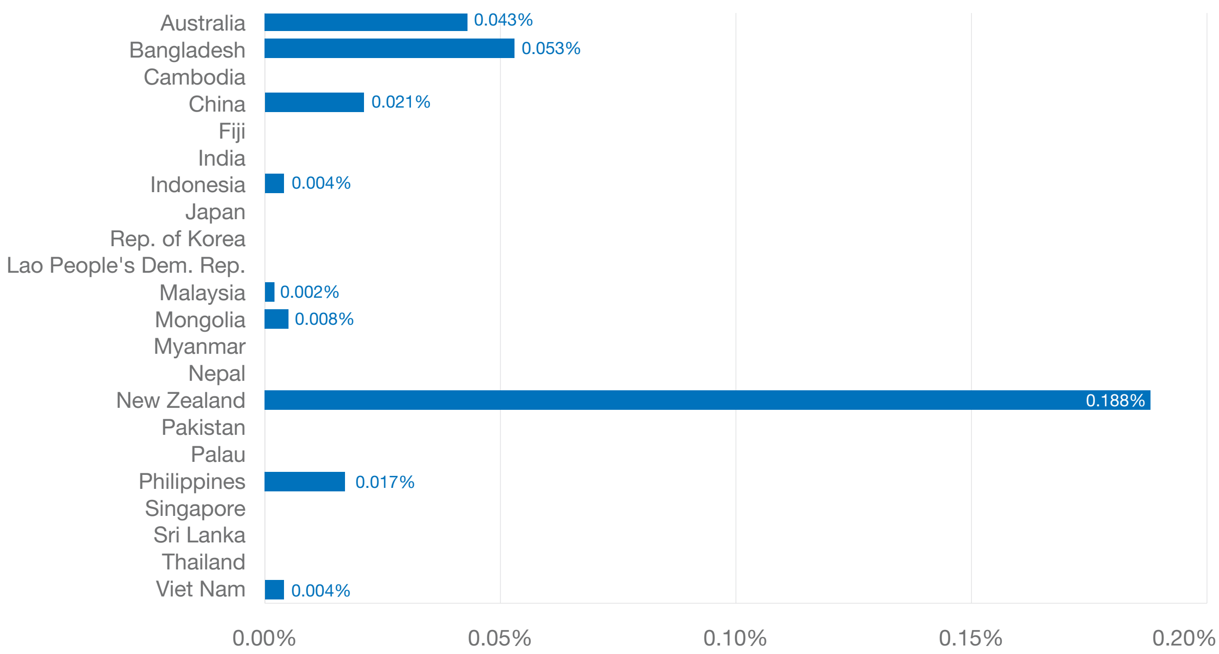


FIG. VI–8. Baseline estimates of real benefits enabled by RCA activities, net of abatement costs.

VI–3.4. Baseline estimates of benefits enabled by RCA activities

Figure VI–8 shows estimates of the benefits enabled by RCA AQM activities in the form of costs of air pollution avoided (net of abatement costs) under baseline assumptions and prior to conversion to present values. These are indicative estimates only, and there is a high degree of uncertainty arising from the assumptions necessary to estimate the impacts of the RCA activities on the actual costs of air pollution. Benefits are only modelled from 2018 to 2021, following the assumptions described above. In practice, it is possible that benefits will extend beyond 2021, but there is insufficient information to forecast future impacts. The present value of real benefits under the baseline assumptions is €69.2 million (1999 base).

VI–4. Estimated costs of RCA air quality monitoring activities

Annual nominal funding provided by the IAEA for the relevant RCA projects (Fig. VI–9) was converted to real 1999 Euro using the average European Union area consumer price index published by Eurostat [VI–11].

The opportunity costs of time associated with participating in the relevant RCA activities were modelled based on information about person-days of participation in those activities (Fig. VI–10). The cost of each person-day was based on GDP per capita in RCA countries, multiplied by a premium for skilled labour in each country, calibrated from wage data from the International Labor Organization. Additional costs to host RCA activities were estimated based on information provided by the IAEA. Training courses were assumed to cost €1600 per day, and other activities €800 per day (2023 values).

FIG. VI–9. Direct annual nominal funding provided by the IAEA for the RCA AQM activities being evaluated.

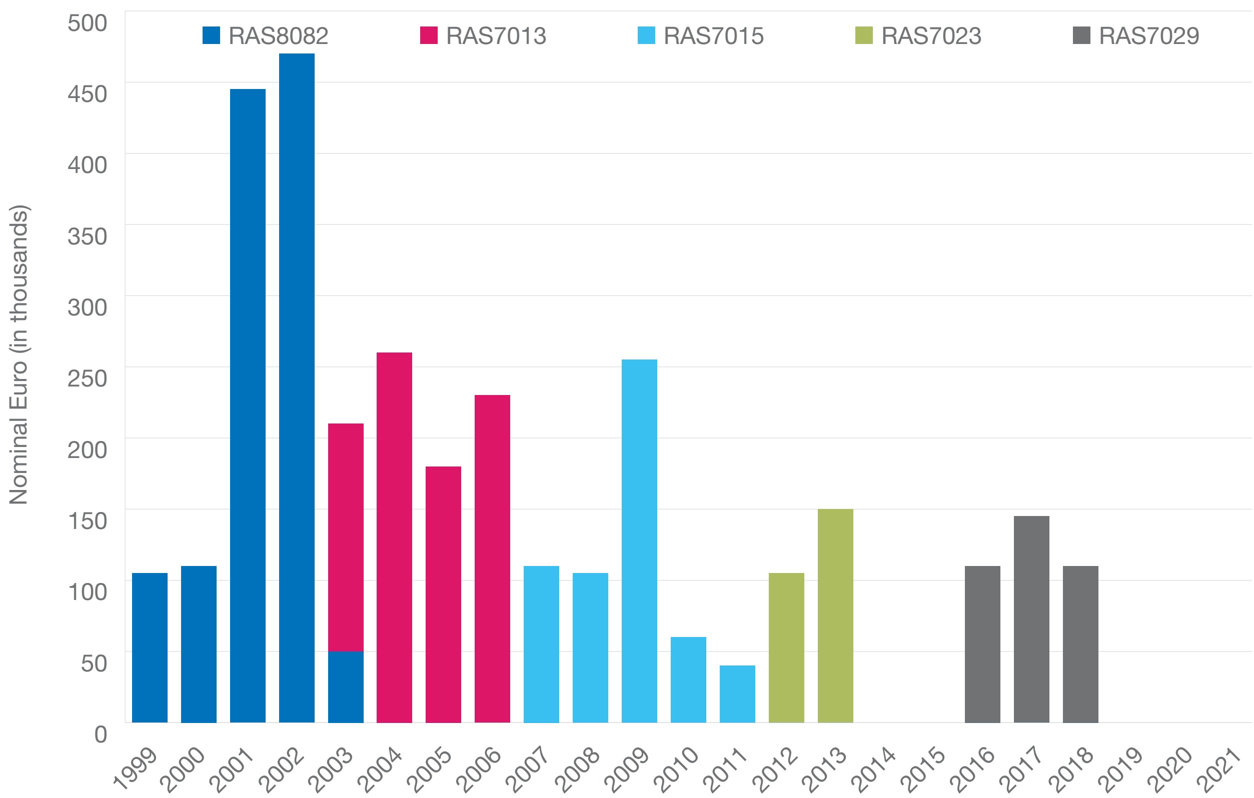
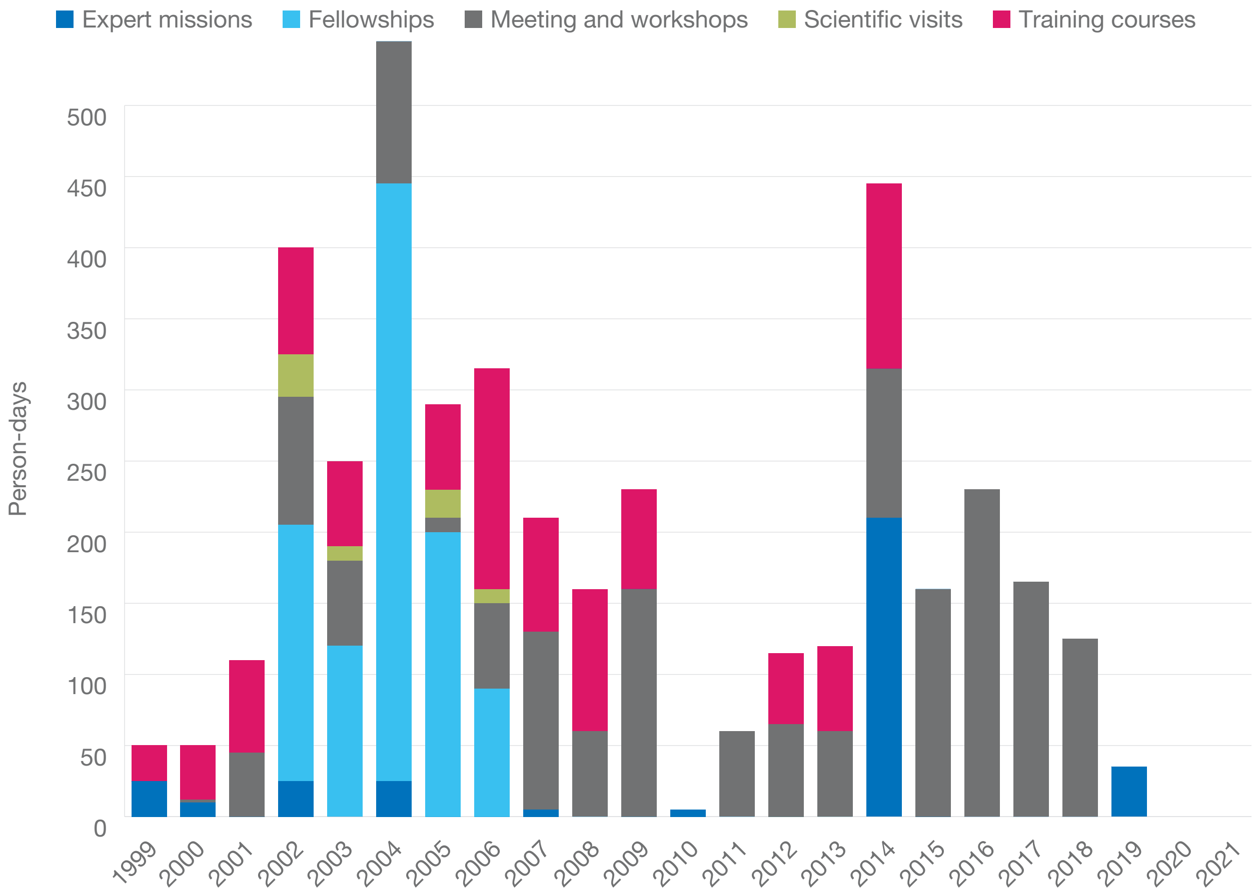


FIG. VI–10. Total involvement in RCA AQM activities.



A programme of air quality sampling was undertaken as part of the RCA activities being evaluated. This involved the collection and analysis of over 36 000 physical air quality samples in RCA countries (Fig. VI–11). The costs to collect and analyze these samples were borne by participating countries. Based on advice from experts, the current cost to collect and analyze a sample was assumed to be €75 in high income RCA countries and €37.50 in other RCA countries. For analysis, this was converted to real 1999 Euro using relevant inflation rates in RCA countries. For sensitivity testing, alternative assumptions of the cost per sample of €60 and 90 in high income countries and €30 and 45 in other countries were also tested.

Figure VI–12 shows the estimates of real annual costs associated with RCA activities prior to the present value conversion under baseline assumptions, following the estimation process described above. The present value of these costs is €2.5 million (1999 base) over the evaluation period from 1999 to 2021.

FIG. VI–11. Annual number of air quality samples collected as part of the RCA activities [VI–3].[1]

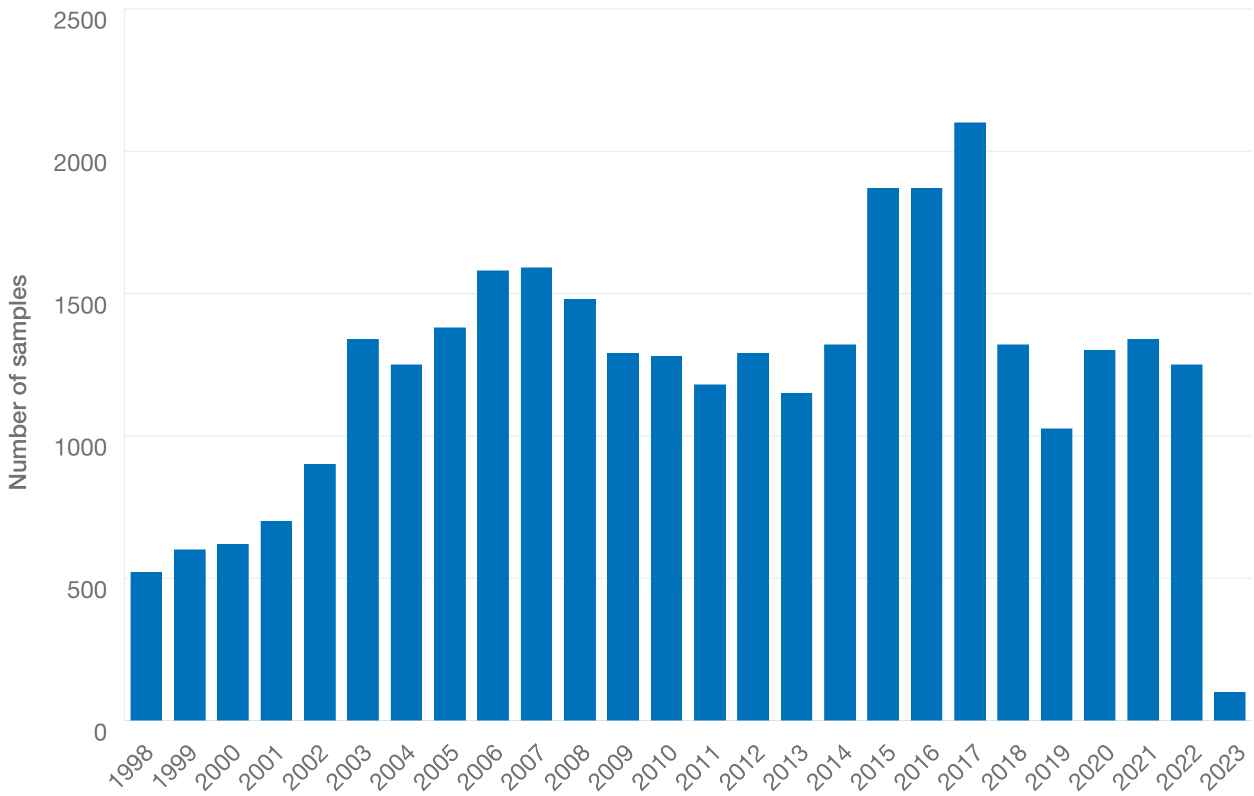
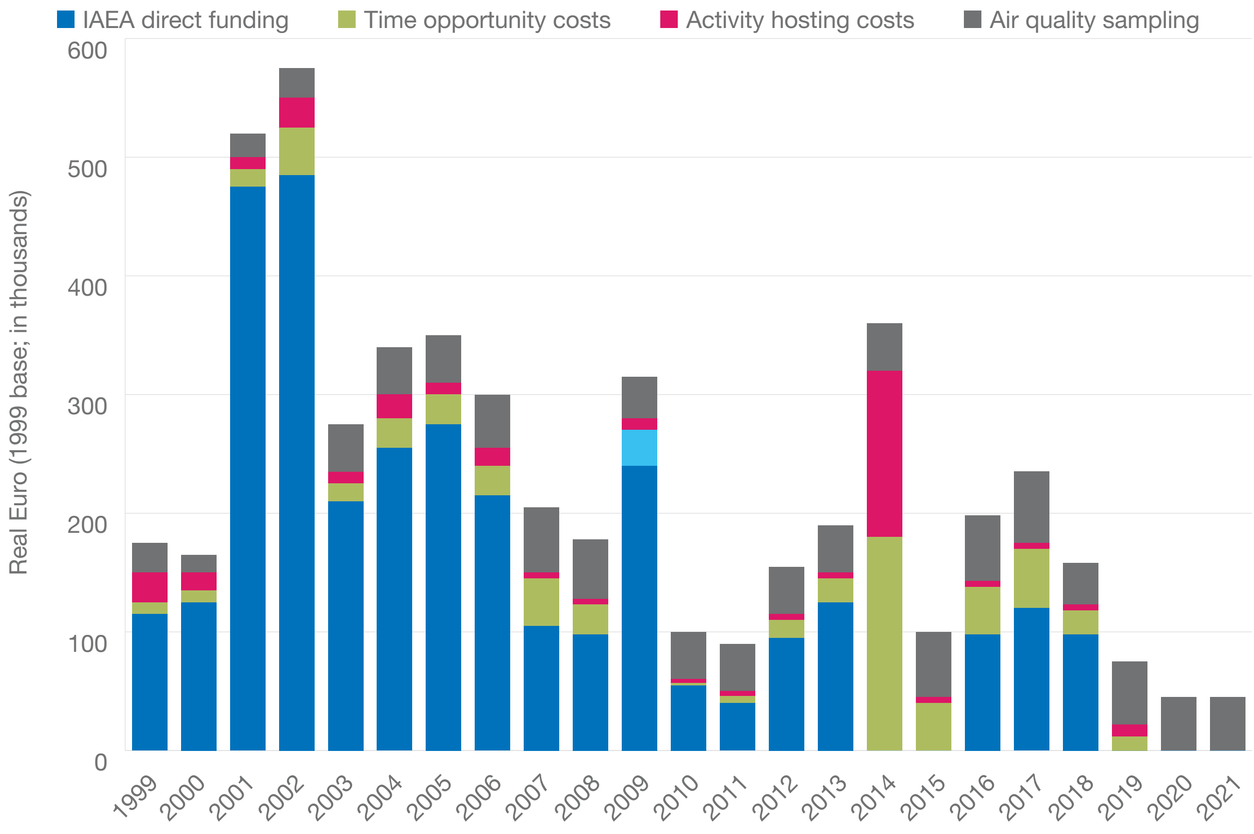


FIG. VI–12. Baseline estimates of real costs of RCA AQM activities.



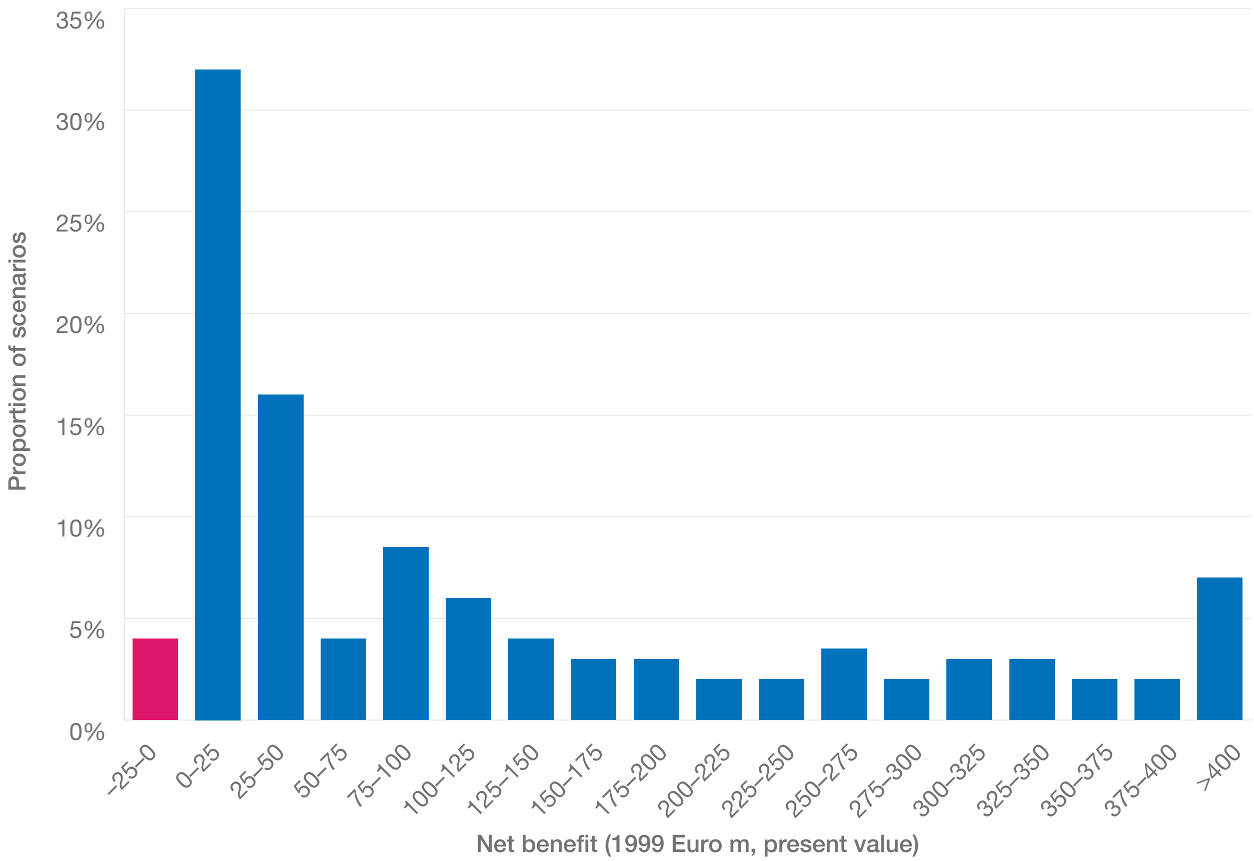
[1] Figure VI–11 shows the annual number of air quality samples that were taken as part of the RCA activities being evaluated. Countries may have continued to monitor air quality after this sampling programme ended.

VI–5. Estimated net benefits enabled by RCA air quality monitoring activities

As described above, results were generated for all combinations of low, baseline and high values of all parameters in the economic model to evaluate the impacts of the RCA AQM activities relative to the criteria and standards developed for economic evaluation. Figure VI–13 summarizes the results of this analysis by showing the distribution of the estimated net benefit across sensitivity scenarios. The estimated net benefit is positive in 97% of scenarios tested and negative in only 3% of scenarios. This suggests it is very likely that the benefits enabled by the RCA AQM activities exceeded the costs associated with those activities.

In this context, net benefits are enabled by the RCA activities but, in practice, require other complementary actions to achieve, such as political support, policy changes, investment in new technologies, changes to production processes and behaviour change. It is, therefore, not possible to say that the RCA activities directly created these benefits. There is also substantial uncertainty associated with the numerical estimates of benefits as it is difficult to translate the available information about the impacts of RCA activities into changes in the costs of ambient air pollution. However, the approach taken is conservative, and sensitivity testing supports the conclusion that the RCA activities enabled substantial benefits.

FIG. VI–13. Distribution of net benefits in the sensitivity analysis.



In practice, the costs of ambient air pollution in RCA countries are so large that even very small changes to reduce these costs can have substantial benefits. The available quantitative and qualitative evidence provided by air quality experts in RCA countries supports the conclusion that the RCA activities have helped to avoid some of the costs of air pollution.

VI–6. Summary of assumptions

Table VI–3 summarizes the assumptions used in the economic analysis, in addition to the assumptions of the RCA impact model that were summarized in Table VI–2. The basis for these assumptions is described in the relevant sections above.

Table VI–3. Summary of parameter assumptions.

Parameter	Low	Baseline	High
Discount rate (real)	5.2%	10.2%	15.2%
Cost of air sample analysis in high-income countries (2023 Euro)	60.00	75.00	90.00
Cost of air sample analysis in other countries (2023 Euro)	30.00	37.50	45.00
Air pollution abatement costs as proportion of costs avoided	10%	20%	30%
Proportion of costs of air pollution that can be mitigated by policy changes	10%	20%	30%
Overhead costs proportion of total	5%	10%	20%

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Annex VII: Methodology[1]

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The social and economic impact assessment methodology was developed specifically for conducting impact assessments case studies of Technical Cooperation (TC) projects under the Regional Cooperative Agreement for Research, Development, and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA). The methodology follows the Value for Investment approach developed by Dr Julian King [VII–2– VII–4] and the Kinnect Group approach to evaluation rubrics [VII–5, VII–6].

VII–1. Evaluating impact in complex environments

From the outset, it was acknowledged that these case studies would be challenging to conduct. The RCA is a complex environment for evaluation. There are diverse countries and stakeholder groups, long term investments of decades, with contexts that are continuing to evolve, and multiple outcomes sought across a range of thematic areas. Impact evidence has not been routinely collected; TC outcome monitoring systems have generally focused on immediate outcomes and have not included longer term social and economic impacts.

VII–2. Developing the methodology

A methodology was needed that could:

- Evaluate impacts retrospectively, looking back many years.
- Evaluate long term effects because there is often a long lag between project completion and the realization of social and economic impacts.
- Capture unexpected outcomes, instead of just looking for the expected outcomes, because these can be as impactful as the project's originally stated target outcomes.
- Measure the intangible value of the RCA's contributions, such as networking, in addition to outcomes that are more amenable to numeric and/or monetary metrics.
- Deal with the complexity of attribution (or at least contribution), recognizing that one outcome can arise from many contributions (of which the RCA project may be only one), and conversely, one project could contribute to many different outcomes or impacts.

An online meeting was held in March 2024 to establish a methodology and work plan for undertaking the assessments. Meeting participants included representatives from TC Division for Asia Pacific (TCAP) and TC Division of Programme Support and Coordination (TCPC), country experts, and members of the evaluation team.

Evaluation is the systematic determination of the merit, worth or significance of something. Evaluation of social and economic impacts requires not only *evidence* of those impacts, but also *valuing* – interpreting the evidence through the lens of what matters to people [VII–3]. Economics and evaluation bring different approaches to valuing. For example, cost-benefit analysis uses money as the metric for understanding value [VII–7], while other approaches include numerical or qualitative synthesis [VII–8] or citizen deliberation [VII–9].

The Value for Investment approach combines approaches to valuing from evaluation and economics. It accommodates multiple values (e.g. social, cultural, environmental and economic) and multiple sources of evidence (qualitative and quantitative) to enable robust and transparent ratings of the RCA's impacts. The approach involves eight steps:

1. Understand the theory of change for the air quality monitoring (AQM) programme of the RCA.
2. Develop performance criteria (i.e. (i) Nationally trained personnel able to carry out consistent air quality sampling, analysis and source apportionment, (ii) improved national research and development (R&D) capacity for air pollution monitoring, (iii) strengthened information exchange in the region on transboundary air pollution monitoring and assessment, (iv) enhanced/established national and regional capacity for air pollution monitoring and assessment, (v) influence on national and international health and environmental regulations, policy decisions and interventions, enforcement, and behaviour change, (vi) economic benefits and (vii) better protected health and environment).
3. Develop performance standards for each performance criterion (e.g. narratives that define excellent, very good, etc.).
4. From the criteria and standards, select and identify the evidence needed.
5. Gather evidence using a mix of methods, including an online survey deployed to all countries participating in relevant RCA projects, collated internal data held by IAEA, financial/cost data provided by IAEA, and narrative case examples provided by selected countries.
6. Analyze the evidence.
7. Synthesize and judge the evidence according to the agreed upon definitions of good value (i.e. the performance criteria from Step 2 and the performance standards from Step 3).
8. Reporting based on the criteria and performance levels decided in advance.

VII–3. Applying the methodology

VII–3.1. Theory of Change

A theory of change is a depiction of the programme to be evaluated, including the needs it is intended to meet and how it is intended to function [VII–3]. A theory of change "…explains how activities are understood to produce a series of results that contribute to achieving the final intended impacts" [VII–10].

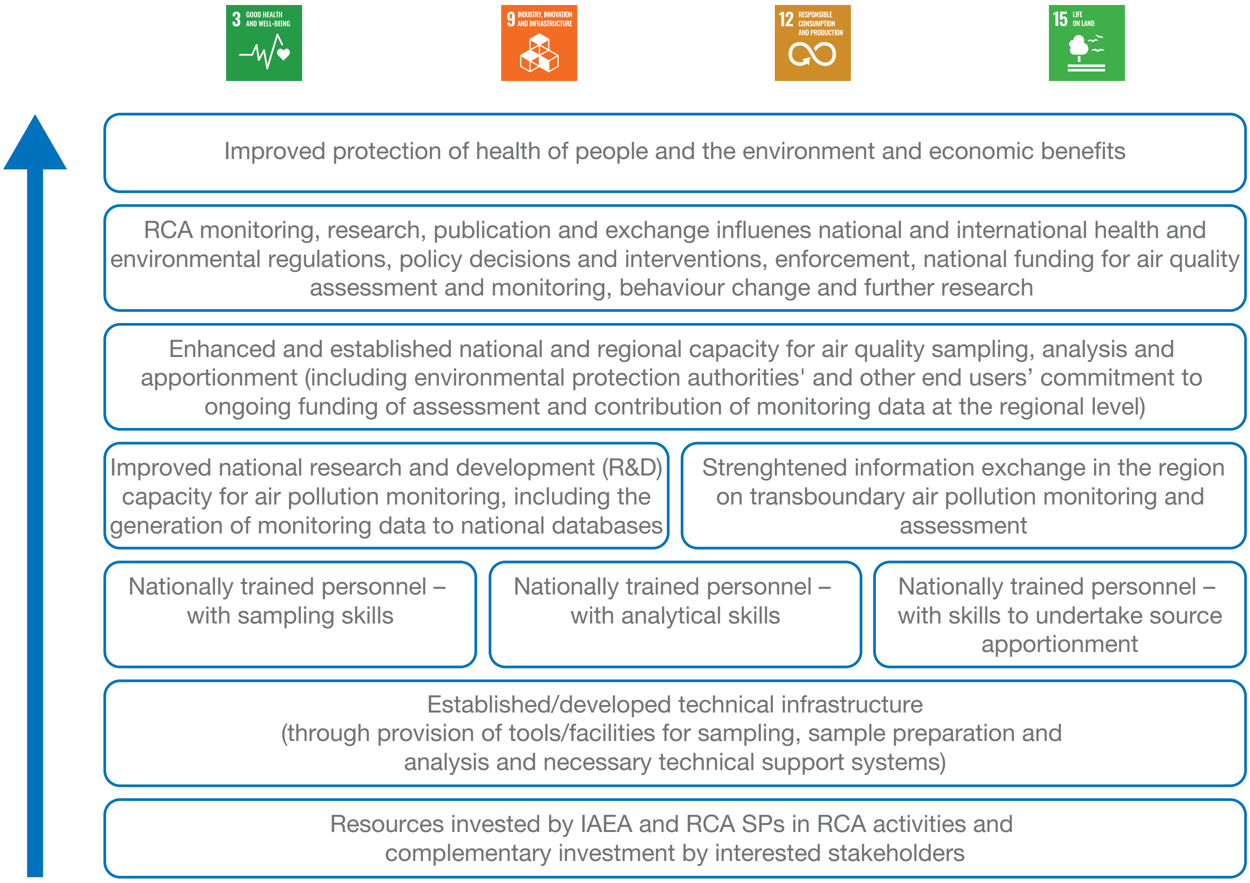
The theory of change for the AQM programme (Fig. VII–1) was developed iteratively by the IAEA, selected experts from participating State Parties (SPs) and the impact assessment team. Developing a theory of change in a participatory manner helps lead to a clear and shared understanding of the programme [VII–11].

A theory of change may be used as a tool when assessing causality or contribution [VII–11]. In the case of AQM under the RCA, the focus was on the value added through regional collaboration. In the absence of a measurable counterfactual (e.g. a control group), the evaluation design theorized that regional collaboration would add value by establishing/developing technical infrastructure alongside ensuring there were nationally trained personnel who could sample, analyze and undertake source apportionment. The result of this would be improved R&D capacity for air pollution monitoring and AQM, as well as strengthened information exchange. It was further theorized that these impacts would influence regulation, policy, interventions and enforcement for AQM, which would result in better protected health of people and the environment and associated economic benefits. These theories were tested by eliciting feedback from the participating countries.

A theory of change can also be used to help identify a complete and coherent set of evaluation criteria [VII–8]. For the AQM case study, it was agreed that the focus of the evaluation would be on seven impact areas:

- Nationally trained personnel able to carry out consistent air quality sampling, analysis, and source apportionment;
- Improved national R&D capacity for air pollution monitoring;
- Strengthened information exchange in the region on transboundary air pollution monitoring and assessment;
- Enhanced/established national and regional capacity for air pollution monitoring and assessment;
- Influence on national and international human health and environmental regulations, policy decisions and interventions, enforcement, and behaviour change;
- Economic benefits;
- Improved protection of people and the environment.

FIG. VII–1. Theory of change for the RCA AQM programme.



VII–3.2. Criteria and standards

Evaluation criteria and standards for the four impact areas were collaboratively developed. Tables VII–1 to VII–7 set out the *rubrics* (criteria and standards) used in this impact assessment. Each rubric corresponds to a selected impact area from the theory of change.

TABLE VII–1. RUBRIC FOR CRITERION 1: Nationally trained personnel able to carry out consistent air quality sampling, analysis and source apportionment.

Standard (to be applied to each SP)	Criterion 1: Nationally trained personnel able to carry out consistent air quality sampling, analysis, and source apportionment
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of IAEA results in the SP providing training to in-country personnel to carry out consistent sampling, analysis and source apportionment.
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in the SP providing training to in-country personnel to carry out consistent sampling and analysis.
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in the SP providing training to in-country personnel to carry out consistent sampling.
Minor (not meeting expectations)	Standard for adequate not met.

TABLE VII–2. RUBRIC FOR CRITERION 2: Improved national R&D capacity for air pollution monitoring.

Standard (to be applied to each SP)	Criterion 2: Improved national R&D capacity for air pollution monitoring
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of IAEA results in: ▸ Research outputs and publications on AQM, and specifically, on air particulate matter; and ▸ Contributing monitoring data to national databases for more than 10 years; and ▸ Research leaders on the topic at the national and international levels.
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in: ▸ Research outputs and publications on AQM, and specifically, on air particulate matter; and ▸ Contributing monitoring data to national databases for 8–10 years; and ▸ Research leaders on the topic at the national level.
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in: ▸ Research outputs and publications on AQM, and specifically, on air particulate matter; and/or ▸ Contributing monitoring data to national databases; and/or ▸ Research leaders on the topic at the national level.
Minor (not meeting expectations)	Standard for adequate not met.

TABLE VII–3. RUBRIC FOR CRITERION 3: Strengthened information exchange in the region on transboundary air pollution monitoring and assessment

Standard (to be applied to each SP)	Criterion 3: Strengthened information exchange in the region on transboundary air pollution monitoring and assessment
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of IAEA results in: ▸ The SP organizing international conferences and/or workshops on transboundary air pollution monitoring and assessment; and ▸ The SP promoting the implementation of international projects on air pollution monitoring and assessment; and ▸ End users becoming aware of the importance of air quality monitoring and assessment.
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in: ▸ The SP participating in international projects on air pollution monitoring and assessment; and ▸ The SP participating in international conferences and/or workshops on transboundary air pollution monitoring and assessment; and ▸ The SP initiating activities to create awareness among end users on the importance of air quality monitoring and assessment.
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in: ▸ The SP participating in international projects on air pollution monitoring and assessment; and/or ▸ The SP participating in international conferences and/or workshops on transboundary air pollution monitoring and assessment.
Minor (not meeting expectations)	Standard for adequate not met.

TABLE VII–4. RUBRIC FOR CRITERION 4: Enhanced/established national and regional capacity for air pollution monitoring and assessment.

Standard (to be applied to each SP)	Criterion 4: Enhanced/established national and regional capacity for air pollution monitoring and assessment
Excellent (exceeding expectations) Meets the standard for Good, plus:	▸ The SP has the technical infrastructure and facilities for air quality sampling, analysis and source apportionment. ▸ The SP has contributed to the development of a regional database of air quality samples for more than 10 years. ▸ There are funding commitments by national EPAs and other end users to lead and support others in national air quality assessment.
Good (meeting expectations) Meets the standard for Adequate, plus:	▸ The SP has the technical infrastructure and facilities for air quality sampling and analysis, but requires external support for source apportionment; and ▸ The SP has contributed to the development of a regional database of air quality samples for 8–10 years; and ▸ There are funding commitments by national EPAs and other end users to sustain national air quality assessment.
Adequate (meeting bottom-line expectations)	▸ The SP has the technical infrastructure and facilities for air quality sampling, but requires external support for analysis and source apportionment; and ▸ The SP has contributed to the development of a regional database of air quality samples; and ▸ There are funding commitments by national EPAs and other end users to undertake some national air quality assessment.
Minor (not meeting expectations)	Standard for adequate not met.

TABLE VII–5. RUBRIC FOR CRITERION 5: Influence on national and international health and environmental regulations, policy decisions and interventions, enforcement and behaviour change.

Standard (to be applied to each SP)	Criterion 5: Influence on national and international health and environmental regulations, policy decisions and interventions, enforcement, and behaviour change
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of IAEA results in **a significant** increase in: ▸ New regulations or changes to existing regulations (e.g. environmental protection authority (EPA)); ▸ Policy decisions and interventions; ▸ Levels of enforcement; ▸ Number of pollution programmes; ▸ Evidence of population-level behaviour change.
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in **some** increase in: ▸ New regulations or changes to existing regulations (e.g. EPA); ▸ Policy decisions and interventions; ▸ Levels of enforcement; ▸ Number of pollution programmes; ▸ Evidence of population-level behaviour change.
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in **any** increase in: ▸ New regulations or changes to existing regulations (e.g. EPA); ▸ Policy decisions and interventions; ▸ Levels of enforcement; ▸ Number of pollution programmes; ▸ Evidence of population-level behaviour change.
Minor (not meeting expectations)	No material increase **in any of:** new regulations or changes to existing regulations, policy decisions and interventions, levels of enforcement, number of pollutions programmes, and evidence of population-level behaviour change.

For the purposes of the impact assessment:

- ‘Significant increase’ is an increase of sufficient magnitude to make a material difference to AQM;
- ‘Some increase’ is a non-trivial increase, but not of sufficient magnitude to make a material difference to AQM;
- ‘Any increase’ is a material increase greater than zero.

TABLE VII–6. RUBRIC FOR CRITERION 6: Economic benefits.

Standard (to be applied to each SP)	Criterion 6: Economic benefits
Excellent (exceeding expectations) Meets the standard for Good, plus:	Economic analysis suggests with a high level of certainty that the investment created more value than it consumed. Break-even is likely in nearly all scenarios (even under conservative assumptions used in the sensitivity analysis).
Good (meeting expectations) Meets the standard for Adequate, plus:	Economic analysis suggests more likely than not, the investment created more value than it consumed. Break-even is likely in over half the range of scenarios (and under realistic mid-range assumptions used in the sensitivity analysis).
Adequate (meeting bottom-line expectations)	Economic analysis suggests that under some scenarios, the investment created more value than it consumed. Break-even is possible (under plausible assumptions used in the sensitivity analysis).
Minor (not meeting expectations)	Break-even is unlikely (or only possible under optimistic assumptions used in the sensitivity analysis).

TABLE VII–7. RUBRIC FOR CRITERION 7: Improved protection of human health and environment.

Standard (to be applied to each SP)	Criterion 7: Improved protection of human health and environment
Excellent (exceeding expectations) Meets the standard for Good, plus:	Participation in the RCA programme of IAEA results in **a significant:** Reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity, and environmental and material damages, and improvement in visibility)
Good (meeting expectations) Meets the standard for Adequate, plus:	Participation in the RCA programme of IAEA results in **some:** Reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity, and environmental and material damages, and improvement in visibility)
Adequate (meeting bottom-line expectations)	Participation in the RCA programme of IAEA results in **any:** Reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity, and environmental and material damages, and improvement in visibility)
Minor (not meeting expectations)	No material reduction in exposure to air pollution (and consequently, reductions in mortality, morbidity, and environmental and material damages, and improvement in visibility)

VII–3.3. Evidence for the assessment

The theory of change, criteria and standards provided important points of reference to identify what evidence is needed for the impact assessment. For this reason, selection of methods was undertaken after clarifying the theory of change, criteria and standards. This sequence of steps helps to ensure that the evidence is relevant and focuses on the right changes [VII–4].

Examination of the rubric above revealed that the social and economic impacts of the RCA are diverse, and a mix of quantitative, qualitative and economic evidence was needed for the impact assessment. For example, the economic value captured by a reduction in mortality due to air pollution has a value that is relatively simple to estimate. However, benefits, such as strengthened information exchange and influence on policy and behaviour change, are more difficult to value monetarily. The inclusion of additional methods and data sources enabled the assessment of wider impacts and value shown in the theory of change.

Accordingly, the case study used a mix of methods, including:

- An online survey was deployed to all countries in the RCA;
- Analysis of administrative data on AQM programmes, provided by IAEA;
- Gathering additional information from AQM experts at the IAEA and RCA SPs;
- Narrative case examples, written from details provided by selected countries on a selection of ‘success cases’ of AQM programmes;
- Economic analysis of costs and benefits of AQM programmes under the RCA.

VII–3.3.1. Online survey

The online survey was designed and piloted in May 2024 and deployed between June and August 2024. The survey was structured in alignment with the rubrics to capture evidence needed in the six impact areas. It included a mix of quantitative (numeric or categorical) and qualitative (free-text) fields. The survey was administered electronically. Respondents entered data into a secure online form with automatic data validation. Responses were automatically compiled into a database for analysis.

Communication with countries about the online survey was led by the IAEA and included communication prior to deployment (to forewarn senior country representatives of the purpose and timing of the survey, giving them time to nominate a staff member responsible for completing the survey and set aside time for this task) and during deployment (including reminders, follow-up questions where needed to clarify responses and thanking country representatives for their close and effective cooperation). The communication and coordination from the IAEA and the RCA SP national representatives and their national experts were critical to the success of the survey.

VII–3.3.2. Case examples

Development of the case examples occurred following survey data collection. The selection of case examples was agreed with the IAEA. The senior contact person from each of the selected countries was contacted by IAEA to invite their participation.

Templates and instructions were developed for the countries preparing case examples and were sent to the nominated contact people. After receipt of the case example data, follow up contact was made with the contact people as required to clarify details. Narrative summaries were prepared.

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ABBREVIATIONS

ANSTO	Australian Nuclear Science and Technology Organization
APM	airborne particulate matter
AQM	air quality monitoring
CIAE	China Institute of Atomic Energy
EPA	environment protection authority
HYSPLIT	hybrid single-particle Lagrangian integrated trajectory
IBA	ion beam analysis
LIPS	laser induced plasma spectroscopy
NAA	neutron activation analysis
NEPM	national environmental protection measures
PIXE	proton induced X ray emission
PM	particulate matter
PM10	particulate matter with a diameter of 10 μm or less
PM2.5	particulate matter with a diameter of 2.5 μm or less
PMF	positive matrix factorization
RCA	Regional Cooperative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific
SP	State Party
TC	IAEA Technical Cooperation
TCAP	TC Division for Asia Pacific
TCPC	TC Division of Programme Support and Coordination
XRF	X ray fluorescence

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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This report evaluates the social and economic impacts of air quality monitoring programmes implemented from 2020 to 2024, supported by the IAEA under the Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific (RCA). It is one of four thematic assessments examining the application of nuclear science and technology in air quality monitoring, food safety, isotope hydrology and nuclear medicine.

Focusing on air quality monitoring, this publication draws on robust evidence from 19 participating State Parties, IAEA administrative data, expert insights, four success stories and a cost-benefit analysis of air quality monitoring initiatives. It highlights how technical cooperation projects leveraging nuclear science and technology on benefits of air quality monitoring have contributed meaningfully to sustainable social and economic development across Asia and the Pacific.

This publication not only highlights tangible outcomes but also emphasizes the collective value created beyond what countries could achieve alone. It is a compelling demonstration of science in action—supporting cleaner air, stronger collaboration and lasting regional progress.

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