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The Linkages between Air Quality Management Related Research and Sustainable Development in Thailand

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Abstract

Air pollution is considered one of the greatest environmental threats to human health in our era. This study aimed to evaluate the linkages between related research and studies on air quality management and the global sustainable development goals (SDGs) and to investigate strengths, weaknesses, opportunities, and threats (SWOT) of air quality management strategies in Thailand. By employing the Scale Assessment Method, the results found that SDGs related to human well-being, cities, and climate change were associated with several studies with medium to high level of agreement and evidence. In accordance with SDG 3, many scholars have been performed to investigate the relationship between both long-term and short-term exposure of air pollution and human health. In SDG 11, many cities are increasing concerned about air pollution, especially the annual mean of particulate matter in cities. Regarding SDG 13, although there is no specific headline goal on air pollution and climate change, there are some research papers available on the development of combined climate change and air quality database in Thailand. In terms of SWOT analysis, availability of research database on multi-pollutant models and research prioritization on air pollution topics were identified as key strengths. Lack of integration of air pollution and cross-cutting issues were defined as major weakness. Impacts of COVID-19 on the research direction and budget allocation were categorized as threats in driving air quality management and research development. Multi-dimensional and inter-sectoral actions for driving air pollution-related SDGs in Thailand should be more strengthened.

Keywords: Air Quality Management; Climate Change; Particulate Matter; Sustainable Development Goals

1. Introduction

The long-term effects associated with global air pollution also concern environmental risks to human health. The World Health Organization (WHO, 2021) reported that ambient air pollution was the leading cause of 4.2 million premature deaths in 2016. Approximately 91% of the global population lives in areas where the air pollution levels exceed the WHO guideline limits. Notably, most developing countries have more serious air quality problems than those experienced by developed nations due to uncontrolled urbanization, industrialization, and rapid population growth (Manisalidis *et al.,* 2020; Manucci and Franchini, 2017). In Thailand, air pollution causes about 50,000 premature deaths each year.

In 2018, cardiovascular disease was one of the main causes of death in the country (Ministry of Public Health, 2020). Furthermore, there is growing evidence that air pollution is considered to be one of the major environmental and sustainability challenges of the modern world. The 2030 Agenda for Sustainable Development was adopted by the United Nations in 2015 as part of the Sustainable Development Goals (SDGs). Seventeen interlinked SDG goals have been proposed as a call for urgent action to ensure a world in which no one is left behind (United Nations Sustainable Development Group, 2022). Air pollution is recognized as a pressing sustainability concern and directly mentioned in the following two SDG targets: SDG 3.9 (Substantial reduction of health impacts from hazardous substances) and SDG 11.6 (Reduction of adverse impacts of cities on people). Action in the energy sector, including industry, transport, and domestic subsectors, is essential to the attainment of air pollution-related SDGs. Given the indivisible nature of the 2030 global agenda (i.e., the SDGs and all related targets are interlinked and interdependent), it is likely that the target of each SDG may possibly overlap or contradict that of one or several other goals. Implementation of the SDGs requires more integrated and cross-sectoral strategies to enhance policy coherence for sustainable development (Breuer *et al.,* 2019). Despite their relevance, there is a knowledge gap in understanding the policy development strategies of different SDGs and targets. Therefore, it is becoming increasingly important to better understand the potential interactions among different SDGs (i.e., how the SDGs interact with each other) (van Soest *et al.,* 2019).

Although air pollution poses a major environmental risk for us all, the literature on its related interaction with SDGs remains scarce (Rafaj *et al.,* 2018). The aims of this research are to i) investigate the linkages between related studies on air pollution/ air quality management and SDG topics in Thailand, and ii) analyze the strengths, weaknesses, opportunities, and threats (SWOT) of air quality management and related activities in Thailand. Ultimately, the findings from this study could provide useful information for policymakers and relevant stakeholders on the linkages between air pollution and SDGs.

2. Methodology

2.1 Scaling method

A scale assessment method was applied in this research, adapted from McCollum *et al.* (2018) and Nilsson *et al.* (2016). As depicted in Table 1, all linkages between research on air pollution/air quality management and SDG-related topics in Thailand, particularly SDGs 3, 11, 13, and 17, were analyzed by considering all significant information on the strength of SDG interactions, along with the robustness and agreement of evidence. As previously mentioned, the above four SDGs were emphasized in this analysis due mainly to the mortality rate attributed to ambient air pollution and the annual mean levels of particulate matter ($PM_{2.5}$ and PM_{10}) in cities, identified as an indicator of global SDGs. Moreover, the co-benefits or additional benefits related to air pollution reduction and climate change mitigation can potentially help global development. In this study, interviews with experts (n = 9) were conducted. The experts consisted of professors or lecturers working in academic institutions with extensive knowledge of research in the areas of air pollution, air quality management, and the policies and strategies for air pollution control. As depicted in Table 1, all experts were asked to evaluate the nature of linkages between the existing research on air quality management and SDGs in Thailand by considering the following seven-point scale (McCollum *et al.,* 2018; Nilsson *et al.,* 2016):

[+3] = Indivisible refers to the strongest form of positive interaction between two objectives/aspects.

[+2] = Reinforcing refers to one objective directly creating the condition that supports the achievement of another objective (i.e., strengthening resilience and adaptive capacity)

[+1] = Enabling refers to the pursuit of one objective which enables the achievement of another.

[0] = Consistent refers to a neutral relationship where one objective does not significantly interact with another.

[-1] = Constraining refers to a mild form of negative relationship when the pursuit of one objective sets the condition for the achievement of another.

[-2] = Counteracting refers to the pursuit of one objective which counteracts another.

[-3] = Cancelling refers to the most negative interaction, where progress in one goal makes it impossible to achieve another.

Furthermore, all experts were asked to consider interactions between air quality management topics and the targets and related thematic areas of SDGs by considering the type, quality, and quantity of relevant literature in terms of "low", "medium", or "high". For instance, if more research appears to be required on a particular idea then the experts would assign a "low" level of evidence to this interaction. Regarding the degree of agreement toward such evidence, all experts were asked to evaluate the extent to which the present body of literature on air quality management/air pollution agrees with a particular finding as "low", "medium", or "high". This assessment was based on small-group expert discussions and three or four individual discussions (McCollum *et al.,* 2018).

2.2. SWOT analysis

Apart from the scaling methodology (section 2.1), all experts (n = 9) were asked to perform Strength, Weakness, Opportunity, and Threat (SWOT) analysis to gain a proper understanding of the external and internal factors influencing the development of effective control policies for air pollution management in Thailand. Theoretically, strength and weakness factors are associated with the internal situation in an organization. Meanwhile, opportunity and threat factors are considered to involve the external situation of an organization. All environmental, economic, and social aspects associated with the proposed air pollution and management policies were fully considered in this study. Moreover, the weakness and opportunity factors were identified for policy recommendation purposes, especially regarding the indicators of SDGs. The overall research framework is presented in Figure 1.

Table 1. The scaling method modified from McCollum *et al.* (2018)

Goals	Identified Interactions	Score	Evidence	Agreement
SDG 3	3.9. By 2030, substantially reducing the number of deaths and illnesses from air pollution 3.9.1: Reducing the mortality rate attributed to household and ambient air pollution	[+3] – [-3]	[+3] – [-3]	[+3] – [-3]
SDG 11	11.6 by 2030, reducing the adverse per capita environmental impact of cities, including paying special attention to air quality 11.6.2. Reducing annual mean levels of fine particulate matter	[+3] – [-3]	[+3] – [-3]	[+3] – [-3]
SDG 13	13.2 Integrating climate change measures into national policies, strategies, and planning	[+3] – [-3]	[+3] – [-3]	[+3] – [-3]
SDG 17	17.3: Mobilizing financial resources for developing countries	[+3] – [-3]	[+3] – [-3]	[+3] – [-3]

Figure 1. Overall research framework

3. Results and Discussion

3.1 Linkage between air quality management and SDGs perspective

3.1.1 Air pollution and SDG3

Table 2 details the results of the linkages between relevant research topics on air pollution/air quality management and SDGs in the context of Thailand by employing the scaling method. Regarding SDG 3, ambient air pollution (mainly particulate matter) accounted for approximately 4.2 million deaths and the loss of 103 million healthy life years in 2015. Furthermore, ambient air pollution was ranked fifth (7.6%) for mortality risk in the Global Burden of Diseases Study (Cohen *et al.,* 2015). The findings of this study reveal that much existing research focuses on the associations between the exposure of ambient air pollution and potential consequences for human health (Phosri *et al.,* 2019; Pinichka *et al.,* 2017; Apichainan *et al.,* 2022; Tunsaringkarn *et al.,* 2015; Vichit-Vadakan *et al.,* 2011; Paoin *et al.,* 2021; Vichit-Vadakan *et al.,* 2008; Pinichka *et al.,* 2016; Jenwitheesuk *et al.,* 2020; Bherwani *et al.,* 2021; Sangkham *et al.,* 2020; Dejchanchaiwong *et al.,* 2020; Wang *et al.,* 2020; Langkulsen *et al.,*2006). For instance, Phosri *et al.* (2019) evaluated the long and short-term effects of concentrated ambient air pollution (i.e., O_3, NO_2, SO_2, PM_{10}, and CO) on the incidence of respiratory and cardiovascular disease and the weather variable in Bangkok, Thailand. Moreover, the comparative risk assessment framework developed by the World Health Organization (WHO) and Global Burden of Disease study was applied to assess the adverse health impacts associated with exposure to ambient air pollution (Pinichka *et al.,* 2017). Furthermore, the study also integrated Geographic Information Systems (GIS) into inverse distance weight (IDW) interpolation models to quantify air pollution exposure and associated mortality based on the population distribution, relative risks, and concentration-response relationships. Cardiovascular (ICD-10 code: I00-99), respiratory (ICD-10 code: J00-99), lung cancer (ICD-10 codes C34), and all-cause mortality (ICD-10 codes V01–Y89) for all ages were considered when estimating the population-attributable fraction (PAF) of ambient air pollution in Thailand. As previously noted, the figures for disease-specific mortality were obtained from the Thai Burden Disease study (Bundhamcharoen *et al.,* 2011) conducted every five years to provide crucial information for the priority setting of national health policies. Key findings indicated that considering the geographical distribution of annual mean $PM_{2.5}$, PM_{10}, and N_2O concentration, the Bangkok Metropolitan Region (BMR) was more seriously polluted than other regions. The PAF summations of adult mortality attributable to NO_2 and $PM_{2.5}$ were the highest among all pollutants. Interestingly, Pinichka *et al.* (2017) also suggested the use of the $PM_{2.5}/PM_{10}$ ratio as an indicator for assessing the exposure to $PM_{2.5}$ based on the empirical evidence contained in the WHO environmental burden of disease study. Besides, some studies focus on the health impacts of air pollution on vulnerable populations. For instance, a cross-sectional study by Apichainan *et al.* (2022) assessed the relationship between residential environments and the respiratory symptoms of about 658 primary school children living in an urban area of Bangkok, Thailand. The results revealed that children living in an environment of cigarette smoke and with smokers in their family exhibited dry cough symptoms at night. Moreover, child respondents living near a clothing factory experienced shortness of breath. Exposure to damp and moldy environments (i.e., damp walls) is considered to be a risk factor for respiratory diseases in children. For the aging population, a cross-sectional survey performed by Tunsaringkarn *et al.* (2015) in Bangkok, Thailand, found that the elderly living in highly populated areas were subject to long-term health problems from poor indoor air quality, especially in relation to volatile organic compounds (VOCs). Some recent studies have attempted to assess the significant relationship between COVID-19 infection and air pollution (i.e., Sangkham *et al.,* 2021). The results reveal that all meteorological parameters (i.e., temperature, humidity, and wind speed) showed significant positive correlations with daily confirmed COVID-19 cases in the Bangkok Metropolitan Region (Sangkham *et al.,* 2021). For all the above-mentioned factors, every expert interviewed indicated “high” for both the degree of agreement and level of evidence concerning the nature of air pollution and SDG 3 interaction (Table 2).

3.1.2 Air pollution and SDG11

When considering the robustness of the relationship between air pollution and SDG 11 targets, increased air pollution in cities was found to be a matter of concern. There is a significant linkage between the annual mean levels of fine particulate matter ($PM_{2.5}$ and PM_{10}) and the environmental quality of cities. In BMR, Chuersuwan *et al.* (2008) identified major sources of particulate matter at four monitoring sites from 2002 to 2003. The results confirmed that the major sources of PM_{10} and $PM_{2.5}$ at the traffic site were automobile and biomass burning. Repeatedly, biomass burning was considered to be the major source of $PM_{2.5}$ at residential sites. In Northern Thailand, Chinsorn and Papong (2021) estimated $PM_{2.5}$ concentrations in nine provinces using the multiple linear regression (MLR) model of monthly $PM_{2.5}$ data, MERRA-2 aerosol reanalysis, and meteorological data. The results highlighted that Chiang Rai contributed the greatest concentration of $PM_{2.5}$, followed by Chiang Mai, and Mae Hong Son. Agricultural burning and bushfires appeared to be the major sources of $PM_{2.5}$ in those particular areas. In addition, the international standard for $PM_{2.5}$ and PM_{10} concentrations can be used to monitor, improve air quality in urban cities, and estimate the impacts of $PM_{2.5}$ mortality. Moreover, the emission standard could also be associated with the USDG model, which revealed “poor availability of standardized, open and comparable data”, as an indicator of the urban sustainable development goal (USDG). For instance, compared to China, where air pollution is not only a national issue but also significant at city and regional level according to the annual Air Quality Guideline of WHO and threshold values. Effective air quality standards are key to reducing the environmental impact on cities and accelerating the sustainable development of urban society and cities in the long run. A recent study by Chenxing *et al.* (2022) also highlighted that a deep understanding of the inter-linkage between cities and global SDGs should be systematically assessed by considering all urban sustainability efficiency indicators (i.e., air quality, energy consumption, population health, economic development, and living conditions). However, there is a dearth of research and reliable data on the topic in the context of Thailand.

For cities with a relatively high level of economic development, urban $PM_{2.5}$ concentrations will decrease as GDP per capita continues to increase. Moreover, existing research indicates that economic development may lead to an improvement in air quality. In Thailand, a recent study by Tantiwat *et al.* (2021) investigated the willingness of people to pay for air quality improvement. Surprisingly, over half the residents (63%) surveyed expressed their unwillingness to pay more to improve air quality as they have already paid taxes. Furthermore, the estimated mean of willingness to pay to improve air quality in this study was approximately 2,272 THB/person/year. Overall, the experts expressed a high level of evidence and medium level of agreement for the air quality management research-related SDG11 (Table 2).

3.1.3 Air pollution and SDGs 13 and 17

In SDG 13, although no goal directly indicates the linkage between climate change and air pollution strategies, some research exists on the development of combined climate change (i.e., greenhouse gases emissions and inventory) and an air quality database in Thailand. Evidently, Arunrat *et al.* (2018) estimated both greenhouse gas emissions and chemical compositions of $PM_{2.5}$ from agricultural burning activities (i.e., grain maize and seed maize residues) and integrated farming systems. The results suggested that integrated farming systems contributed the lowest amount of both greenhouse gases and chemical compositions of $PM_{2.5}$ emissions. Regarding air quality management and climate change planning, the application of Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS), the Comprehensive Air Quality Model with Extensions (CAMx), and the ECHAM5 Global Climate Model are very useful for assessing the impact of global and regional climate change on air quality-related meteorological conditions in a systematic way. Specifically, a study by Cheewaphongphan *et al.* (2017) estimated emissions from on-road transportation in BMR from 2007 to 2015 using the GAINS Model to analyze the country-specific data and emission factors obtained from the GAINS-Asia database. The key results indicated that CO, NH_3, N_2O, and NMVOC were mostly released from light-duty vehicles, with NOx, SO_2, and PM mainly emitted from heavy-duty vehicles. The potential future impacts of climate change (i.e., precipitation and temperature) (2031 to 2070) in Thailand were predicted by Manomaiphiboon *et al.* (2013) who used three emission scenarios and a regional climate model (RegCM3) based on the ECHAM5/MPI-OM global climate model.

Significantly, SDG 13.2 aims to integrate climate change measures into national policies, strategies, and planning. Conceptually, the co-benefits of air quality improvement and climate change have attracted the attention of many scholars (i.e., the Climate and Clean Air Coalition (CCAC)). However, the co-benefits of implementing climate and pollution control policies are highly complex. Therefore, the experts interviewed considered that a medium level of evidence and high level of agreement existed in the relationship between the climate change goal (SDG13) and air quality management. Lastly, since the experts rated both evidence and agreement for the interconnection between SDG 17 and air pollution/air quality management related studies at the medium level (Table 2), this could indicate that the government of Thailand has continually cooperated with other related international agencies (i.e., academic, INGOs, and public sectors) in implementing policies and measures to deal with air pollution. For instance, the Climate and Clean Air Coalition, the ASEAN Transboundary Haze Agreement, Stockholm Environment Institute (SEI), WHO, and so on.

Table 2. Overview of the literature review and conclusions drawn on interactions between air pollution and the targets of global SDGs 3, 11, 13, and 17 in Thailand

SDG	Target Category	Supporting Literature	Identified Interactions	Score	Evidence	Agreement
3 GOOD HEALTH AND WELL-BEING	3.9.1 Mortality rate attributed to household and ambient air pollution	Pinichka *et al.* (2017); Apichainan *et al.* (2022); Tunsaringkarn *et al.* (2015); Vichit-Vadakan *et al.* (2011); Vichit-Vadakan *et al.* (2008); Paoin *et al.* (2021); Pinichka *et al.* (2016); Jenwitheesuk *et al.* (2020); Bherwani *et al.* (2021); Sangkham *et al.* (2021); Dejchanchaiwong *et al.* (2020), Wang *et al.* (2020); Langkulsen *et al.* (2006)	There are several research articles on the relationship between ambient air pollution and the spatial distribution of mortality rates. The following classic examples of the research direction are presented to represent the linkage to SDG3 related themes: - The effects of ambient air pollution on hospital admissions for respiratory and cardiovascular diseases in Bangkok by considering the concentrations of O_3, NO_2, SO_2, PM_{10}, and CO along with the weather variable, monitored in Bangkok, Thailand, from 2006 to 2014. - Short-term effects of PM on daily hospital admissions in Bangkok, Thailand, from 2006 to 2014 based on an analysis of the over dispersed Poisson regression model and daily PM_{10} concentrations and the daily cardiovascular and respiratory admission data. - The mortality risk from air pollution in Bangkok, Thailand, from 1999 to 2003. - Long-term exposure to air pollution and self-reported morbidities (i.e., high blood pressure, cholesterol, and diabetes) was observed and analyzed in the Thai cohort study (TCS) of the Bangkok Metropolitan Region, Thailand. - Assessment of the spatial patterns in the mortality burden attributed to ambient air pollution in Thailand in 2009 through the comparative risk assessment framework developed by the World Health Organization (WHO), the Global Burden of Disease study (GBD), and GIS method. Concentrations of air pollutants, the distribution of exposure, and the concentration-response (CR) relationship were also considered in the assessment. - Association between the exposure to Thai children from pesticides, heavy metals, and air pollution and their subsequent health outcomes. - Investigation of the relationship between residential environments and respiratory symptoms in primary school children. - The burden of disease attributed to Thailand's ozone in 2009 based on the following empirical evidence: disability-adjusted life years (DALYs) attributable to O_3 using the comparative risk assessment framework, the population distribution of exposure, and the exposure-response coefficient. - Relationship between colon cancer risk and pollution in Thailand by employing the Bayesian hierarchical spatiotemporal model and the Poisson log-linear model. - Assessment of health impacts and economic loss in ten countries (including Thailand) during the COVID-19 lockdown by considering the patterns of $PM_{2.5}$ based on the Validated Simplified Aerosol Retrieval Algorithm (SARA) binning model. - Investigation into the relationship between long-term exposure to air pollution (i.e., PM_{10} and SO_2) and illness (i.e., hypertension, high blood cholesterol, and diabetes) in the Bangkok Metropolitan Region, Thailand. - Analysis concerning the effects of weather conditions, air pollutants, and air quality index (AQI) on daily confirmed COVID-19 cases in the Bangkok Metropolitan Region (BMR). The results indicate that CO, NO_2, SO_2, O_3 PM_{10}, $PM_{2.5}$, and AQI have a significantly negative association with COVID-19 cases in the BMR. - Investigation into the relationship between the chronic effects of air pollution and the lung function and respiratory symptoms of 570 children aged 10 to 15 years in Bangkok.	[+2, +3]	High	High

Table 2. Overview of the literature review and conclusions drawn on interactions between air pollution and the targets of global SDGs 3, 11, 13, and 17 in Thailand (Cont.)

SDG	Target Category	Supporting Literature	Identified Interactions	Score	Evidence	Agreement
11 SUSTAINABLE CITIES AND COMMUNITIES	11.6.2. Annual mean levels of fine particulate matter (i.e., $PM_{2.5}$ and PM_{10}) in cities (population weighted)	Chinsorn & Papong (2021); Pakpom *et al.* (2016); Tantiwat (2021)	- Identification of the linkage between annual mean levels of fine particulate matter ($PM_{2.5}$ and PM_{10}) in cities and the environmental impact. - Assessment of $PM_{2.5}$ using MERRA-2 Aerosols in Northern Thailand. - Analysis on the potential sources of $PM_{2.5}$ and PM_{10} in Bangkok, especially areas exceeding the threshold value given by the WHO guideline. - Highlights the importance of the PM concentration level and its associated linkage with premature mortality to improve Bangkok's air quality and estimate the impact of $PM_{2.5}$ on mortality, and reduce annual premature mortality in Bangkok. - Highlights examples of urban sustainable development goal (USDG) indicators. The study also suggests integrated policies to put the world on track toward three interlinked goals for achieving universal energy access, limiting climate change, and reducing air pollution.	[+3]	High	Medium
13 CLIMATE ACTION	13.2 Integrate climate change measures into national policies, strategies and planning	Cheewaphongphan *et al.*, (2017); Arunrat *et al.* (2018); Manomaiphiboon *et al.*, 2013; Chotamonsak *et al.*, (2020), Allard *et al.* (2016), Wongwatcharapaiboon (2020)	Development of climate change and air quality and assessing the air quality impacts of combined climate change database management. The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model is applied, based on country-specific activity data and emission factors from the GAINS-Asia database and the Comprehensive Air Quality Model with Extensions (CAMx). Furthermore, the ECHAM5 Global Climate Model was also employed to assess the impact of regional climate change on air quality-related meteorological conditions in Thailand. Previous studies have also presented R&D and related policies on climate change mitigation and air pollution abatement co-benefits: - Analysis of the Effects of the Power Development Plan of Thailand 2015 on Air Quality from 2016 to 2036 (Allard *et al.*, 2016). - Control agricultural open burning activities. - Motor vehicles and traffic control policies, especially in the city center.	[+1, +2]	Medium	High
17 PARTNERSHIPS FOR THE GOALS	17.3: Mobilize financial resources for developing countries		- Thailand and the Climate and Clean Air Coalition. Correlation between the Center for Air Pollution Mitigation (CAPM) of the Pollution Control Department (PCD), Thailand, and the Climate and Clean Air Coalition (CCAC) to identify solutions for reducing "short-lived climate pollutants" (CCAC, 2021). - ASEAN Transboundary Haze Agreement.	[0, +1]	Medium	Medium

3.2 SWOT analysis for R&D air quality management activities in Thailand

Based on the expert interviews, Table 3 shows the results of SWOT analysis for on-going air pollution/air quality management, R&D activities, and related SDG movement in Thailand. The results identified the availability of a research database on multi-pollutant models, national policies and strategies to deal with air pollution, as well as research prioritization on air pollution topics as strengths (S) in driving air quality management in Thailand through the lens of global SDGs. In contrast, the absence of a research database on multiple sources of air pollution, the integration of air pollution topics and cross-cutting issues, as well as the lack of investment in research and innovation on air quality improvement were defined as weaknesses (W) inhibiting the attainment of air quality-related SDGs in Thailand. Besides, in terms of external factors, opportunities (O) for supporting air quality management research in Thailand involve both international and private collaborations to tackle the problem of air pollution, while $PM_{2.5}$ draws significant attention from local communities and social media. Lastly, the impacts of the COVID-19 pandemic on the research direction of environmental protection and air pollution abatement directly linked to budget allocation were categorized as threats in driving air quality management and related R&D in Thailand. These results are consistent with a recent study on SWOT analysis for air pollution management in Thailand's eastern region conducted by the Eastern Economic Corridor (2020) who found that limited resources and lack of regular/continuous air pollution monitoring were considered as weaknesses (W) for effective air quality management in Thailand. In practical terms, the stakeholder's level of knowledge and understanding on policies and laws designed to control air pollution and lack of common approaches for sharing data and new technological innovation were defined as the key threats to fully achieving air pollution-related SDGs.

According to the SWOT analysis, and considering the opportunities and threats (OT), this research strongly suggests: i) international organizations and the private sector should collaborate further and support the government in R&D on the integration of air pollution and SDG cross-cutting issues; ii) the government and related authorities should provide more financial support for research into the co-benefits of air quality management and progressing the SDGs in Thailand. This view is supported by Tantiwat *et al.* (2021), who indicated that insufficient funds were considered to be one of the most important constraints to improving air quality in Thailand; iii) the government and social media should utilize a broad reaching social media strategy and communication

Table 3. Results of SWOT analysis on air quality management and related research and development in Thailand based on the perspectives of respondent experts

Strength (S) - Availability of a research database on multi-pollutant models and the Greenhouse Gas and Air Pollution Interactions and Synergies model. - Availability of national policies, plans, and strategies for dealing with air pollution (single demand). - Air pollution and SDGs are defined as priority research topics by the National Research and Innovation Information System.	**Weakness (W)** - Multiple sources of air pollution and atmospheric complexity. Chemical transformation and transport. - Lack of multi-pollutant air quality management plans, strategies, and potential solutions. - Limitation of R&D on the integration of air pollution and cross-cutting issues. - Lack of air quality monitoring coverage and an existing research database in many high-risk areas. - Direct sources of $PM_{2.5}$ remain unclear. - Lack of investment in research and innovation to reduce the negative impacts of air pollution.
Opportunity (O) - International support and collaboration on air pollution R&D and related dimensions of SDS (i.e., Stockholm Environment Institute). - Private sector engagement in mitigation activities, air quality management, and research contributions. - Financial support for the co-benefits of air quality management and related SDGs research areas. - $PM_{2.5}$ draws significant attention in Thailand (i.e., Bangkok). - The government and social media provide air quality information to the public via the internet and other information channels.	**Threat (T)** - Effect of the COVID-19 pandemic on current policy and R&D directions. - Lack of budget allocation to "continuously" support research and development, particularly on the topic of air quality management.

platform to raise awareness among local citizens on air pollution prevention and the related impact on their health, cities, and climate system. From the long-term perspective, the following discussion points are presented for driving Thailand toward the achievement of air quality-related SDGs and relevant targets:

Multidimensional of air pollution-related SDGs: As previously stated, the issues of air quality management are not directly defined in any of the 17 SDGs. Elder and Zusman (2016) observed air pollution and air quality management to be closely associated with other global SDGs such as no poverty (SDG1) (i.e., since the poorest people are most affected by air pollution, reducing it may also reduce inequality), zero hunger (SDG2), energy (SDG7), industry, innovation and infrastructure (SDG9), sustainable cities (SDG11), sustainable consumption and production (SDG12), and life on land (SDG15), even though the linkages between multiple targets of the these SDGs are not specifically stated. For instance, target 11.2 of the global SDGs aims at sustainable transportation systems for all by 2030, which would make an important contribution to minimizing air pollution-related problems. It should be noted that the interlinkages between global SDGs can be classified into drivers of air pollution (i.e., industry and transportation) and solutions (i.e., SDG7 aims to promote energy efficiency and clean energy R&D, which would potentially minimize air pollution) (Elder & Zusman, 2016). Therefore, the synergies between air quality management, all SDGs, and relevant targets should be better promoted. An integrated approach for engaging multi-stakeholder partnerships (as a shared expression of stakeholder needs) should also be considered in Thailand's air quality planning. To recognize the interlinkages between air quality management and other SDGs, capacity building, technical assistance, technology transfer, and financial support would be a very good starting point in prioritizing efforts to achieve long-term air quality-related SDGs.

Multisectoral and intersectoral actions for driving air pollution-related SDGs: Air pollution control and management should be a part of a broader integrated approach to encourage the participation of multisectoral and multi-stakeholders in the policy process. All economic (i.e., SDGs 8, 9, 10, and 12), social (i.e., SDGs 1, 2, 3, 4, 5, 7, 11, and 16), environmental (i.e., 6, 13, 14, and 15), and cross-cutting issues (i.e., SDG17) should also be considered (Longhurst et al., 2018). For example, from the economic perspective, the study by Longhurst et al. (2018) emphasized that air pollution prevention would help to enhance the economic productivity of the country by reducing the number of working days lost to illness. In the social dimension, efforts to prevent and reduce air pollution would mitigate the potential risk to the vulnerable population of exposure, thereby reducing inequality in air pollution-related health outcomes. The following R&D aspects should be addressed in future studies on Thailand: people's willingness to pay and the health benefits of air quality improvement, public attitudes toward policies for improving air quality in both rural and urban areas, environmental taxation, sustainable transportation and urban planning, smart farming techniques to reduce climate change and pollution, as well as the COVID 19 infection risk associated with ambient air pollution. Integrated assessment models (IAMs) focusing on the complex interactions between humans and the environment (i.e., interconnections between climate change mitigation and other sustainability issues, including air pollution, energy, biodiversity, and public health) (van Soest *et al.,* 2019) should also be employed in Thailand as potential strategies for driving the simultaneous achievement of multiple SDGs. In short, as indicated in Figure 2, all the "5 Ps" of the global SDGs (people, planet, prosperity, peace, and partnership) must be systematically included in the national framework for air quality management.

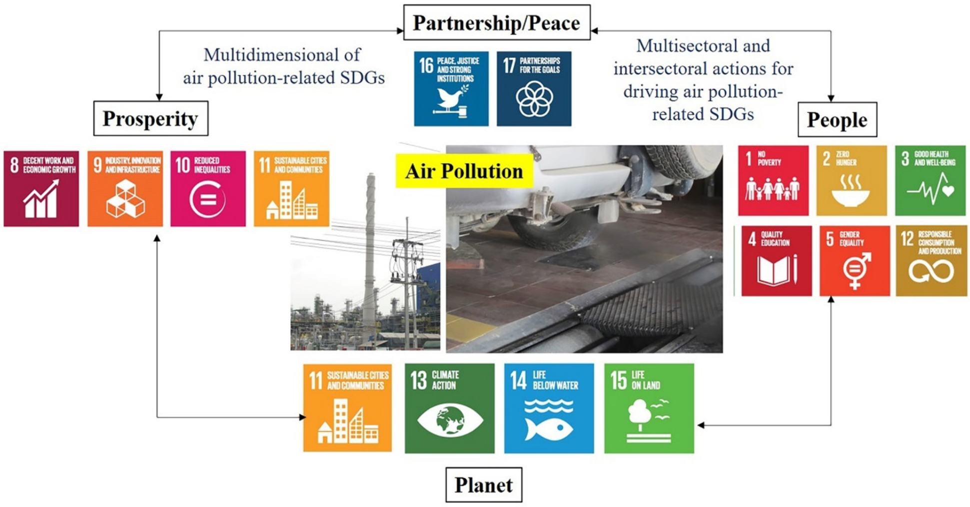

Figure 2. The 5Ps of SDGs associated with air quality management

4. Conclusion

Air quality plays an important role in building a greener city and driving the achievement of SDGs in all related aspects of human health, cities, and climate actions. This study applied the scale assessment method, literature reviews, expert interviews, and SWOT analysis to identify the inter-linkages between air pollution/air quality management research activities in Thailand and the global SDGs, mainly focusing on SDG3, SDG11, SDG13, and SDG17. The results indicate that many studies exist concerning the effects of air pollution on mortality and hospitalizations mainly due to cardiovascular and respiratory diseases. The health impacts on vulnerable groups associated with ambient and indoor air pollution were assessed, as well as the potential exposure to air pollution by GIS applications (high levels of agreement and evidence for SDG3). Concerning SDG11, some studies have evaluated the main sources of air pollution in both urban and rural areas of Thailand and people's willingness to pay for air quality improvement (a high level of evidence and medium level of agreement for SDG11). Although there is no direct relationship between climate change and air pollution in the global SDGs, some scholars have already begun to estimate the greenhouse gas emissions and $PM_{2.5}$ chemical compositions arising from agricultural burning activities in Thailand. They have also investigated the interplay between climate and air pollution using regional and global models (a medium level of evidence and high level of agreement for SDG13). The experts expressed a medium level of evidence and agreement toward on-going collaboration and partnerships with international organizations for air quality management. Concrete plans, strategies, and potential solutions for dealing with air quality-related SDGs and targets in Thailand should be further investigated.

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