Effective options for addressing air quality– related environmental public health burdens in Saudi Arabia

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Overview

Air pollution remains a major contributor to the global burden of disease, accounting for approximately 10% of annual deaths globally (WHO, 2016). Ambient concentrations of fine particulate matter (PM; where fine is 2.5 µm or less, PM2.5), ozone (O3), sulfur dioxide (SO2), and oxides of nitrogen (NOx) contribute to a variety of illnesses.. Saudi Arabia experiences deaths attributable to outdoor air pollution at a much greater rate than other countries of comparable income (Our World in Data, 2019; World Bank, 2020). Common sources of combustion emissions in Saudi Arabia are transportation, electricity, and water desalination. Saudi Arabian shipping supports large trade volumes of 7.1 million barrels per day of oil and 8.9 million twenty-foot equivalent units (TEUs—i.e., shipping containers) (World Bank, 2021). This research is designed to assess existing evidence and recommendations on effective options for addressing environmental public health burdens in Saudi Arabia. Specifically, what effective technologies and policy options are available for avoiding exposure to existing air pollution and what are the key drivers of their effectiveness relevant to the Saudi Arabian context? And also What cost effective technology and policy options are available for preventing air pollution and what are the key drivers of their costs relevant to the Saudi Arabian context?

Methods

We conduct a semi-systematic literature review of available costs and effectiveness information. The literature review is designed to cover the two distinct approaches to addressing environmental public health concerns by either (1) adapting to existing pollution through avoidance measures or (2) mitigating air pollution sources through pollution control measures.We evaluate the availability, content, and relevance of cost and effectiveness information from our search results for efficiently and effectively addressing the prevailing sources and ambient pollution in Saudi Arabia. For adaptation, we first identified options—ranging from air filtration to air quality warning systems— for avoiding poor ambient air quality. For mitigation, we searched for both technologies and policies designed to reduce air pollutant emissions. Each search includes the pollutants relevant to the air quality hazards identified by the WHO. We conducted literature searches for adaptation responses to reduce exposure to pollution in both the Web of Science and PubMed and literature searches for pollution mitigation in the Web of Science only, with all searches over the years 2011–2021. We retrieved a list of titles, authors, abstracts, and select other bibliometric information for all our literature search results. We then organized the results by adaptation and mitigation and divided mitigation results into those returned with the search term "policy" and those with the search term "technology," forming three sets of results for our review. We assigned one author per result set (i.e., adaptation, mitigation technology, and mitigation policy) to review and rate each result on four criteria (enumerated below) based on abstract and title. We removed duplicate results within each of these three sets of results but not across them, leaving results to be scored multiple times and compared to assess inter-rater reliability. We ranked papers as "confident criterion is not met" (0), "not confident whether criterion is met" (0.5), or "confident the criterion is met" (1.0) for each of the four inclusion criteria. one reviewer and all received consistent scoring of either 3.5 or greater or less than 3.5. Finally, we re-ranked results in our full-text review on the same criteria as in the abstract review. one reviewer and all received consistent scoring of either 3.5 or greater or less than 3.5. Finally, we re-ranked results in our full-text review on the same criteria as in the abstract review. From the full-text reviews, we summarized both qualitative information on mitigation and adaptation interventions and their effectiveness. All papers receiving a score of 3.5 were reviewed for our qualitative summaries. For quantitative mitigation results, we required that the study provide quantitative cost and abatement information in the form of either currency per emission unit reduced (e.g., USD/tonne) or a cost followed by a reduction in emissions so that cost-effectiveness could be calculated. On some occasions, we also had to estimate the pollution reduction amount. Some of the studies provided a baseline value and percent reduction.

Results

In total, our literature searches returned 3,068 articles, two-thirds of which came from the adaptation search and 748 of which were duplicates within searches. The mitigation searches returned similar numbers of technology and policy results. The initial screening, based on abstract and title, excluded 1,890 articles that did not receive a scoring of 3.5 or higher in our review. We recategorized articles that were determined to be a better fit for a category other than the one they were initially identified under (e.g., mitigation policy rather than mitigation technology) and removed duplicate articles that were identified in multiple searches, leaving 335 articles for full text review, 276 of which we excluded for not meeting the screening criterion after full text review. The qualitative and quantitative results that follow are based on a full text review of 59 articles passing all stages of our screening. Figure 3 provides a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement of our literature review process across our searches. The review of adaptation measures to address air quality identified 12 studies that detail effectiveness and/or cost information. Of the studies identified in the review, all discussed effectiveness information and only one discussed cost. The measures identified can be taken by society, a household, and/or an individual. Of those identified, most studies examined air quality messaging systems that use constructed indices for communication to the public. Other studies identified examined measures to reduce human exposure to automobile traffic in urban settings, indoor air filtration and ventilation, and personal mask usage.

Although there is substantial interest in identifying and characterizing cost-effective technologies for mitigating air pollution, our search of the literature found relatively few studies in the academic literature that meet our search criteria. Generally, there is wide variation in estimated costs associated with alternative mitigation technologies, partly because the cost of reducing a given level of emissions depends heavily on the incremental costs of the mitigation technologies as well as the emissions reduction efficiency available at each emitting facility. Table 2 summarizes the findings of our review of recent literature with sufficient information to derive estimates of cost-effectiveness. We separated the available observations into those based on controlling single pollutants and those assessing the simultaneous control of multiple pollutants. Among the estimates assessing single pollutants, the majority (24 estimates) focused on PM, followed by NOx (11), and SO2 (10). The median costs per tonne reduced were similar for PM and NOx, with both exceeding the median cost-effectiveness of mitigating SO2 by more than three times. The ranges are so large that they all overlap, though the interquartile range of cost-effectiveness for SO2 is substantially lower and narrower than it is for PM or NOx. Negative costs imply that some opportunities exist for cost savings (e.g., through efficiency improvements) in controlling emissions.

Mitigation policies are designed to encourage market participants to put into effect pollution control technologies that would not be privately economical. Pollution mitigation policies are innumerable in their specific provisions and regulatory requirements. In terms of categories, they include one or more of the following mechanisms to induce the adoption of pollution controls: (1) taxes or subsidies provide direct economic penalties or incentives for polluting for mitigating pollution; (2) permitting schemes create a restricted commodity for pollution, limiting a quantity or emissions rate; (3) "command-and-control" approaches require specific action by emitters; (4) public information and other nonpecuniary and non-remunerative policies can help encourage the adoption of mitigation options where individuals or firms may find it privately beneficial to do so given sufficient information (e.g., explaining the cost savings of energy efficiency upgrades).

The effectiveness of adaptation options at reducing pollution exposures suggests that policies that provide actionable information (e.g., air quality alerts) and that subsidize required resources (e.g., equipment) could provide cost-effective environmental public health improvements in Saudi Arabia. Still, our literature review did not identify robust costbenefit evaluations of environmental public health adaptation policies, and the centrality of behavioral responses in determining the effectiveness of such policies suggests that existing studies may not generalize well to other populations. Behavioral responses include populations' responsiveness to air quality information; their financial capacity to invest in air quality equipment; their willingness to invest given how they value and discount future air quality benefits against up-front investment costs; and their ability and willingness to operate air quality equipment at optimal efficiency. For example, face masks may be excessively hot to wear outdoors in Saudi Arabia's climate, separating pedestrian spaces from vehicular traffic may be costly given the country's current infrastructure, and such separation may also be inconvenient or otherwise undesirable for pedestrians.

Conclusions

Significant opportunity exists for improving environmental public health in Saudi Arabia relative to the standards enjoyed by its peers by income. While existing international guidelines such as those from the WHO provide a helpful reference point for ambient air quality goals, they lack the cost and performance specificity for technologies and policies needed to address the air quality challenges Saudi Arabia faces. To address this gap, this review focused on the level and determinants of the effectiveness of mitigation and adaptation options for addressing environmental public health. We reviewed approximately 3,000 peerreviewed publications relevant for improving environmental public health outcomes in Saudi Arabia. Our literature review identified research with effectiveness evaluations of specific pollution control interventions relevant to Saudi Arabia. Our review focused on technologies and policies available for mitigating and adapting to some of the most prominent air pollutants relevant to environmental public health: PM,NOX, and SO2.

Pollution mitigation technologies are myriad and, while they may be thoroughly studied and demonstrated as effective, must be evaluated in the Saudi context. Technology costs also vary widely. The specific costs that apply to Saudi Arabia must be determined through local engineering evaluations of existing and potential new sources. Policies that allow for flexibility in who mitigates their emissions will generally provide firstbest options for cost minimization; however, important spatio-temporal heterogeneity exists in benefits and distributional equity considerations that must be factored into policy design. For the pollution that is not mitigated, several important adaptation strategies exist for creating less polluted indoor environments, filtering outdoor air with face masks, avoiding outdoor areas with especially hazardous pollution levels, and raising public awareness of pollution hazards when and where they exist.The literature suggests that these adaptation measures are effective at reducing exposure, but their cost-effectiveness requires further study with local relevance. Saudi-specific evaluations of adaptation measures may be especially important, as many local determinants of adaptation effectiveness exist, including behavioral responses and local infrastructure.

Our review found that adaptation has the least available information, especially with respect to cost effectiveness evaluations. We also found relatively few relevant studies on technology cost-effectiveness. While this may be partly the result of the “durability” of older technical reports and studies, up-to-date, local information remains a necessity for new environmental public health initiatives in locations that have less pollution control history such as Saudi Arabia. The policy cost evaluations identified several different important aspects of policy design but offered relatively little on optimal multipollutant policy design. While highly relevant for broadscale environmental public health efforts, such research may be primarily theoretical and therefore would have been excluded by our literature review for lack of specificity.

Future research evaluating specific multipollutant outcomes from policy interventions in diverse settings would serve this literature well. While techno-economic, economy-wide simulation modeling can be very informative, it is an incomplete substitute for empirical evidence of policy effectiveness. Still, richer simulations of diverse physical and techno-economic systems can greatly enhance policy evaluations by combining atmospheric modeling, spatially rich information on infrastructure and exposed populations, and multisectoral techno-economic characterization of pollution-generating activities. Such studies remain scarce and geographically under-diversified. Finally, behavioral studies that can account for individual and institutional biases in responding to policy initiatives over a greater range of socio-demographic diversity and with local relevance to countries expected to significantly expand their pollution control regimes such as Saudi Arabia can greatly enhance our understanding of policy effectiveness.