Human health and economic costs of air pollution in Utah[1]

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Understanding the costs and causes of air pollution in Utah is crucial to implementing effective solutions. To address disagreement in the public discussion of these costs, we compiled research from the best medical and economic studies and collected Utah-specific estimates and input from 21 researchers with expertise in medicine, public health, atmospheric science, or economics. This process—known as *expert assessment*—has proven highly reliable at compiling the best available evidence to solve time-sensitive issues in engineering, medicine, and many other research fields[1]. The Utah-based experts combined their own research and professional expertise with the broader scientific literature to provide integrative estimates of the costs, causes, and potential solutions for air pollution in Utah. Some key findings:

1. **Air pollution shortens the life of the average Utahn by 2** (1.1–3.5) **years** (Fig. 1A). This loss of life is distributed across most of the population rather than only affecting "sensitive groups." For example, 75% of Utahns lose 1 year of life or more because of air pollution and 23% lose 5 years or more (Fig. 1B). These estimates are directly in line with medical studies of the health effects of exposure to air pollution[2–4].
2. **Air pollution costs Utah's economy $1.8** ($0.58–3.2) **billion annually** (Fig. 1C). This economic damage is split roughly equally between direct costs (such as healthcare expenses and lost earning potential) and indirect costs (such as loss of tourism, decreased growth, regulatory burden, and business costs). These estimates are more conservative than those from national economic studies, which suggest that air pollution in Utah costs $7.4 ($6.2–8.6) billion annually when downscaled to Utah by population and GDP[2,5–7].
3. **Fossil fuel pollution causes or worsens many illnesses and conditions in Utah (Fig. 2)**. 85% of the pollutants causing health and economic harm are fossil fuel combustion products (fine particulate matter, ozone, and various oxides). Heart and lung diseases (congestive heart failure, heart attack, pneumonia, COPD, asthma, etc.) account for 62% of the pollution impact, with 38% from stroke, cancer, reproductive harm to mothers and children, mental illness, behavioral dysfunction, immune disease, autism, and other conditions[2,8–10].
4. **There are many state-level actions that could reduce air pollution while benefiting the economy (Fig. 3)**. Increasing efficiency of vehicles and buildings, investing in awareness, removing subsidies for nonrenewable energy, pricing carbon pollution, and expanding alternative transportation could all result in double-digit decreases in air pollution. Similar measures elsewhere have had immediate benefits for human health and a large economic return on investment, averaging $32 in economic benefits for every $1 invested towards improving air quality [2,11]. Utahns overwhelmingly support such measures[9,12].

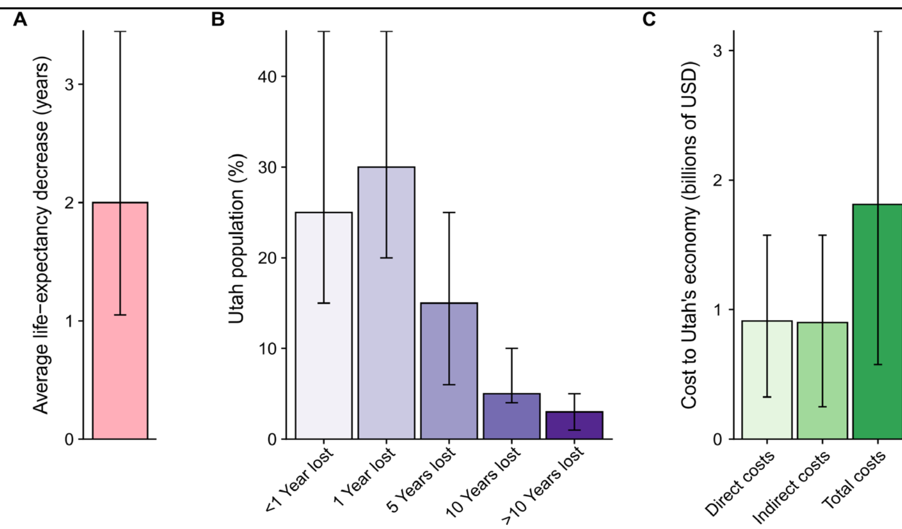

Figure 1. Estimates of the human health impact and economic costs of air pollution in Utah. A shows the number of years lost by the average Utahn due to death or serious disability caused by air pollution. B shows the distribution of the loss of life expectancy across the Utah population (the percentage of Utahns losing different numbers of years). C shows the economic costs of air pollution in Utah. The median and 95% confidence range are shown based on quantitative estimates from 10 (A and B) and 8 (C) Utah researchers. Details about the methods and experts on the following pages.

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Global and national costs of air pollution: Recent medical and economic research has found that air pollution causes much more damage to our health and economy than previously understood[8]. Worldwide, more than 6% of all deaths are attributable to air pollution—at least 8.8 million people each year[3,4]. That is 15 times more deaths each year than caused by all wars and acts of violence and 3 times more than caused by tuberculosis, malaria, and AIDS combined[2,4]. Globally, the economic damage of air pollution exceeds $5 trillion—more than 7% of the global gross domestic product[2,13]. In the U.S. alone, air pollution causes the premature deaths of 100,000 to 300,000 people each year and costs at least $886 billion annually[2,5–7]. Air pollution in the U.S. comes mainly from fossil fuel use, which creates toxic combustion products including particulate matter, ozone, and oxides of nitrogen, sulfur, and carbon[5,6,14,15].

Air pollution is a complex problem with multiple drivers and diverse health and economic consequences[2,5]. Unlike causes of death and economic harm that are directly observable (for example, a car crash), the effects of air pollution are widespread and diffuse. For this reason, air pollution is almost never recorded on a death certificate, though it contributes directly to many diseases and conditions that ultimately cause death (for example, heart attack, cancer, Alzheimer's disease, suicide, etc.)[8,16]. To estimate the health and economic effects of air pollution, researchers use several independent and complementary methods, including 1. Longitudinal studies: following a group of individuals through time as they experience different pollution levels, 2. Comparative studies: comparing the health of similar populations living in different pollution conditions, and 3. Exposure studies: quantifying toxicity directly by exposing animals to acute or chronic pollution[2,6,7,7,15,17]. These methods—which are the same used to measure the effects of smoking, obesity, or other long-term conditions on human health—are the gold standard in research because they integrate the acute effects associated with exposure to dirty air (stroke, heart attack, asthma, increased miscarriage, stillbirth etc.) as well as the chronic effects (cancer, neurological disorders, depression, suicide, etc.)[2,11,18].

The link between air pollution and health is well understood for a wide range of conditions, including respiratory and cardiovascular diseases, central nervous system disorders, mental health and psychological problems, metabolic conditions, and reproductive harm[19–25]. Additionally, many other adverse health conditions are known to be associated with air pollution, but they are not yet sufficiently quantified to integrate into health risk models[2,26]. Consequently, current estimates of the health burden should be considered as conservative and will likely grow as more data becomes

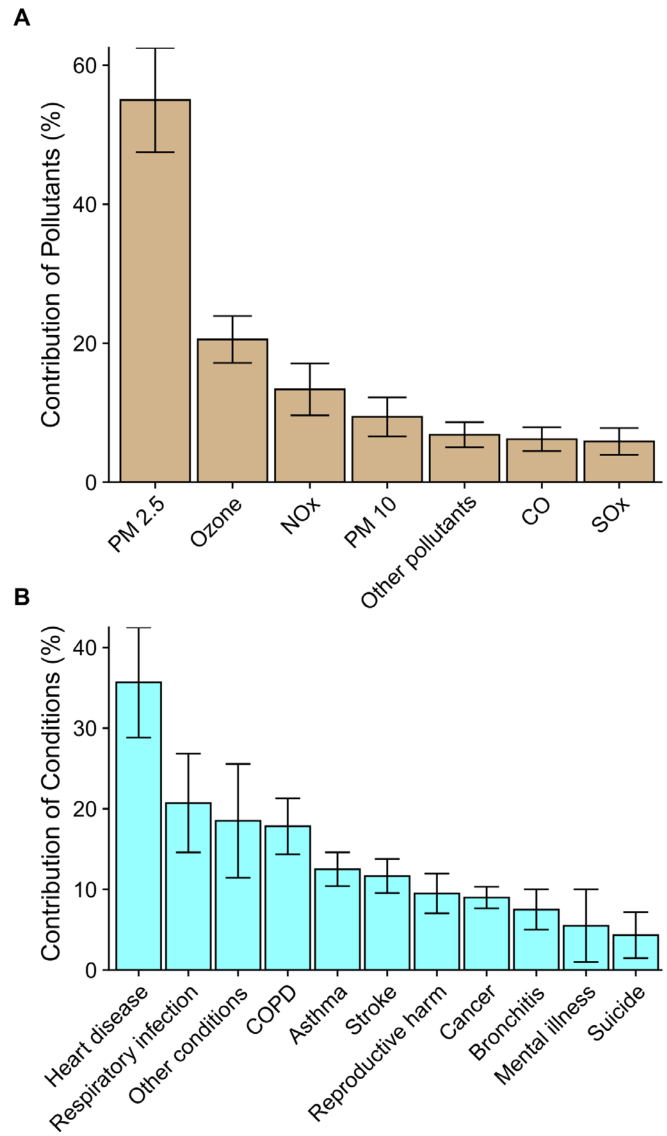

Figure 2. Estimates of the relative contribution of various pollutants (**A**) and health conditions (**B**) to the loss of life and economic productivity in Utah from air pollution. Bars show the average and standard error of estimates from 11 and 9 experts, respectively.

available[2,4]. Likewise, even when pollutants are below legal limits and the air quality is described as "healthy" or "good," pollution still degrades human health[7]. Air pollution affects the economy directly via healthcare costs and lost productivity (for example, missing work or school) as well as indirectly via changes in immigration, tourism, and business investment[2,13,27]. As with the health effects of pollution, current estimates of the economic cost of air pollution almost certainly underestimate actual direct and indirect consequences of air pollution[2,7,11,13].

Air pollution in Utah: In the Intermountain West, several factors have created poor air quality, including a quickly growing population, winter inversions trapping polluted air[28], and high levels of per-capita fossil fuel use due to heating and transportation infrastructure and power generation[9,29]. While there is universal agreement in the research community that air pollution is degrading the health and economic wellbeing of Utahns[22,23,26,30,31], specific estimates of the direct and indirect costs vary widely[27]. For example, estimates of annual mortality and morbidity due to air quality for Utah range from hundreds to tens of thousands, though even the most conservative estimates of the costs of air pollution to Utah's economy are substantial[7,32–37].

Though air pollution in Utah is a constant subject of discontent and discussion[9], the long-term perspective of air pollution is often left out of the public debate. In the 1970s and 1980s, there were large improvements in air quality and the overall air pollution index dropped by half[31,38]. These gains were attributable primarily to regulations (for example, the Clean Air Act and the Air Quality Act), which required removal of sulfur and lead from fuels, as well as technological and behavioral changes[39]. More recently, some air pollutants have continued to improve, while others have stagnated or gotten mildly worse[31,40]. Specifically, acute and long-term concentrations of CO, NO_x, and SO_x have continued to decrease in recent years, while ozone and particulate matter fractions ($PM_{2.5}$ and PM_{10}) show little improvement or even recent worsening, depending on the region within Utah[31,40]. Across the state, there is substantial geographic variation in air pollution, with

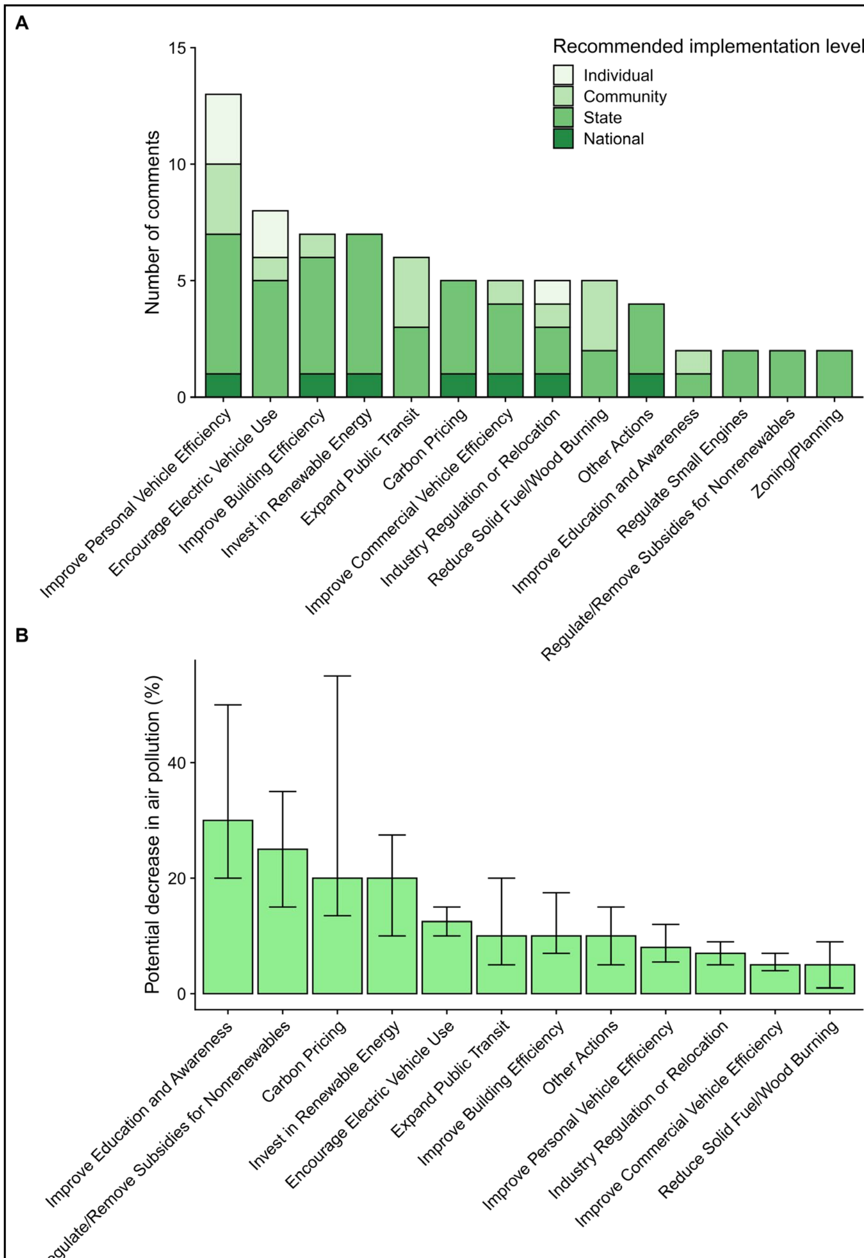

Figure 3. Recommendations to improve air quality. (**A**) Actions and the most effective scale of implementation. (**B**) Potential decrease in air pollution possible for various actions. Bars show the count (**A**) or median and 95% confidence range (**B**) from 13 experts.

different pollutants dominating the overall impacts in different regions[31]. These regional differences are associated with the type and degree of business, domestic, and industrial activity in those areas as well as natural environmental differences[9,30,41].

There is widespread support among Utahns to improve air quality. Utahns ranked air quality as the 3rd most important issue in the state, after only water and education, and 80% of Utahns said they would accept additional taxes and legislation to improve air quality[9,12]. Recent, state-sponsored reports and this study (for example, Fig. 3) have outlined concrete changes that could reduce pollution and enhance the health and economy of Utah[9,31]. These recommendations align with proven measures taken in communities around the U.S. and the world, some of which we briefly outline in the next section.

Immediate and long-term opportunities of improving air quality: Cities, states, and countries that have invested in reducing air pollution have universally seen immediate and long-lasting economic and health benefits. The most comprehensive summary to date on the effects of improving air quality concluded the following, based on a synthesis of 95 large-scale studies[11]:

> *Reducing pollution at its source can have a rapid and substantial impact on health. Within a few weeks, respiratory and irritation symptoms, such as shortness of breath, cough, phlegm, and sore throat, disappear; school absenteeism, clinic visits, hospitalizations, premature births, cardiovascular illness and death, and all-cause mortality decrease significantly. The interventions are cost-effective. Reducing factors causing air pollution and climate change have strong co-benefits. Although regions with high air pollution have the greatest potential for health benefits, health improvements continue to be associated with pollution decreases even below international standards. The large response to and short time needed for benefits of these interventions emphasize the urgency of improving global air quality and the importance of increasing efforts to reduce pollution at local levels.*

Economic analysis confirms that improving air quality substantially stimulates economic growth across sectors while also addressing other environmental issues such as climate change[2,37,42]. For example, the Clean Air Act of 1970 was followed by a decrease of 68% in common air pollutants while the U.S. Gross Domestic Product grew by 212%[39]. More recently, the direct and indirect benefits of the 1990 Clean Air Act Amendment have added at least $2 trillion to the U.S. economy (an average of $65 billion each year), representing a return on investment of $32 for every $1 of cost[2,11,39]. Cleaning Utah's air would increase property values, stimulate tourism, and encourage business investment[9]. Increasing state and federal investment in clean air could result in billions of dollars of economic growth in Utah and reduce billions of dollars of expenses currently associated with health, education, and the economy[37].

In addition to decreasing ambient (outdoor) air pollution, short-term interventions to improve indoor conditions have been highly effective. For example, installing commercially available filters in elementary school classrooms improved student performance by the same amount as more costly measures[43]. Additionally, cleaner indoor air has been found to enhance performance of employees doing a broad range of cognitive and physical activities[44].

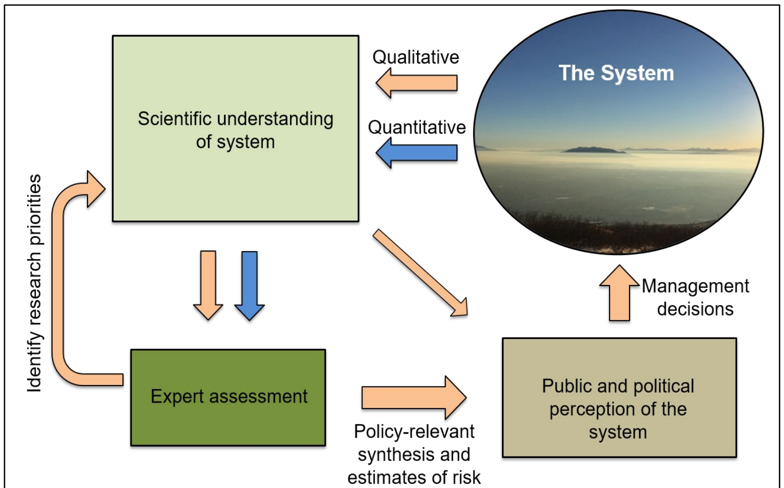

Figure 4. Conceptual diagram of the role of expert assessment in generating and communicating scientific understanding (modified from Abbott *et al.* 2016).

Expert assessment methods: When management decisions are urgent but uncertainty is high, *expert assessment* (combining multiple expert opinions) has long been used to estimate possible system responses and risk of dangerous or undesired outcomes[45–48]. Expert assessment complements modeling and empirical approaches by allowing the synthesis of formal and informal knowledge about the system to inform decision makers and researchers[49–51] (Fig. 4). The approach is based on evidence that multiple estimates built on different assumptions and data provide more robust and reliable numbers[52]. Because the experimental unit in an expert assessment is an individual researcher, each data point integrates multiple types of knowledge available to that person, providing a holistic and integrative estimate of all available information.

This study consisted of 4 stages, during which we:

1. Compiled a list of 85 subject matter experts with expertise in air quality, human health, and economics in Utah by searching the scientific literature, asking for referrals from local to national agencies, and querying university websites.
2. Developed the questionnaire, which consisted of 7 questions and a summary of recent health and economic studies.
3. Distributed the questionnaire and received 14 completed responses, with an average of 10 responses per question (participants only answered questions for which they had pertinent expertise).
4. Analyzed the responses and produced this report with input from all contributors (7 additional experts provided feedback during this stage). 19 of the 21 contributors are listed at the beginning of this report as co-authors (two participants wished to remain anonymous until submission of the report for review). We are now preparing these results for submission to a peer-reviewed journal.

Study questions (number of respondents in parentheses):

1. What is the number of disability-adjusted life years (DALYs) lost to air pollution in Utah each year? (9)
2. What percentage of Utahans experience the following shortening of life because of air pollution? (10)
3. What pollutants contribute most to your health burden estimates from Questions 1 and 2? (11)
4. What health conditions contribute most to your health burden estimates from Questions 1 and 2? (9)
5. What is the direct cost of air pollution to Utah's economy? (8)
6. What is the indirect cost of air pollution to Utah's economy? (8)
7. What actions would you recommend to reduce air pollution in Utah and how much could they reduce the health and economic costs estimated above? (13)

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