Improving children’s environmental health is integral to achieving sustainability. Sustainability is often presented as the balance among three interdependent components—environment, economy, and social dynamics—the goal of which is to improve life for future generations. Traditionally rooted in resource conservation and management, sustainability efforts have focused on environmental and economic elements, at times neglecting human health as an important aspect of the social component. Improving quality of life for future generations requires protecting the environmental health and well-being of today’s children and women of childbearing age. During early stages of physiological development, from critical prenatal windows of development through infancy and childhood, people may be particularly sensitive to environmental hazards. Children also have higher exposure to certain factors, per unit of body mass, than adults. Consequently, environmental insults during development may increase the risks for adverse health outcomes at birth, during childhood, or later in life. Protecting children’s environmental health has overlapping environmental, economic, and social benefits. This research analyzes the intersections between children’s environmental health and sustainability and explores children’s environmental health indicators as quantitative metrics to evaluate existing sustainability initiatives in the United States.

KEYWORDS: public health, pollution effects, children, environmental indicators, developmental stages

Introduction

The modern concept of sustainability originated in physical resource use and was conceived to design strategies to ensure that, for example, a harvested catch of fish did not threaten extinction of the overall population (Dixon & Fallon, 1989; Bartlett, 1998; Bell & Morse, 2008). Broadly interpreted, the term now encompasses the idea of living without jeopardizing the needs of future generations (WCED, 1987; Institute of Medicine, 2013). Research has linked physical resources and health; for instance, dominant patterns of planning in the United States and concepts such as urban sprawl have been correlated with health outcomes including obesity, diabetes, and depression (Frumkin et al. 2004). Initiatives like the Safe Routes to Schools National Partnership (2014) and its local counterparts strive to design the built environment to encourage children to walk and bike to school. Goals of the Partnership and similar programs include reducing obesity, improving air quality, and enhancing cardiovascular fitness (Rosenberg et al. 2006; Davison et al. 2008; Watson & Dannenberg, 2008; Wendel et al. 2008). Much guidance on evaluating these initiatives focuses on reductions of vehicle emissions, decreases in the number of miles walked or biked to schools, and changes in attitudes toward physical activity (Boarnet et al. 2005; NCSRS, 2012). These are important metrics in addressing the environmental component of sustainability, but they do not allow evaluation of children’s environmental health.

The benefits of improving children’s health are sizeable and should not be overlooked. Trasande & Liu (2011) estimated direct and indirect costs of children’s diseases with an environmental origin including lead poisoning, methylmercury toxicity, and asthma, at US$76.6 billion in 2008. While the link between asthma and air pollution is often made in introductions to and justifications for Safe Routes to Schools programs, asthma reductions are not included in the evaluation metrics. Further, these programs do not address how improving present-day children’s environmental health will continue to improve health for future generations. More holistic integration of children’s environmental health and sustainability is needed, particularly efforts to quantify improvements in children’s environmental health as it relates to sustainability goals. When sustainability is measured in terms of children’s environmental...
health—not just general health or adult health—we can more efficiently measure the health of current and future generations.

**Sustainability**

A common illustration of sustainability includes three pillars: economic, environmental, and social (Hecht et al. 2011; 2012; National Research Council, 2011; USEPA, 2012a). Sustainability can be achieved when equal weight is given to all three pillars in decision-making processes across sectors. These ideas are also found in the National Environmental Policy Act of 1969, which states that the federal government in the United States will “create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans” (NEPA, 1969).

Sustainability continues to be pursued at different geopolitical scales. On the federal level in the United States, President Obama’s Executive Order 13514 focuses on reducing energy use and greenhouse-gas (GHG) emissions across agencies (Obama, 2009). This effort is laudable in its goals to reduce the federal government’s environmental footprint while saving taxpayers’ money, but it neglects the social component. Including children’s environmental health goals would help address this gap. For example, the United States government has changed its purchasing decisions to only include EnergyStar certified appliances. This same approach may also change purchasing decisions to include only furniture without chemical-flame retardants, since some of these ingredients have been implicated in childhood disease when exposed in utero (Boekelheide et al. 2012).

To help achieve sustainability, many cities in the United States have also developed plans to reduce their GHG emissions. For instance, New York City has targeted a 30% reduction below 2006 levels by 2017 (City of New York, 2013), Los Angeles a 35% reduction below 1990 levels by 2030 (EnvironmentLA, 2011), and Washington, DC a 30% reduction below 2006 levels by 2020 (DOE, 2010). In contrast to these ambitious targets, sustainability plans have overlooked how improving children’s health can contribute. Most city and state agencies have not integrated their sustainability initiatives with ongoing children’s environmental health efforts to reduce risk and to enhance well-being. These cities have concurrent but separate efforts to improve children’s environmental health by reducing blood-lead levels (BLLs) and asthma hospitalizations. For example, New York’s city sustainability plan, PlaNYC (2011), focuses on housing and neighborhoods, but does not mention childhood-lead poisoning, even though New York City had 1,316 new cases of children with BLLs equal to or greater than 10 micrograms per deciliter (µg/dL) in 2008 (NYSDH, 2008). The Centers for Disease Control and Prevention (CDC) recommend 5 µg/dL as the reference level for taking public health action (CDC, 2013). PlaNYC does include information linking ozone and asthma and acknowledges the economic burden of asthma on the individual and the state. However, this plan does not include reducing asthma as a goal with respect to achieving sustainability, exemplifying the neglect of sustainability’s social pillar and of the holistic goal of finding the intersection of the three pillars. Improving children’s environmental health represents this intersection; improving environmental, economic, and social conditions improves children’s health and a healthy child is more likely to grow into a healthy adult. Although the New York City report includes indicators and milestones for each of the proposed initiatives, its plans do not include health (PlaNYC, 2011). The plans developed for Washington, DC and Los Angeles are similar in their consideration of health, with the Washington plan referring to health as an ancillary benefit with no metrics, and the Los Angeles plan simply acknowledging that GHG emissions harm human health without further detail. As examples of why such plans should include health, this article will expand upon BLLs and ozone exceedances as case studies of indicators to measure progress toward sustainability while improving children’s environmental health.

**Children’s Environmental Health**

Two key concepts must be addressed to fully explain how children’s environmental health can contribute to evaluating progress toward sustainability. First, the concept and biology of developmental life stages are important (USEPA, 2014). Although they may seem like smaller versions of us, children are not simply miniature adults. Their experiences, exposures, and physical characteristics do not mirror those of adults. Any exposures through inhalation will be different in children because a child’s lungs are small and still developing through age 18, and their mean breathing rate through age 12 is about twice as rapid as that of adults (Miller et al. 2002). Therefore, assessment of environmental exposures and effects must consider the sequence of physiological life stages, from conception through maternal/fetal development, infancy, toddlerhood, childhood, and adolescence. The contemporary physiological life-stage concept moves beyond the historical classification of children as a “susceptible subpopulation” and fully captures their unique health and developmental stages (USEPA, 2014).
In addition to biological differences, children exhibit unique behaviors at each life stage. For example, infants spend much of their time lying, sitting, or crawling on the ground. Further, increased hand-to-mouth activity during this stage can augment exposure to environmental contaminants (Cohen Hubal et al. 2000). Children’s susceptibilities can lead to acute symptoms, and a growing body of research indicates that early exposure, including prenatal environmental exposure, can also have chronic health effects. The same environmental exposure at one life stage may have a dramatically different effect than at another stage. Among several later-life diseases associated with early exposure, researchers have identified associations between exposure to chemicals like polybrominated diphenyl ethers—used as flame retardants in couch cushions and clothing—and children’s development and are studying these chemicals as potential carcinogens (Boekelheide et al. 2012). The physiological life-stage approach is particularly important to consider within the framework of sustainability.

The second key concept is the novel one of approaching children’s environmental health as a product of the three pillars of sustainability. Figure 1 illustrates these pillars, with examples of indicators in each pillar, and in every combination. Children’s environmental health is at the center, demonstrating overlap among all three pillars and the importance of using children’s environmental health indicators to measure progress toward sustainability.

**Opportunities for Integration of Children’s Environmental Health in Sustainability: Children’s Health Indicators**

A sustainability indicator is “a measurable aspect of environmental, economic, or social systems that is useful for monitoring changes in system characteristics relevant to the continuation of human and environmental well-being” (Fiksel et al. 2012). Common examples include GHGs as measured by grams of carbon dioxide (CO$_2$) emitted per gallon of gasoline and resource consumption as measured by energy use per household in kilowatt hours. An environmental health indicator is a summary statistic that synthesizes available data to represent a topic such as environmental condition, human-body burden of a particular chemical or substance, or health outcomes due to environmental stressors (Axelrad et al. 2013). Examples include mercury emissions from power plants, the number of asthma hospitalizations, and additional cases of lung cancer caused by environmental tobacco smoke. Both sustainability and environmental health indicators are chosen to measure trends over time and are limited by the strength of the collected data.

In an October 2012 report, the United States Environmental Protection Agency (USEPA) recommended several indicators appropriate for national scale sustainability reporting. The report concludes that existing definitions of sustainability are difficult to operationalize using indicators and therefore defines sustainability as “the continued protection of human health and the environment while fostering economic prosperity and societal well-being” (Fiksel et al. 2012). Based on this definition, children’s environmental health indicators, such as BLLs and air-quality exceedances, can serve as strong measures of sustainability, as they often address all three pillars—economic, environmental, and social (Bell & Morse, 2008; USEPA, 2012c; 2013a). The report, America’s Children and the Environment (ACE), is one source for children’s environmental health indicators that policy makers can use to measure holistic progress toward sustainability (Axelrad et al. 2013). The following examples, children’s environmental health indicators found in ACE, illustrate the ability of these measures to address all three pillars of sustainability.

**Case Study #1: Children’s Exposure to Lead**

Lead is a pervasive environmental contaminant that occurs both naturally and as a result of human
activities. Lead exposure remains an issue today following its historical use as an additive in paint and in gasoline until the 1970s (ATSDR, 2010). Prenatal and early-life exposure, even at low levels, can impact neurologic development, while high levels can cause abdominal pain and seizures (Lidsky & Schneider, 2003; Makri et al. 2004). Exposure to lead is measured through a blood sample, but lead can also be stored in bone tissue for years, mobilizing later in life (for instance, during lactation) (Axelrad et al. 2013; ATSDR, 2007). Lead passes more easily through the blood-brain barrier than other chemicals and children are more susceptible to the effects of lead exposure than adults because their brains are still developing (Goldstein, 1990; Lidsky & Schneider, 2003). Neurocognitive effects caused by lead exposure are irreversible and can lead to lower intelligence quotients (IQ), attention deficit disorders, hyperactivity, and criminal behavior (Wright et al. 2008; Gould, 2009). Mounting evidence suggests there is no safe level of lead exposure (Jones et al. 2009); accordingly, the CDC does not identify a safe level, but rather a reference BLL of 5 µg/dL—based on the 97.5th percentile of the National Health and Nutrition Examination Survey’s (NHANES) blood-lead distribution in children—as the trigger for public health action (CDC, 2012). The USEPA continues to research sources of lead exposure and ways to reduce risk of lead poisoning in children.

In the United States, USEPA (2008) regulates lead through several statutes, including the Clean Air Act, the Safe Drinking Water Act (1986), and the Toxic Substances and Control Act (1976), which have greatly reduced or eliminated many sources of exposure in the United States. Lead was unregulated in drinking-water pipes and soldering until congressional passage of the Safe Drinking Water Act Amendments in 1986. However, exposure continues today mainly via deteriorating paint in houses built before 1978, dust from demolition projects, and contaminated soil and water (ATSDR, 2010). The United States Department of Housing and Urban Development is striving to eliminate lead exposure as a major threat to children’s environmental health by providing grants and technical assistance to states and local governments addressing unsafe housing (USHUD, 2009).

Adverse health effects resulting from lead exposure may differ by life stages. In addition to increased risk of a lower IQ, an early-life exposure of a female child may jeopardize neurodevelopment in her offspring through the remobilization of lead stored in bone tissue (Lanphear, 2014). During pregnancy, lead in the mother’s bones may mobilize, resulting in fetal exposure. In a number of animal studies, up to 39% of the maternal lead burden transferred to the fetus during pregnancy came from the maternal skeleton, with the remainder from current external environmental exposures (Kirrane et al. 2013). Domestic regulations now ban lead in most commercial uses, but its historical use continues to affect current and future generations (USHUD, 2009). Limiting the lead exposure of today’s children simultaneously decreases the risk of current and lifelong neurocognitive deficits and the risk to the next generation via in utero exposure to lead, thus working toward sustainability.

Data on lead in the blood of children can be used to measure sustainability (Axelrad et al. 2013). Not only is lead present in several media (environ-

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1 The CDC website explains that “Experts now use a reference level of 5 micrograms per deciliter to identify children with blood lead levels that are much higher than most children’s levels. This new level is based on the U.S. population of children ages 1–5 years who are in the highest 2.5% of children tested for lead in their blood.” See http://www.cdc.gov/nceh/lead/acc/acc/blood_lead_levels.htm.

2 Safe Drinking Water Act of 1986, CFR 141.43—Prohibition on use of lead pipes, solder, and flux. Toxic Substances Control Act of 1976, 40 CFR 745—Lead-based paint poisoning prevention in certain residential structures.
mental), but lead exposure affects neurocognitive development (social), which can be costly to treat and can limit an individual’s earning potential throughout his or her lifetime (economic) (Needleman et al. 1990; Gould, 2009; Jones et al. 2009). Table 1 summarizes some of these effects, but is not an exhaustive list.

Indirect costs of lead poisoning include potential loss in lifetime earnings, loss of tax revenue for the state from reduced earning potential, increase in special education costs for lead-poisoned children, and the cost of crime. Neurocognitive effects have been well documented for decades and more recent studies have associated prenatal and early childhood elevated BLLs with a greater likelihood of arrest and criminal behavior. Adults who had been exposed to lead in early-life stages are less likely to achieve their full academic and social potential (Wright et al. 2008), exemplifying potential health and economic impacts in different life stages. Furthermore, lead’s health impacts have both short- and long-term costs which constitute a marked economic impact for the individual and society. Direct medical costs for testing and treatment can be several thousand dollars per child with very high BLLs ( >70 µg/dL), and abatement can cost up to US$7,000 per housing unit, hugely burdensome amounts for residents of low-income communities where older housing and lead exposure are more common (Gould, 2009). Landrigan & Garg (2002) estimate the total cost of pediatric lead poisoning in the United States to be US$43.4 billion annually, while Gould (2009) estimates that for a 2006 cohort of children aged 6 and under with BLLs between 2–10 µg/dL, the net lifetime earnings loss would be between US$165 and US$233 billion. Based on 2004 and 2006 data, this same study estimates that the total number of crimes that could have been averted if there were a 1 µg/dL reduction in the average preschool BLL (including 116,541 fewer burglaries, 2,499 fewer robberies, 53,905 fewer aggravated assaults, 4,186 fewer rapes, and 717 fewer murders) would result in savings of a total of US$1.8 billion in direct costs.

**Case Study #2: Children’s Exposure to Ozone**

Tropospheric, or ground-level, ozone is harmful to human health, aggravating existing respiratory conditions such as asthma and increasing susceptibility to respiratory infections (USEPA, 2012a). Ground-level ozone is formed through chemical interactions among nitrogen oxides, sulfur oxides, and volatile organic compounds that can come from anthropogenic emissions or other sources, such as wildfires. In the United States, ozone is primarily regulated via the National Ambient Air Quality Standards (NAAQS) provision of the Clean Air Act, which has currently set the eight hour (8-hr) standard for ground-level ozone at 75 parts per billion (ppb) (USEPA, 2012b). States can be more stringent; California set its 8-hr standard for ozone at 70 ppb in 2005 based on a study mandated by the state’s Children’s Environmental Health Protection Act (Ozone and Ambient Air Quality Standards, 2008).

Ozone is an environmental contaminant that also touches all three pillars of sustainability. In 2009, 12% of American children lived in counties that exceeded the 8-hr standard for at least four days in the calendar year (Axelrad et al. 2013). Children are more likely to have asthma than adults, and they may be exposed to higher levels of ozone because they are more likely to be outside at peak ozone times (i.e., at recess during school or just after school) (Hall et al. 2008). Ozone can initiate and exacerbate asthma symptoms in children who already suffer from the disease (Brown et al. 2013), and long-term exposure can also cause asthma in healthy children (McConnell et al. 2002). Exposure to ozone and resulting respiratory distress (social) can lead to missed days of school and work for children and their caretakers respectively (economic), and is the product of interactions among environmental chemicals (environment). Table 2 summarizes some of these effects, but is not an exhaustive list.

Hall et al. (2008) estimate that implementing more stringent ozone standards saved California between US$156–334 million annually in prevented school absences during the 1990s just in the state’s South Coast Air Basin (vicinity of Los Angeles), when considering direct medical costs as well as lost revenue from caretakers’ missed work days (Hall et al. 2008). On average, counties in this region exceeded USEPA’s ozone NAAQS 30 days per year from 2005–2007. Annual ozone-related incidences during this period included approximately 1.1 million school absence days (ages 5–17), 120,970 asthma-related incidences (all ages), and 825 respiratory hospital admissions (all ages), costing US$105.97 million, US$65.14 million, and US$33 million, respectively (Brajer et al. 2011).

**Recommendations**

Based on the research presented in this article, we offer several concrete recommendations. Rather than creating new indicators that would require time and funding, we recommend synthesizing work across sectors to develop a comprehensive suite of indicators measuring sustainability.

First, include human health explicitly in the definition of sustainability. A recent Institute of Medicine (2013) publication states that health has not been fully incorporated into work on sustainability in the
United States and health practitioners have yet to take an active role in this work (National Research Council, 2013). The USEPA (2012a) definition of sustainability as “the continued protection of human health and the environment while fostering economic prosperity and societal wellbeing” should be more widely adopted to better incorporate health considerations into policy decisions. This definition not only reflects USEPA’s mission to protect human health and the environment, but it is also responsive to National Research Council (2011) recommendations and advice from USEPA’s Children’s Health Protection Advisory Committee (CHPAC) (2011), which recently stated, “Protecting health during early life stages is fundamental to the concept of sustainability.” While the USEPA definition and CHPAC’s recommendation are targeted to USEPA (Fiksel et al. 2012), sustainability initiatives in general would benefit from a broader incorporation of health needs. For example, within the scope of smart growth, local planning boards could consult children’s environmental health and public health practitioners to provide input on land-use decisions. These would address certain children’s unique exposures to chemicals in the environment associated with adverse health outcomes like delayed neurocognitive development, respiratory disease, and increased susceptibility to later life and intergenerational disease.

Second, no matter the level of governance (state or federal), it is important to clearly define sustainability goals prior to the initiation of a project or action. Recent recommendations from the National Research Council (2013) outline a structured decision framework to aid decision makers in their sustainability planning. Plans need to be explicit about how improving health outcomes contribute to sustainability. Setting children’s environmental health-related sustainability goals solidifies a commitment to the health of future generations. This strategy also enables organizations to identify what indicators they will measure to define successful implementation of their goals, by setting benchmarks that quantify their sustainability initiatives during program evaluation.

Third, use children’s environmental health indicators as measurement tools to fully assess progress toward sustainability initiatives. To operationalize health within a sustainability framework, it is imperative to include indicators and benchmarks with specific health targets and to shift from a framework of reducing risk to one that maximizes benefits (Goldstein, 2011). Rather than creating artificial silos, officials should be working to achieve sustainability by improving children’s environmental health and well-being.

Finally, integrate children’s environmental-health indicators with sustainability indicators to enable consideration of resource quality alongside quantity. This approach is applicable to regulatory agencies, as well as state and local governments, planning commissions, and others addressing smart growth to provide measures on the progress of sustainability initiatives. The smart growth and sustainable community movements are beginning to address health—through, for example, efforts to promote asthma reduction—as part of a healthy homes program, but there is still a need for a three-pillar approach on a large scale (Yee et al. 2012). Identifying elevated BLLs in children can stimulate action to prevent exposure and/or alleviate adverse health outcome.

| Environment | Social | Economic |
|-------------|--------|----------|
| - Tropospheric ozone is the main component of smog; may be elevated on hot, sunny days in urban environments | - Children may be exposed to higher levels of ozone than adults because they are more likely to be outside at peak ozone times | - CA saved between $156-334 million annually in prevented school absences during the 1990s after more stringent ozone standards |
| - Ozone is formed by chemical reactions between NO, & volatile organic compounds | - Children are more likely to have asthma than adults | |
| - Ozone is regulated by the Clean Air Act, which currently sets the 8-hr standard at 75 parts per billion | - Children’s lungs are still developing | |
| | - In 2009, 12% of children lived in counties that exceeded the 8-hr standard at least 4 days | |

+The citations used for this figure can be found in the text.
comes caused by lead exposure. Sustainability plans should therefore include goals to lower BLLs in children, which saves money, improves physical and mental health, and reduces toxins in the environment. Government, urban planning, and business sustainability planning should include the reduction of ozone exceedances, which improves children’s health and education outcomes, saves money, and improves the environmental outlook. One way to facilitate this change is to systematically include indicators of children’s environmental health as sustainability goals in strategic plans.

Conclusion

Former USEPA Administrator Lisa Jackson recently stated, “A child born in America today will grow up exposed to more chemicals than a child from any other generation in our history.” Rather than focus exclusively on conserving resources and maintaining healthy ecosystems, sustainability must also make sure people are healthy enough to utilize those resources. One way to maximize benefits in terms of sustainability is to improve the environmental health of today’s children (Landrigan & Garg, 2002), a concept thus far lacking in the sustainability literature. Using children’s environmental health as a guiding principle behind sustainability strategies can address many gaps that currently hinder a balance among environmental, economic, and social goals. The recommendations made in this article are feasible—many children’s environmental health and sustainability indicators already exist, but they need to be integrated. Children’s environmental health is not just one more benefit from sustainability and sustainable development, but should be an integral part of any truly sustainable initiative from the outset.

Authors’ Note

The views expressed in this article are those of the authors and do not necessarily represent those of the United States Environmental Protection Agency or the Association of Schools and Programs of Public Health.

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