Global Engineering Design Tools

Taylor Sharpe

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Mortenson Center in Global Engineering at CU Boulder

About the speaker

PhD Student and Lab Manager

Taylor Sharpe has been helping to develop novel IoT technologies to support Global Engineering efforts since 2011.

BS & MS, Mechanical Engineering, Portland State University
PhD Student, Environmental Engineering, CU Boulder

- CU Boulder SILC Fellow – Rapid Prototyping Lab Manager
- Project Engineer, SweetSense Inc.
- Autodesk Pier 9 Impact Resident, 2018

Learning Objectives

(1) BROAD: GLOBAL ENGINEERING

What is Global Engineering?

How does Global Engineering aspire to function on the World Stage?

(2) DEEP DIVE: AIR QUALITY

What are the public health impacts of air pollution?

Who is most at risk?

Where is this an issue?

(3) IOT AS A GLOBAL ENGINEERING TOOL

Why do we use IoT as a Global Engineering tool?

What does this look like in our Rapid Prototyping Space?

What contributions have we made so far?

(4) AIR QUALITY SENSOR CASE STUDIES

What does this process look like in partnership with target populations?

What does this process look like in partnership with Autodesk engineers & designers?

What is the Engineer's role in International Development Projects?

sustainability

MDPI

Opinion

Toward a New Field of Global Engineering

Evan Thomas

Mortenson Center in Global Engineering, University of Colorado Boulder, Boulder Colorado, CO 80303, USA;
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check for updates

Abstract: The Engineer's role in addressing global poverty challenges has often been confined to village and community-scale interventions, product design and development, or large-scale infrastructure design and construction. Yet despite fifty years of these approaches, over half the world's population still lives on less than $5.50 a day, the global burden of disease in low-income countries is overwhelmingly attributable to environmental health contaminants, and climate change is already negatively affecting people in developing countries. The conventional community, product or infrastructure focuses of development engineering is insufficient to address these global drivers that perpetuate poverty. The emerging field of Global Engineering can work to identify and address these structural issues. Global Engineering should be concerned with the unequal and unjust distribution of access to basic services such as water, sanitation, energy, food, transportation and shelter, and place an emphasis on identifying the drivers, determinants and solutions favoring equitable access. Technology development and validation, data collection and impact evaluation can contribute to evidence-based influence on policies and practice. Global Engineering envisions a world in which everyone has safe water, sanitation, energy, food, shelter and infrastructure, and can live in health, dignity, and prosperity.

Keywords: global engineering; sustainable development; sustainable development goals; poverty reduction

1. Introduction

Engineers are solutions-oriented people. Engineers enjoy the opportunity to identify a product or service need, and design technical solutions that can be deployed. Mission accomplished.

This model can be effective in high-income regions, where the engineering profession is complemented by a strong tax base leveraged to provide essential government services such as water, sanitation, electricity and roads, an enforced regulatory environment to maintain the quality and safety of these services, and business and consumer markets that pay for products and services. These complementary facets of society are often nearly transparent to the engineer, and engineering education does not typically include crash courses in economics or governance. As a result, engineers are poorly equipped to address or even recognize structural gaps when they exist in lower-income settings.

2. Global Context

Development optimism is abound. Pointing to the billions of people who have entered the middle class, the billions provided with vaccinations, and the often impressive accomplishments cited in the reports on the United Nations Millennium Development Goals and Sustainable Development Goals, the case is made that economic growth, life expectancy and overall prosperity are the inevitable outcome of current development policies and practice [1].
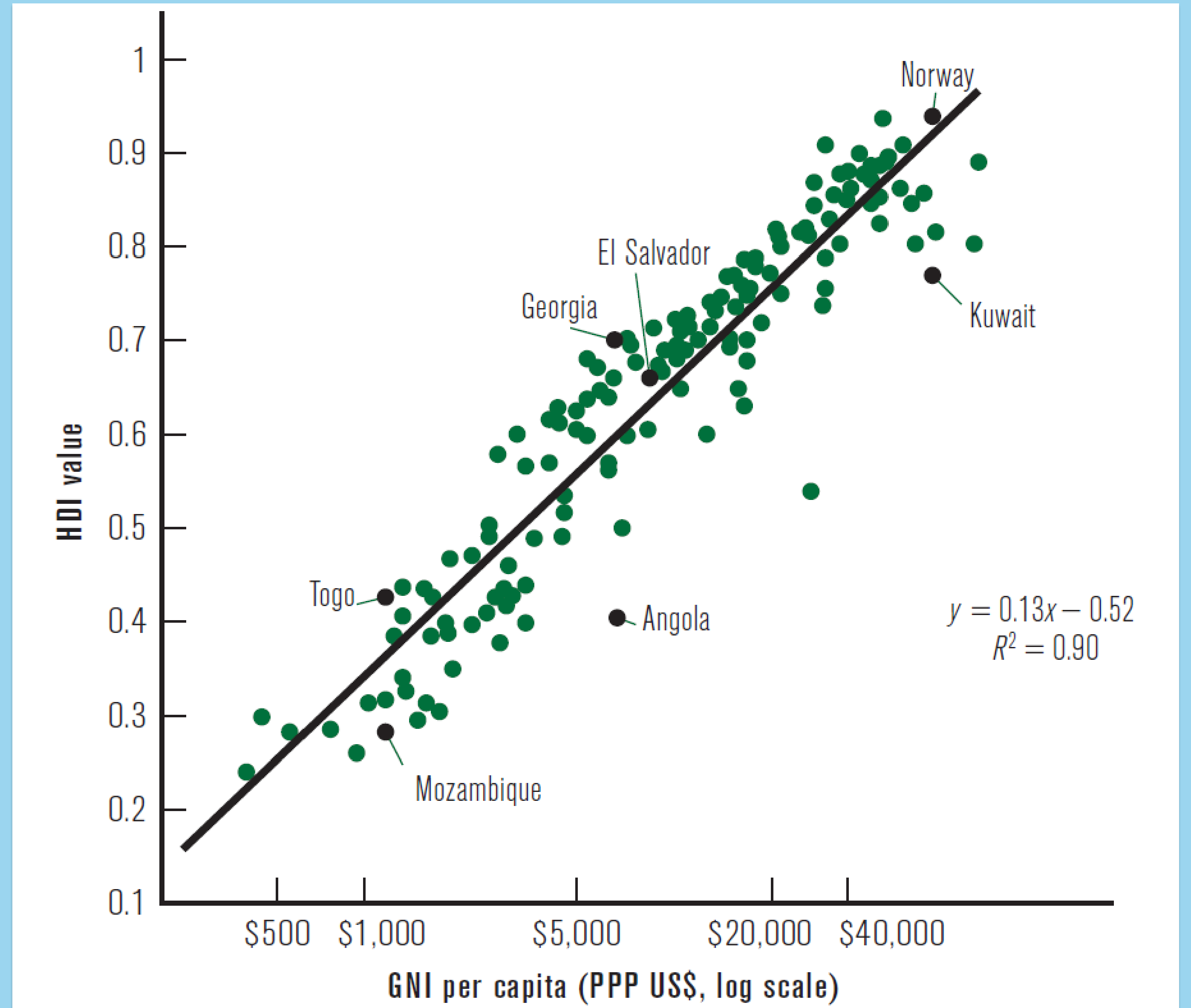
However, today over half the world's population lives on less than $5.50 dollars a day [2]. The burden of disease in low-income countries is overwhelmingly attributable to environmental health

What is **national**

Source: The World Bank, Cebr analysis

ENGINEERING
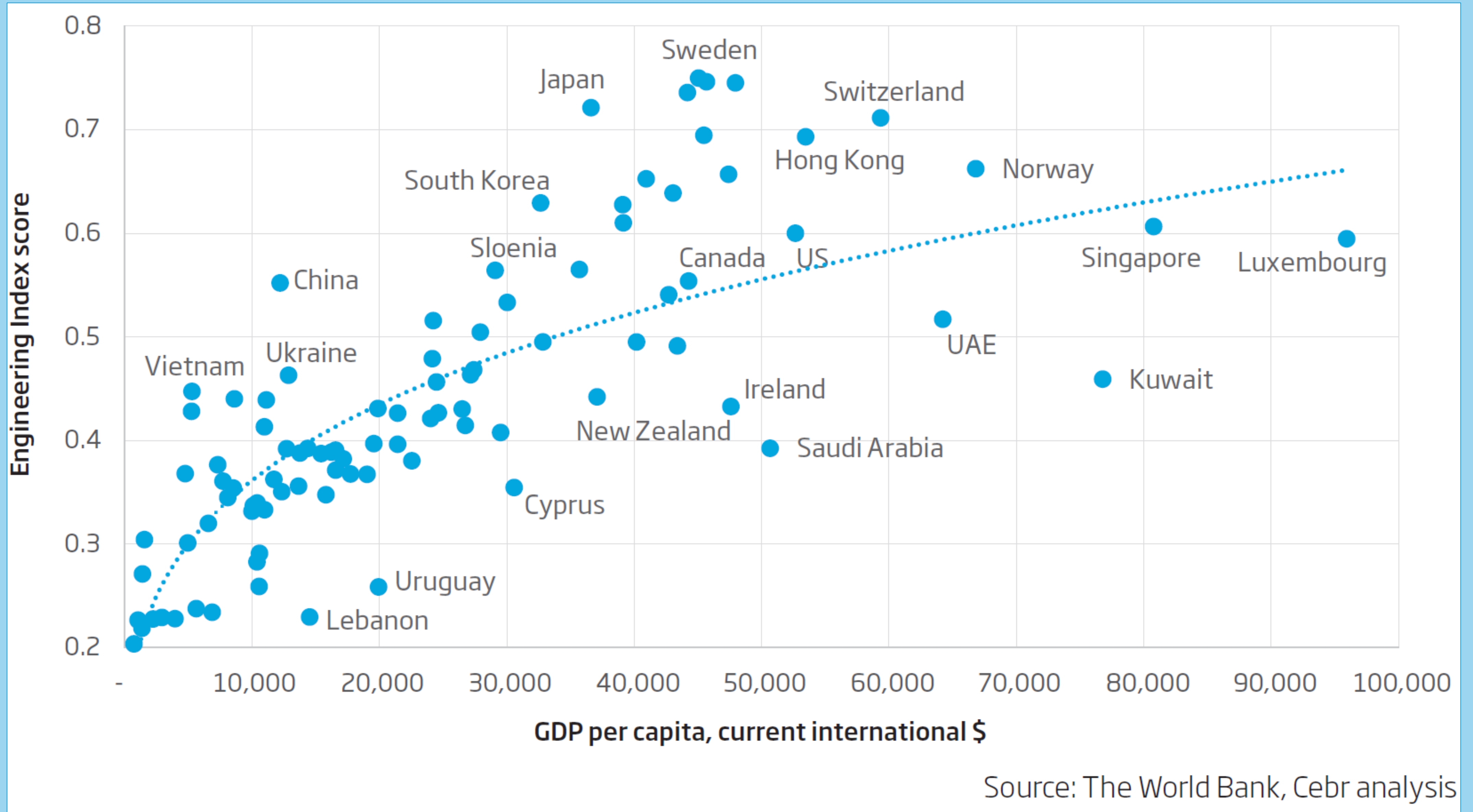
*Engineering and economic growth: a global view* (2016), Royal Society of Engineering

ECONOMICS

World population living in extreme poverty, 1820-2015

Extreme poverty is defined as living on less than 1.90 international-$ per day. International-$ are adjusted for price differences between countries and for price changes over time (inflation).

Number of people not in extreme poverty

Number of people living in extreme poverty
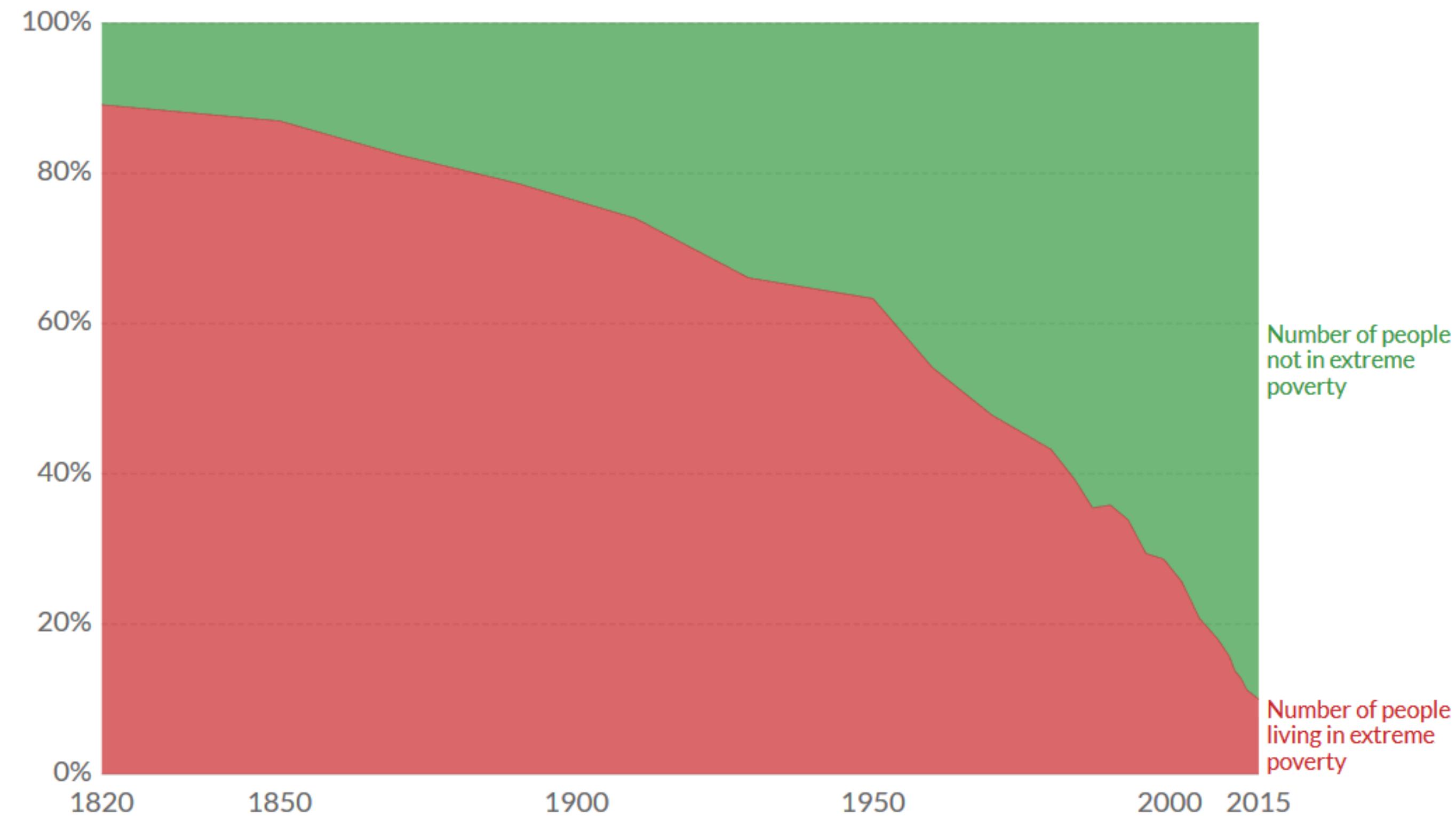
Source: OWID based on World Bank (2019) and Bourguignon and Morrisson (2002)
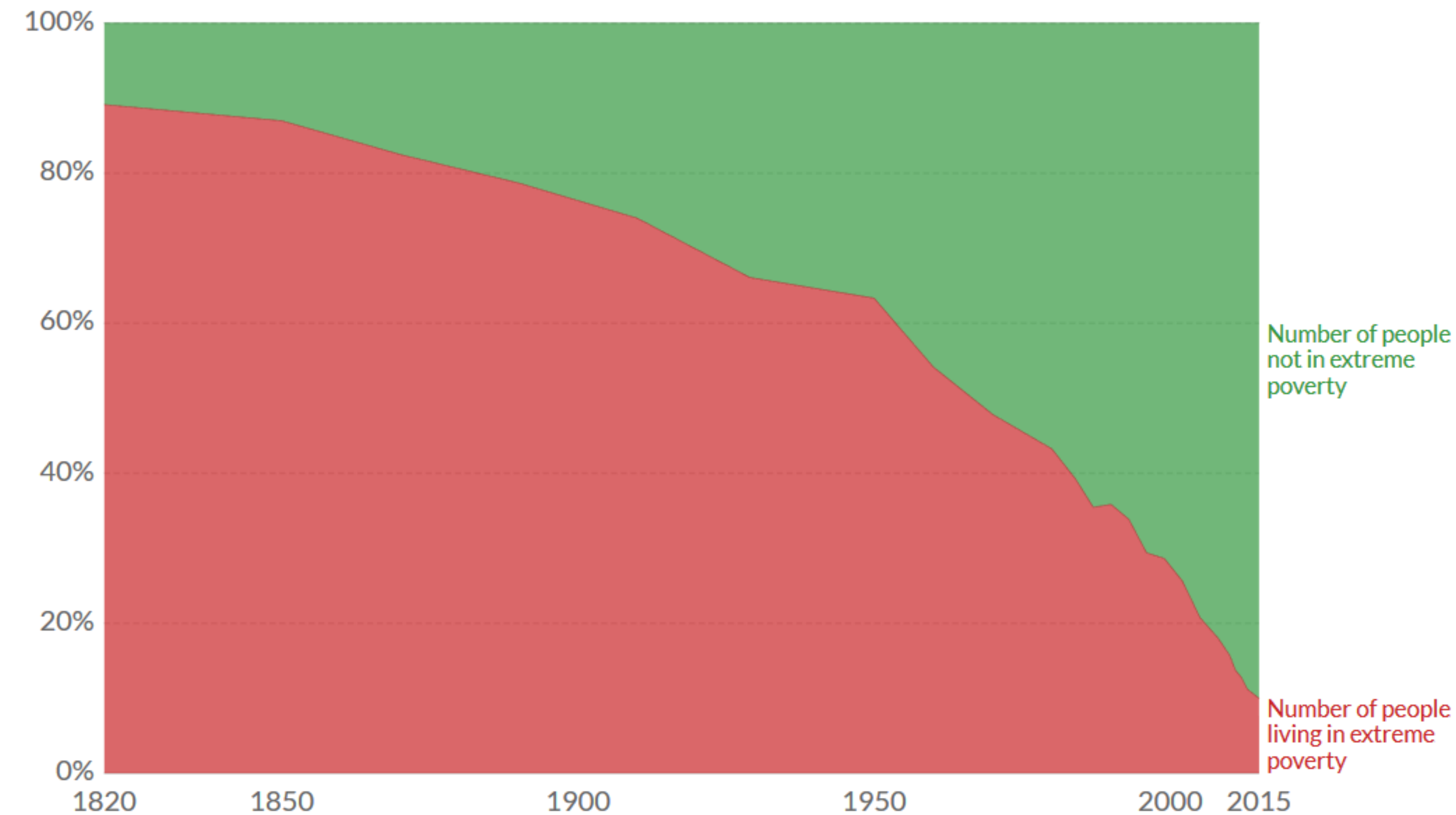
Is Poverty Decreasing Globally?

Source: Max Roser, ourworldindata.org

World population living in extreme poverty, 1820-2015

Extreme poverty is defined as living on less than 1.90 international-$ per day. International-$ are adjusted for price differences between countries and for price changes over time (inflation).

Number of people not in extreme poverty

Number of people living in extreme poverty

Source: OWID based on World Bank (2019) and Bourguignon and Morrisson (2002)

Is Poverty Decreasing Globally?

Source: Max Roser, ourworldindata.org

Number of People in Poverty
(under $7.40/day 2011 PPP)
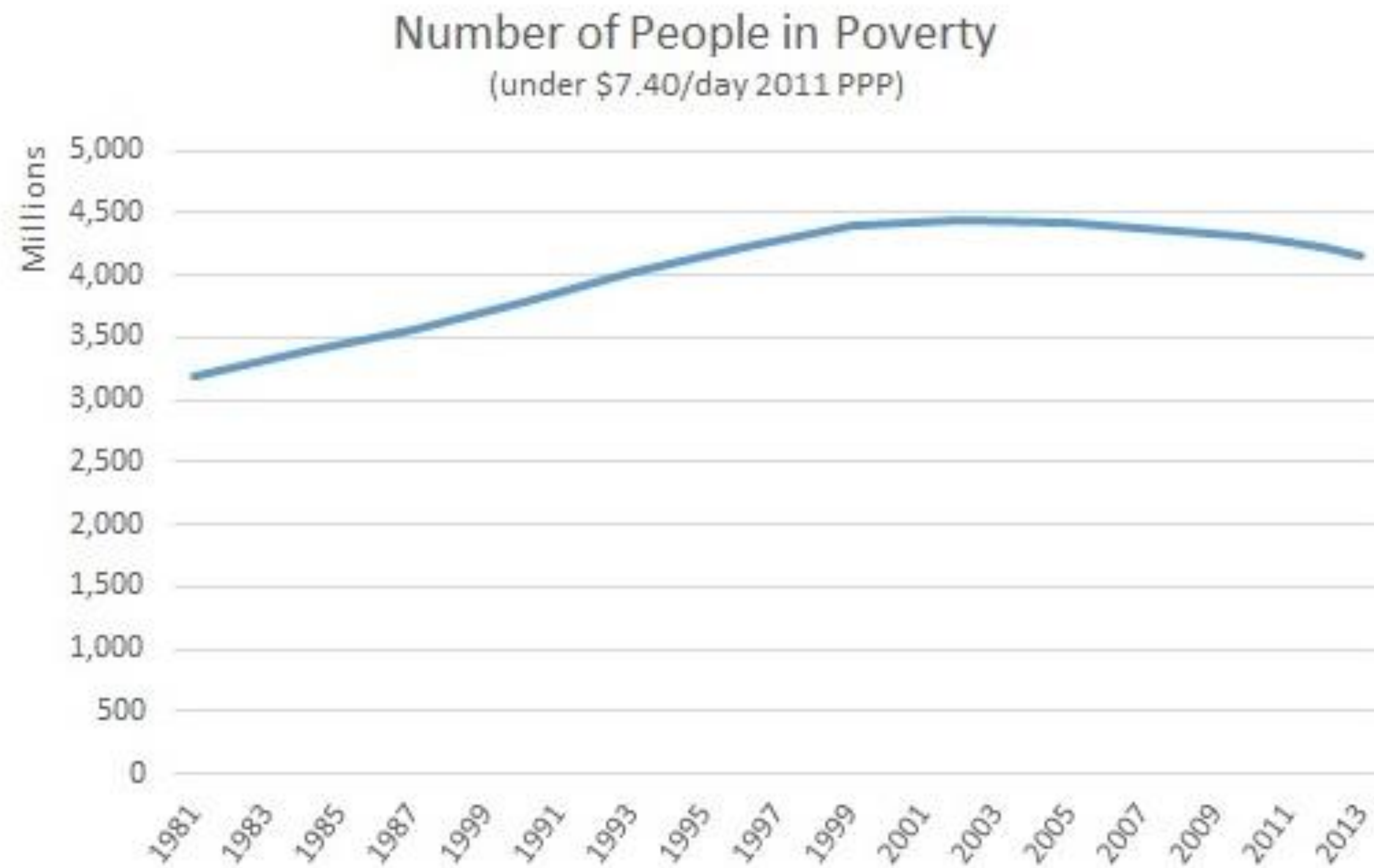
Is Poverty Decreasing Globally?

Source: Jason Hickel, jasonhickel.org

Measurement

Politics

Economics

M~onitoring~ & E~valuation~
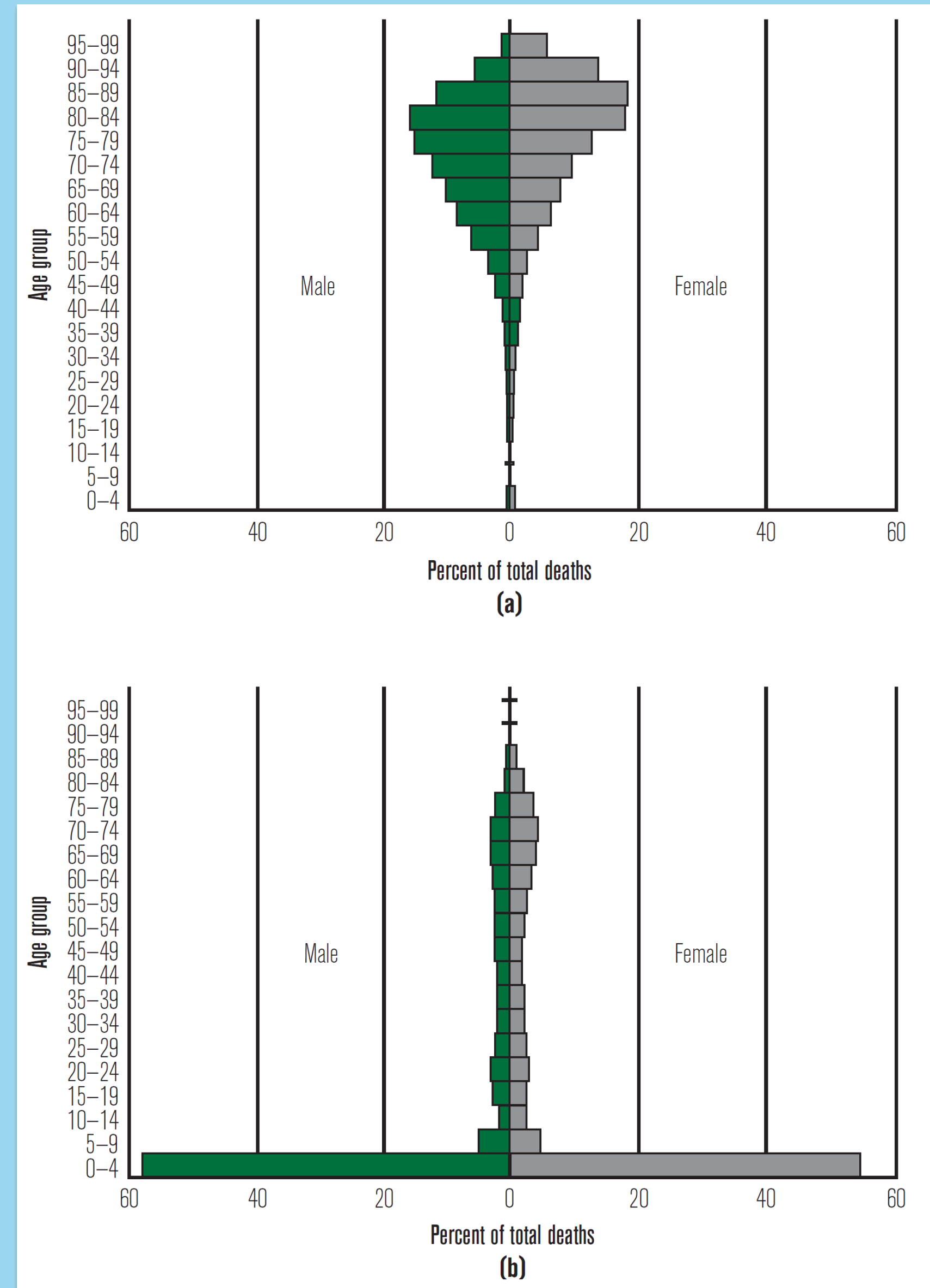
Development
Economics

"…engineering education does not typically include crash courses in economics or governance. As a result, engineers are poorly equipped to address or even recognize structural gaps when they exist in lower-income settings."
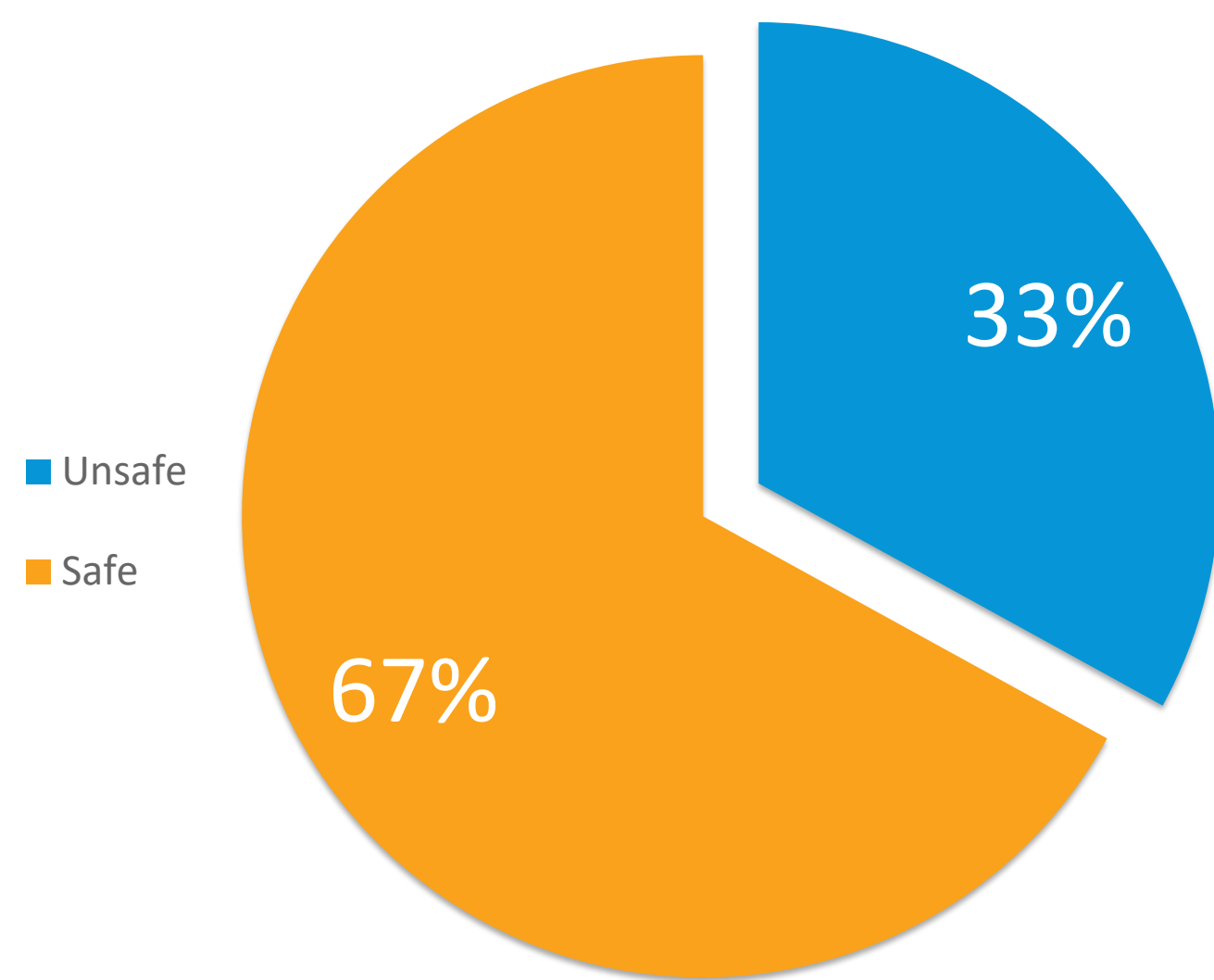
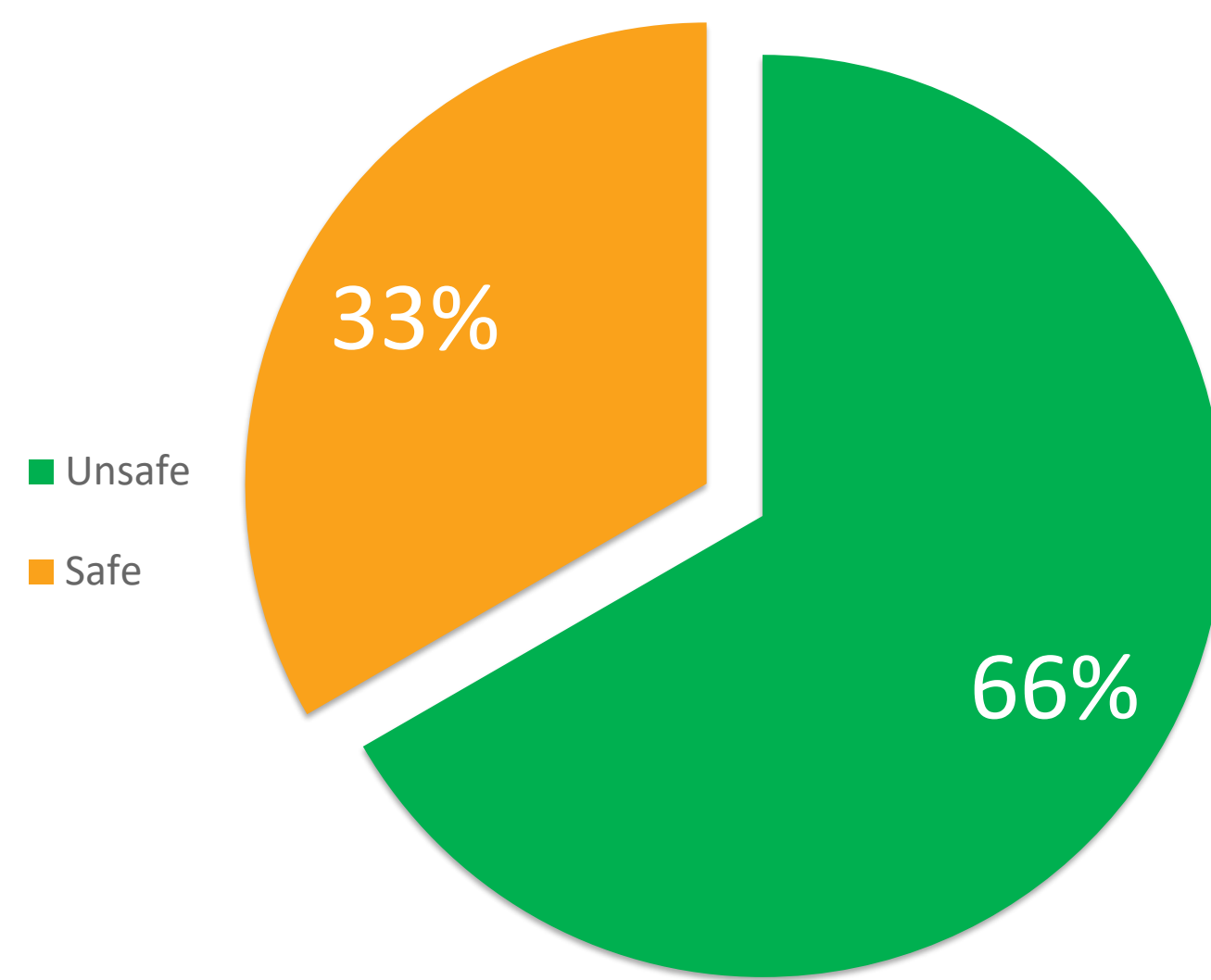Evan Thomas, *Toward a New Field of Global Engineering*, Sustainability (2019)

Denmark

Sierra Leone

HEALTH

33%

67%
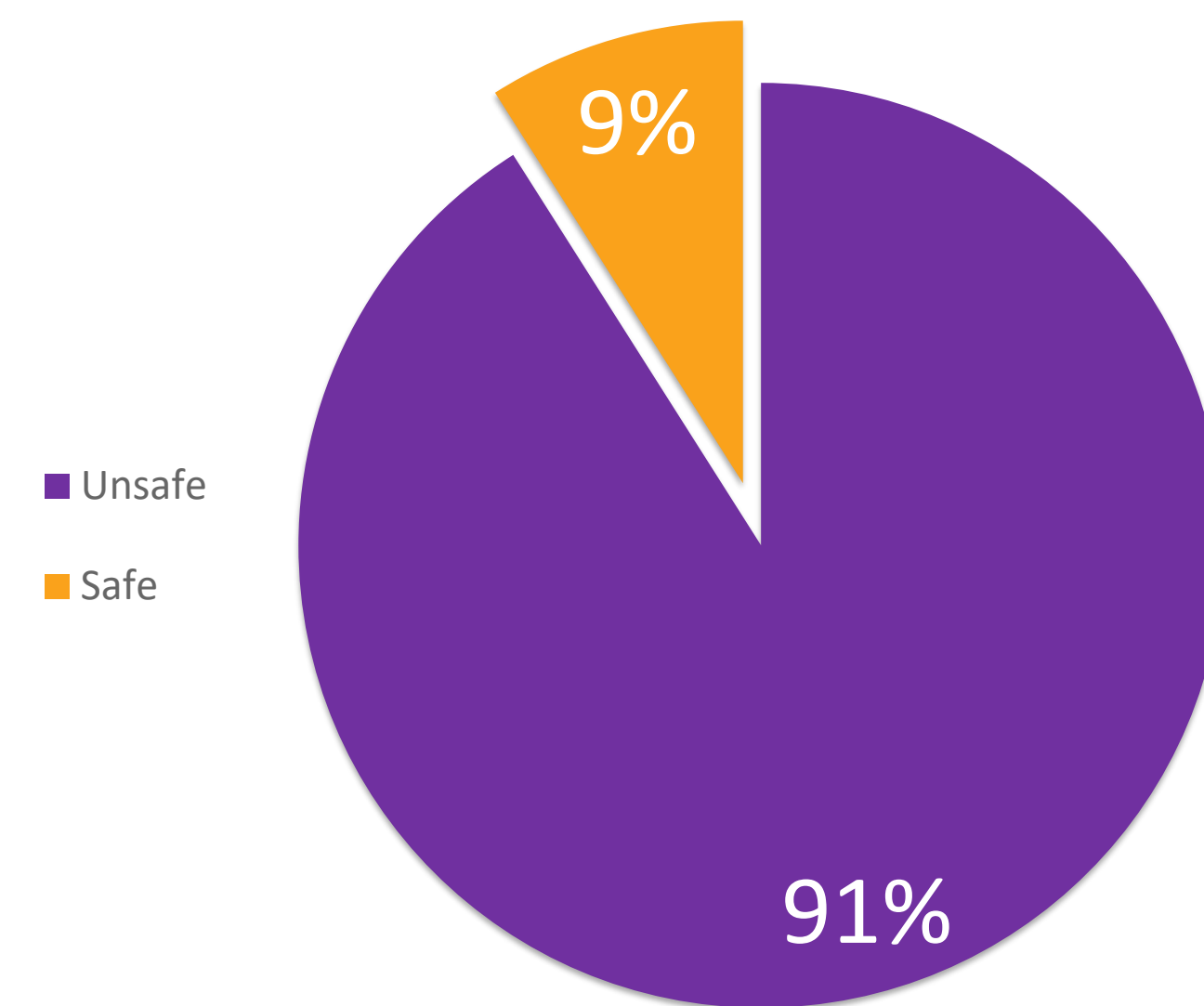
Unsafe
Safe

How Many People Lack Access to Clean Drinking Water?

33%

66%

Unsafe
Safe

How Many People Lack Access to Safe Sanitation?

9%

91%

Unsafe
Safe

How Many People Breath Polluted Air Daily?

Source: WHO 2018, WHO 2019

Health

Environment

Climate

Populations

Global
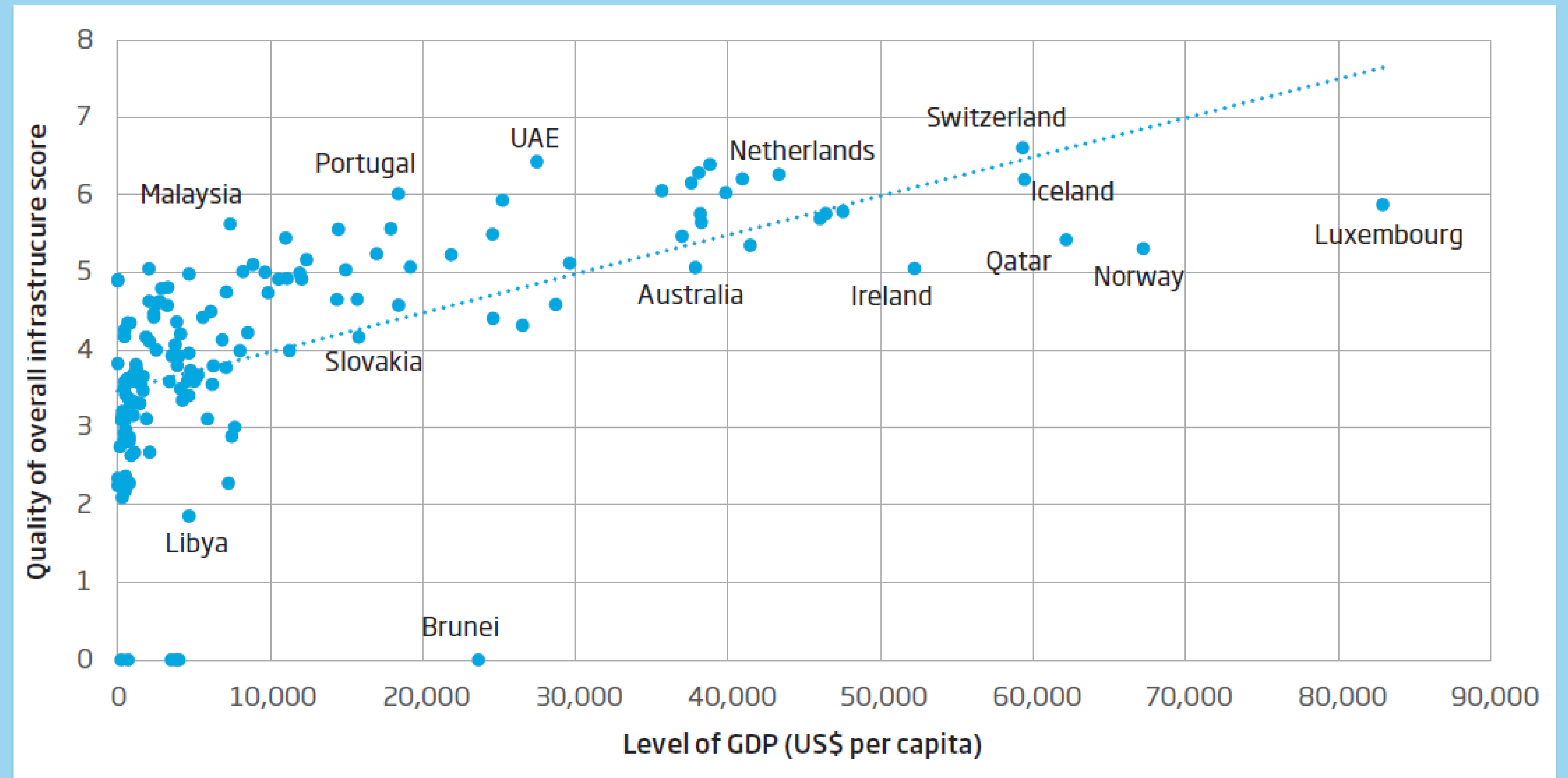Health

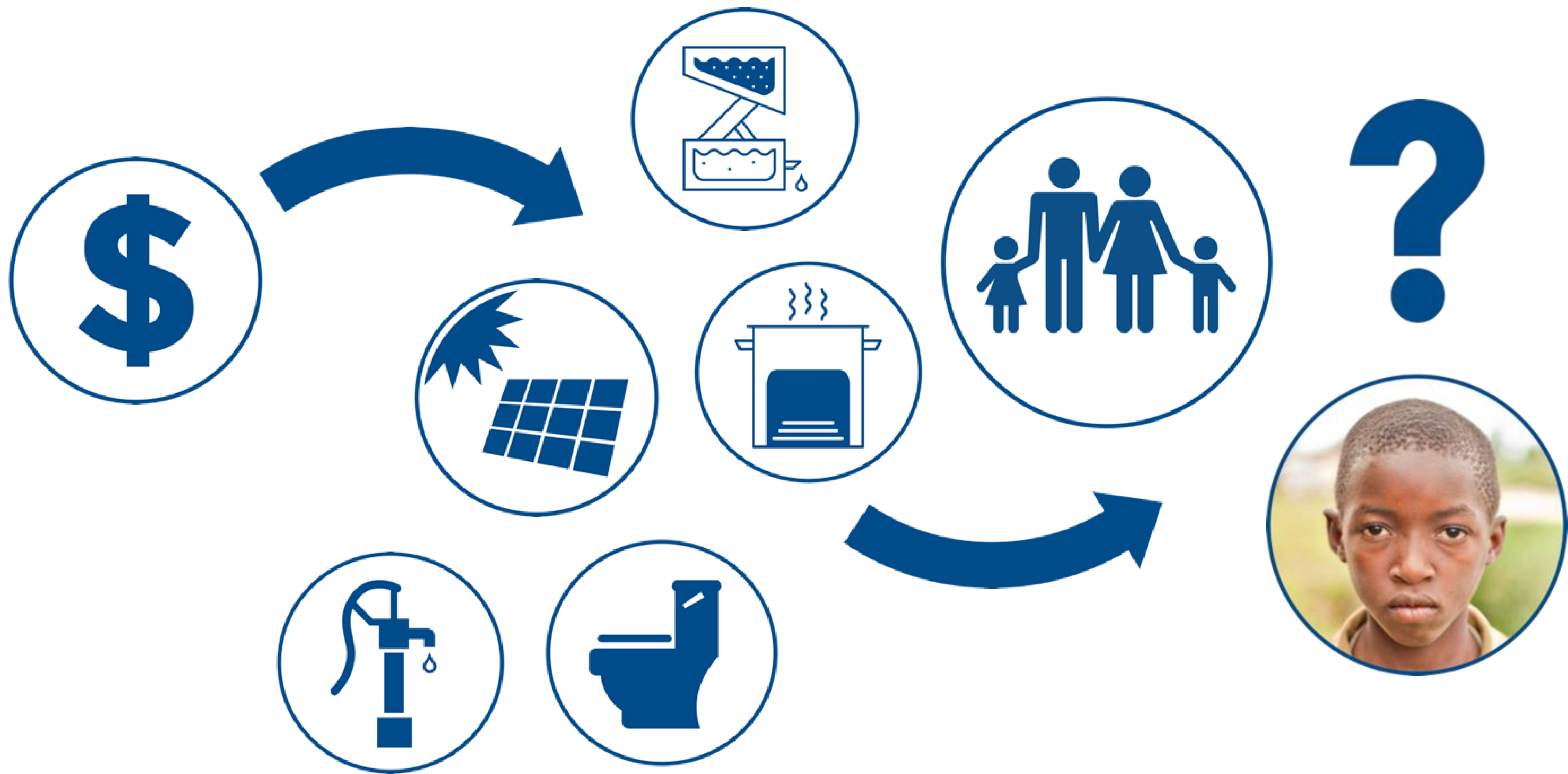"…Global Health…[is] better established, in track record and philosophy, from which we can learn."

Evan Thomas, *Toward a New Field of Global Engineering*, Sustainability (2019)

Quality of overall infrastrucure score vs Level of GDP (US$ per capita)

Malaysia, Portugal, UAE, Netherlands, Switzerland, Iceland, Luxembourg, Qatar, Australia, Ireland, Norway, Slovakia, Libya, Brunei
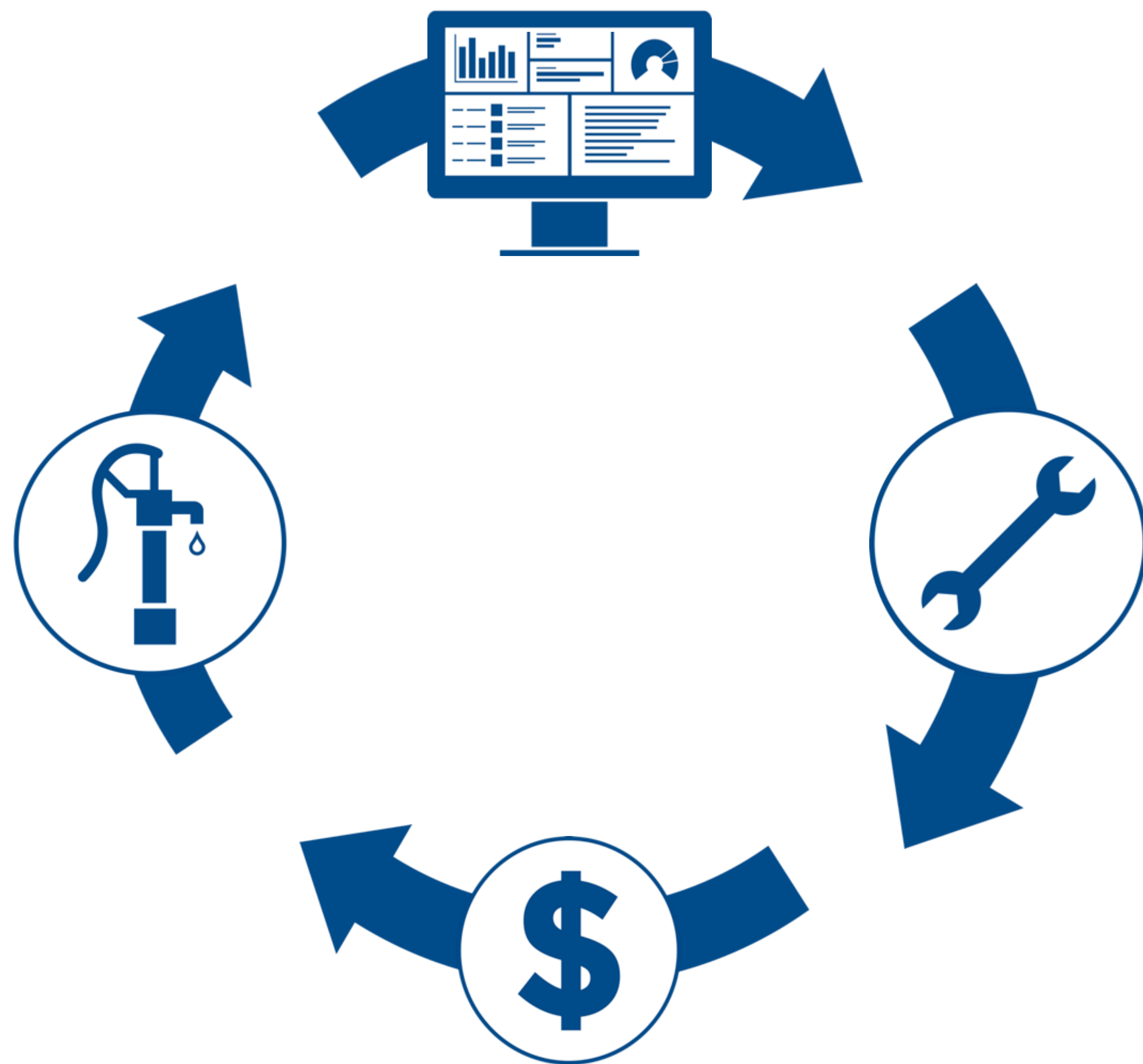
ENGINEERING

Systems/Structures

Technology

Data Collection

Impact Evaluation

Global
Engineering

"Put simply—no new water filter product, social business sanitation service, elementary school rainwater catchment tank, electricity grid, or lecture to a local government on the importance of water pump maintenance will make a dent in a system that precludes countries from developing robust tax bases that can support governmental services."

Evan Thomas, *Toward a New Field of Global Engineering*, Sustainability (2019)

"…**Global Engineering** can therefore be the **professional** and **academic complement** to **Global Health** and **Development Economics**."

Evan Thomas, *Toward a New Field of Global Engineering*, Sustainability (2019)

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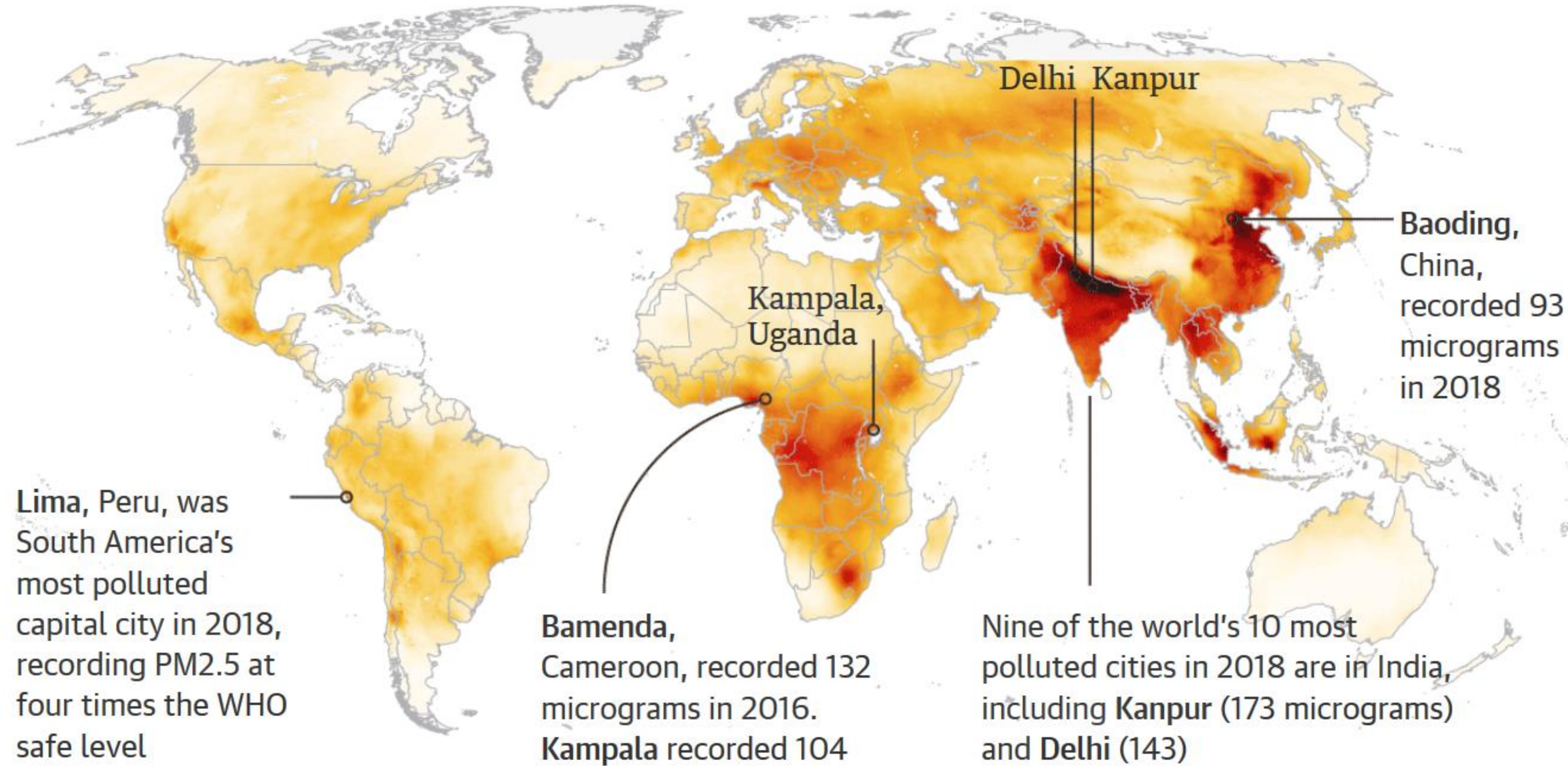
WHO safe level

2x 4x 6x 8x safe level

10 20 40 60 80 micrograms

Annual mean concentration of PM2.5* per cubic metre air in urban areas

Delhi Kanpur

Baoding, China, recorded 93 micrograms in 2018

Kampala, Uganda

Lima, Peru, was South America's most polluted capital city in 2018, recording PM2.5 at four times the WHO safe level

Bamenda, Cameroon, recorded 132 micrograms in 2016. Kampala recorded 104

Nine of the world's 10 most polluted cities in 2018 are in India, including Kanpur (173 micrograms) and Delhi (143)

The Guardian, "Air Pollution is the New Tobacco". Source: NASA, WHO Ambient Air Quality Database, April 2018

Air Pollution Public Health Impacts

4.2m	3.8m	90%+	91%
PREMATURE DEATHS	DEATHS	LMICS	EXPOSED
Deaths annually due to ambient air pollution	Deaths annually due to household exposure	Most mortality occurs in Low- and Middle-Income Countries	91% of the world's population breathes polluted air daily

Source: WHO

Air Pollution Public Health Impacts

8%

of <u>all</u> premature

death globally

Air Pollutants & WHO Standards

10
$\mu g/m^3$

PM$_{2.5}$

WHO Guideline:

10 µg/m³ annual mean

25 µg/m³ 24-hour mean

20
$\mu g/m^3$

PM$_{10}$

WHO Guideline:

20 µg/m³ annual mean

50 µg/m³ 24-hour mean

40
$\mu g/m^3$
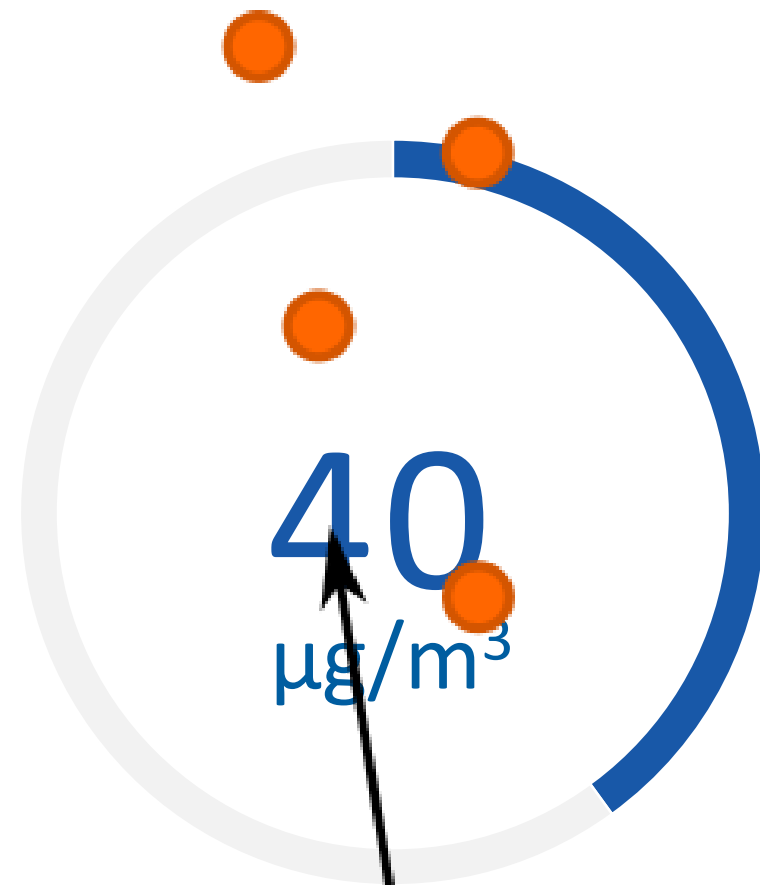
NO$_2$

2.5µm
particles

WHO Guideline:

40 µg/m³ annual mean

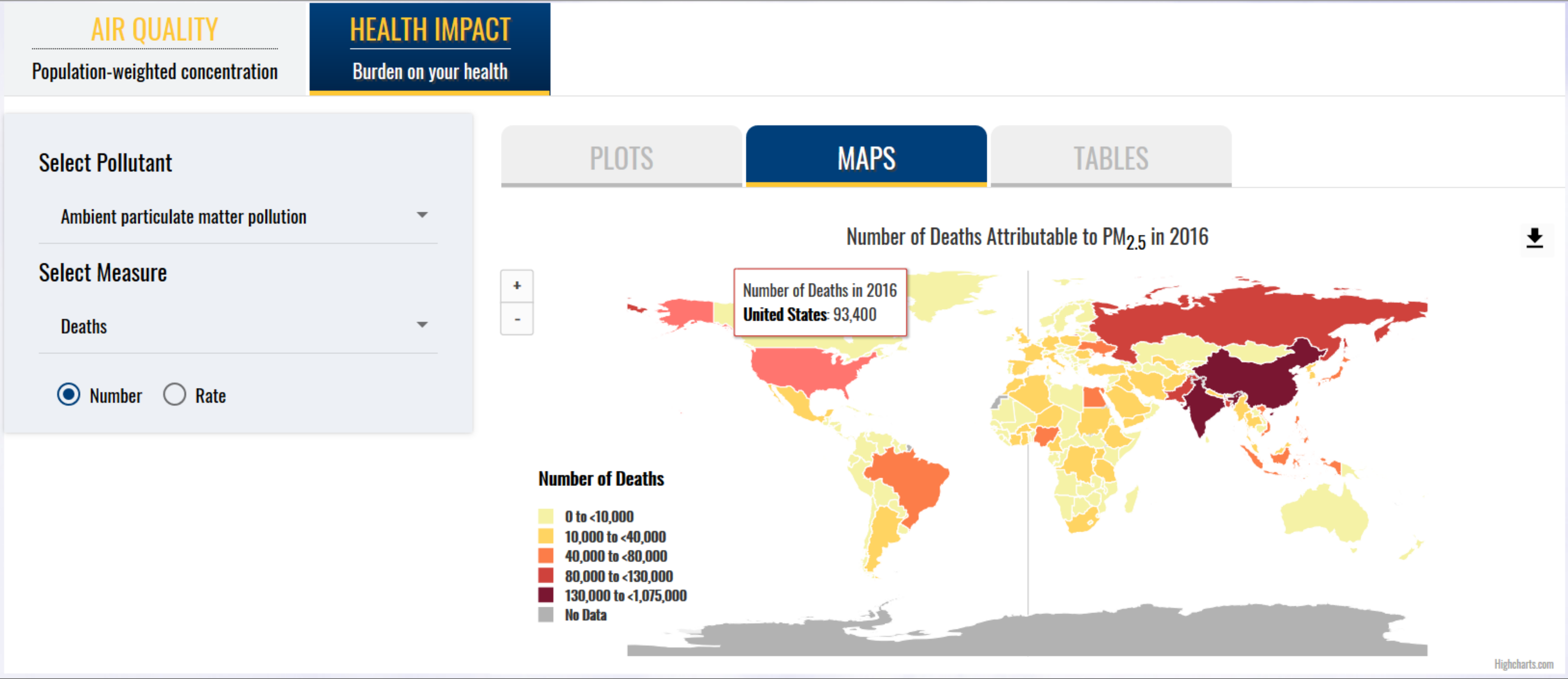200 µg/m³ 24-hour mean

100
$\mu g/m^3$

O$_3$

WHO Guideline:

75µm

100 µg/m³ 8-hour mean
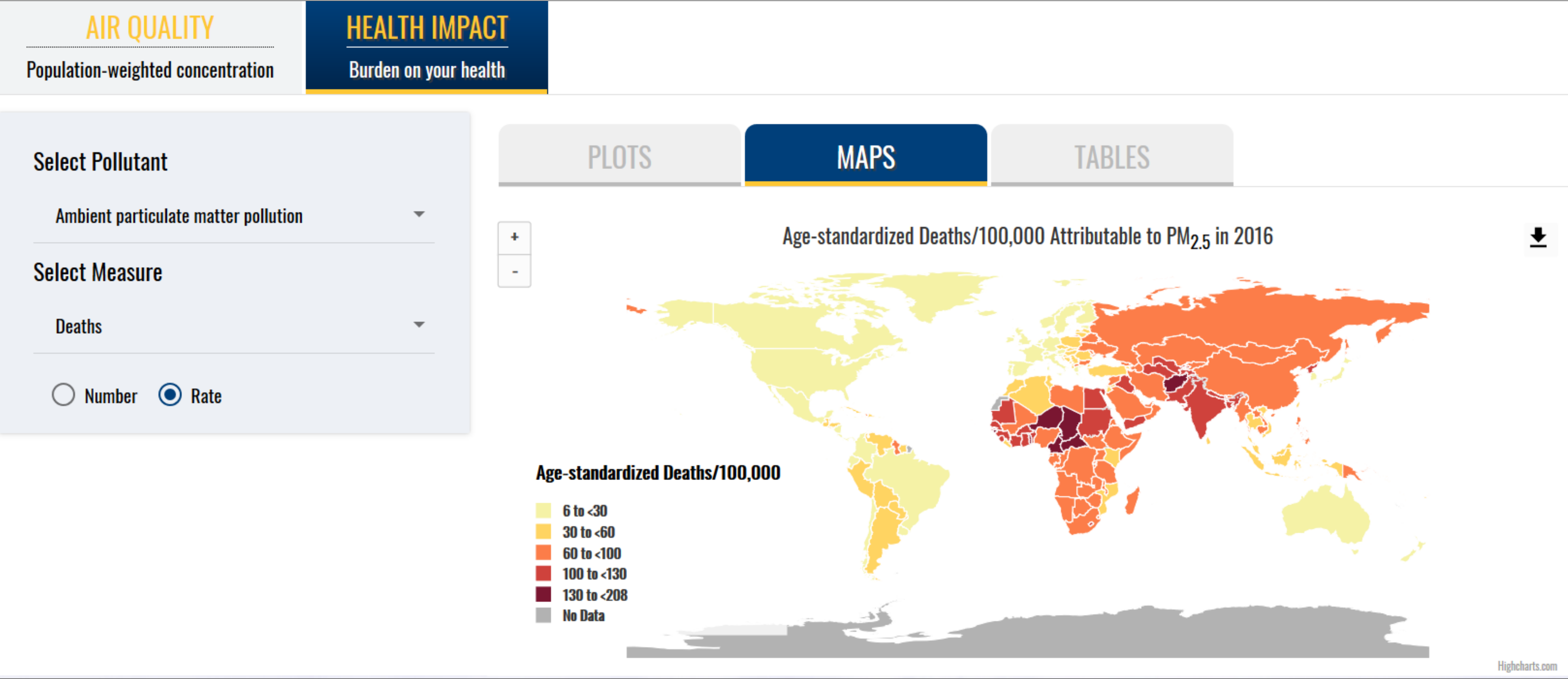
Where?

Health Effects Institute. 2018. State of Global Air 2018. Boston MA.

Where?

In the News

The Washington Post
Democracy Dies in Darkness

Business

Air pollution is getting worse, and data show more people are dying

Eroding air quality was linked to 10,000 additional U.S. deaths over a two-year period

The map of American air pollution
Daily average small particulate matter (PM2.5) concentration in 2014
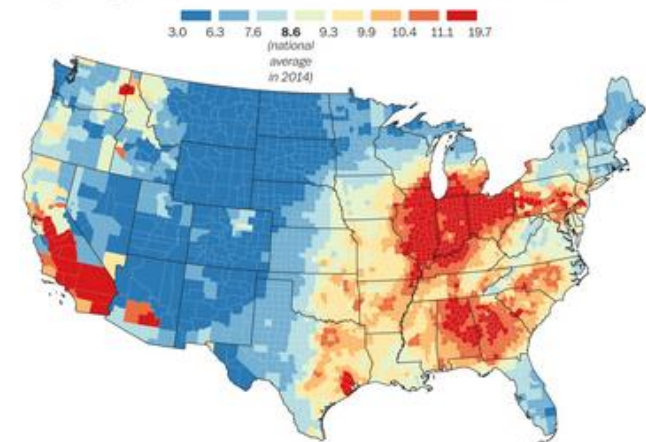
Source: Robert Wood Johnson Foundation County Health Rankings — THE WASHINGTON POST

By Christopher Ingraham

Oct. 23, 2019 at 5:00 a.m. MDT

Air pollution worsened in the United States in 2017 and 2018, new data shows, a reversal after years of sustained improvement with significant implications for public health.

In 2018 alone, eroding air quality was linked to nearly 10,000 additional deaths in the U.S. relative to the 2016 benchmark, the year in which small-particle pollution reached a two-decade low, according to researchers at Carnegie Mellon University.

The study focuses on fine-particle air pollution, known as PM2.5, which is of particular concern to regulators and public health experts because its microscopic size means it can be inhaled and absorbed into the bloodstream. Its ill effects are only now starting to be fully understood — the Environmental Protection Agency didn't even have a regulatory standard for it until 1997.

Fine particles can damage a person's respiratory system, accumulate in the brain and send people to the emergency room. The elderly appear to be especially susceptible to PM2.5, which has been linked to dementia and cognitive decline. And the data shows that many of the pollutant's effects occur at levels well below current regulatory thresholds.

Air pollution is back on the rise
National average small particulate matter (PM2.5) concentration, 2000 to 2018

Most Read Business

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hindustantimes

Monday, Nov 11, 2019

india cities opinion world cricket entertainment election gurugram trending videos ht-weekend real-estate lifestyle tech • • •

Capital punishment: Noxious smog engulfs Delhi, PM2.5 level 16 times safe limit

According to Central Pollution Control Board (CPCB)'s 4pm bulletin, average air quality index (AQI) for the preceding 24 hours sharply rose from 399 to 494, worst level recorded since November 6, 2016.

INDIA Updated: Nov 04, 2019 06:36 IST

Joydeep Thakur and Soumya Pillai
Hindustan Times, New Delhi

A view of Red Fort shrouded in smog in Old Delhi.(Sonu Mehta/HT PHOTO)

The New York Times

Air Pollution Is Linked to Miscarriages in China, Study Finds

A new study published on Monday adds to growing evidence of the negative health effects of air pollution on pregnant women and their fetuses.

By Amy Qin

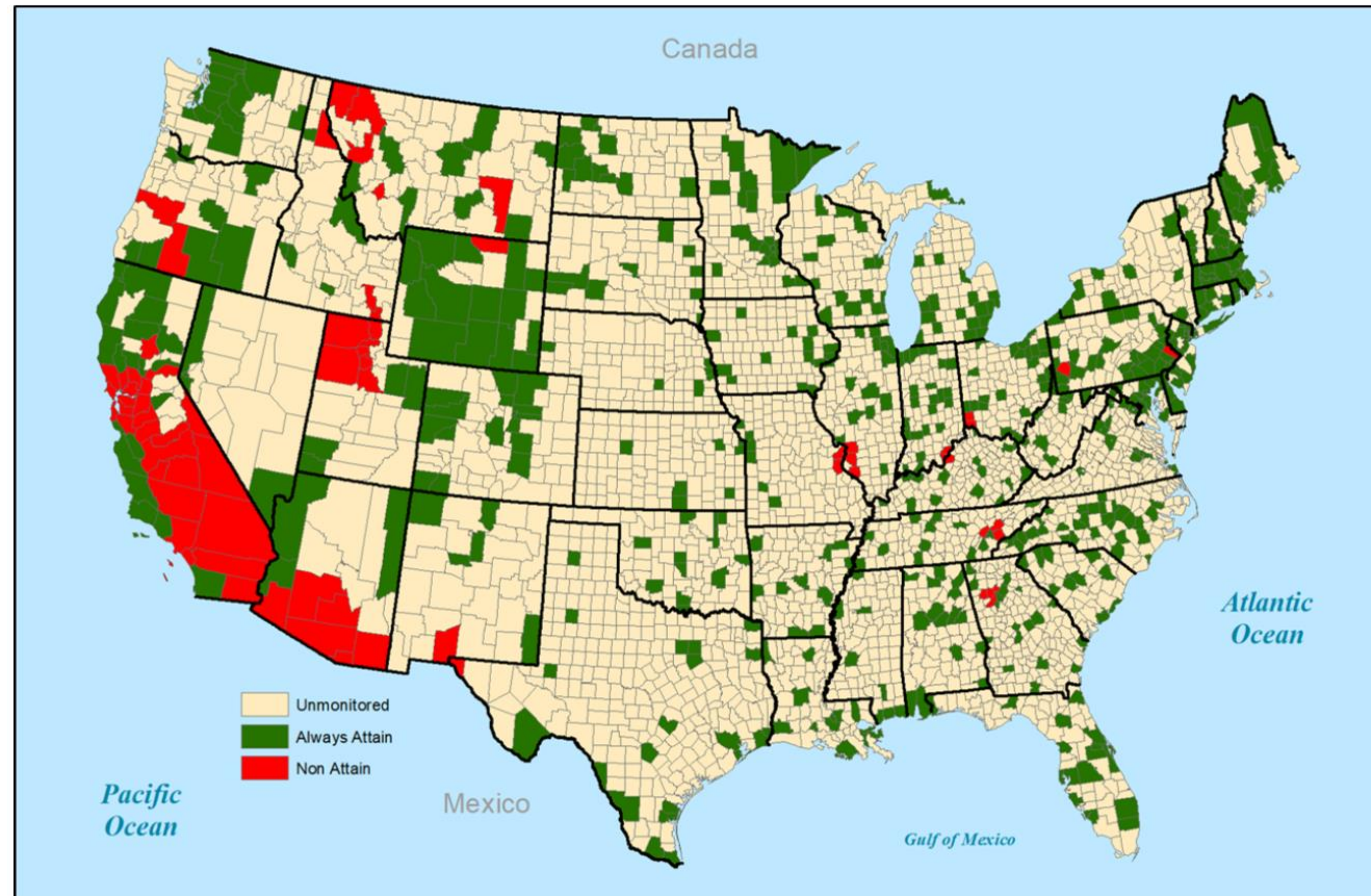Oct. 14, 2019

阅读简体中文版 · 閱讀繁體中文版

Chinese women wearing masks to protect against pollution in Beijing in 2015. The government has made inroads against China's pollution problem. Kevin Frayer/Getty Images

In the Literature

Inequitable Exposure to Air Pollution from Vehicles in the Northeast and Mid-Atlantic

Who Bears the Burden?

HIGHLIGHTS

This analysis explores the significant contribution of cars, trucks, and buses to particulate matter air pollution in the Northeast and Mid-Atlantic and its disproportionate impact on communities of color. Clean transportation policies—such as those that encourage vehicle electrification, cleaner fuels, and reduced driving—will help lower these emissions. Additionally, policymakers should evaluate investments in clean transportation and other clean transportation solutions for their ability to reduce inequities in exposure to vehicular air pollution. Quantitative evidence of such inequities in the region's air pollution helps to inform such evaluations.

In the Northeast and Mid-Atlantic region, transportation is a significant source of both global warming emissions and air pollution (EPA 2019). The region contains four of the 20 US metropolitan areas that are most polluted by year-round fine particulate matter.[1] This air pollution has a significant impact on the health of the region's residents, and varies greatly geographically and across different types of community. This analysis from the Union of Concerned Scientists (UCS) quantifies the formation of fine particulate matter from on-road vehicles in the Northeast and Mid-Atlantic, covering the District of Columbia and 12 states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. The analysis identified the locations and populations most exposed to fine particulate matter by measuring its annual average concentration using a 2014 estimate of emissions as input data (EPA 2014).

Research links exposure to particulate matter smaller than 2.5 micrometers in diameter ($PM_{2.5}$)—20 times smaller than even fine human hair—to increased illnesses and deaths, primarily from heart and lung diseases. The use of vehicles that burn fossil-based fuels in the Northeast and Mid-Atlantic directly produces $PM_{2.5}$, and, at the same time, produces gases that lead to the formation of additional $PM_{2.5}$.

The UCS analysis of annual average $PM_{2.5}$ concentrations due to cars, trucks, and buses in the Northeast and Mid-Atlantic finds that:

Millions of residents in the Northeast and Mid-Atlantic live near major highways and urban centers, and are exposed to high levels of vehicular air pollution; in certain New York City neighborhoods, pollution levels are 3.7 times higher than the regional average. People of color are disproportionately exposed to more of this pollution.

Particulate Air Pollution from Wildfires in the Western US under Climate Change

Jia Coco Liu[1], Loretta J. Mickley[2], Melissa P. Sulprizio[2], Francesca Dominici[3], Xu Yue[2], Keita Ebisu[1], Georgiana Brooke Anderson[4], Rafi F. A. Khan[1], Mercedes A. Bravo[5], and Michelle L. Bell[1]

[1]School of Forestry and Environmental Studies, Yale University, 195 Prospect Street, New Haven, CT, USA, 06511

[2]School of Engineering and Applied Sciences, Harvard University, 29 Oxford Street, Cambridge, MA, USA, 02138

[3]Department of Biostatistics, T.H. Chan School of Public Health, Harvard University, Building II, Room 441, 655 Huntington Avenue, Boston, MA, USA, 02115

[4]Department of Environmental & Radiological Health Sciences, College of Veterinary Medicine & Biomedical Sciences, Colorado State University, 146 Environmental Health Building, Fort Collins, CO, USA, 80521

[5]School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI, USA, 48109

Abstract

Wildfire can impose a direct impact on human health under climate change. While the potential impacts of climate change on wildfires and resulting air pollution have been studied, it is not known who will be most affected by the growing threat of wildfires. Identifying communities that will be most affected will inform development of fire management strategies and disaster preparedness programs. We estimate levels of fine particulate matter ($PM_{2.5}$) directly attributable to wildfires in 561 western US counties during fire seasons for the present-day (2004–2009) and future (2046–2051), using a fire prediction model and GEOS-Chem, a 3-D global chemical transport model. Future estimates are obtained under a scenario of moderately increasing greenhouse gases by mid-century. We create a new term "Smoke Wave," defined as ≥2 consecutive days with high wildfire-specific $PM_{2.5}$, to describe episodes of high air pollution from wildfires. We develop an interactive map to demonstrate the counties likely to suffer from future high wildfire pollution events. For 2004–2009, on days exceeding regulatory $PM_{2.5}$ standards, wildfires contributed an average of 71.3% of total $PM_{2.5}$. Under future climate change, we estimate that more than 82 million individuals will experience a 57% and 31% increase in the frequency and intensity, respectively, of Smoke Waves. Northern California, Western Oregon and the Great Plains

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ABSTRACT

After declining by 24.2% from 2009 to 2016, annual average fine particulate matter (PM2.5) in the United States in counties with monitors increased by 5.5% between 2016 and 2018. Increases occurred in multiple census regions and in counties that were in and out of attainment with National Ambient Air Quality Standards (NAAQS). We explore channels through which the increase may have occurred including increases in economic activity, increases in wildfires, and decreases in Clean Air Act enforcement actions. The health implications of this increase in PM2.5 between 2016 and 2018 are significant. The increase was associated with 9,700 additional premature deaths in 2018. At conventional valuations, these deaths represent damages of $89 billion.

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Nicholas Z. Muller
Department of Engineering, and Public Policy
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Monitoring

Figure 1: Map Showing Counties with at Least One Monitor

Clay & Muller, Recent Increases in Air Pollution: Evidence and Implications for Mortality

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What does this process look like in partnership with low-income countries?

What does this process look like in partnership with Autodesk engineers & designers?

MEASUREMENT

Delea, M., Nagel, C., Thomas E., Halder, A., Amin, N., Shoab, A., Freeman, M., Unicomb, L., Clasen, T., "Comparison of respondent-reported and sensor-recorded latrine utilization measures in rural Bangladesh: a cross-sectional study," Transactions of The Royal Society of Tropical Medicine and Hygiene, 2017.

O&M Optimization

- Is your infrastructure broken?
- How much should O&M be prioritized?
- Are you optimizing your intervention?

Service Delivery

- What's the health of your network?
- What do usage patterns look like?
- Are you optimizing your services?

Impact Evaluation

- Was the intervention effective?
- Did people adopt new technology?
- How long does your intervention have the desired impact?
- Does your model fit actual data?

Ending Drought Emergencies

O&M PROJECT

Monitoring water supplies in drought-prone regions from East Africa to California

Partners: Govt. & Water Bureaus, Utilities, others

Funding: USAID, MWA, others

CellPump Trial

RESEACH PROJECT

Compared water infrastructure uptime between different models to assess GSM sensors as O&M tools

Partner: Living Water International Rwanda

Funding: DFID
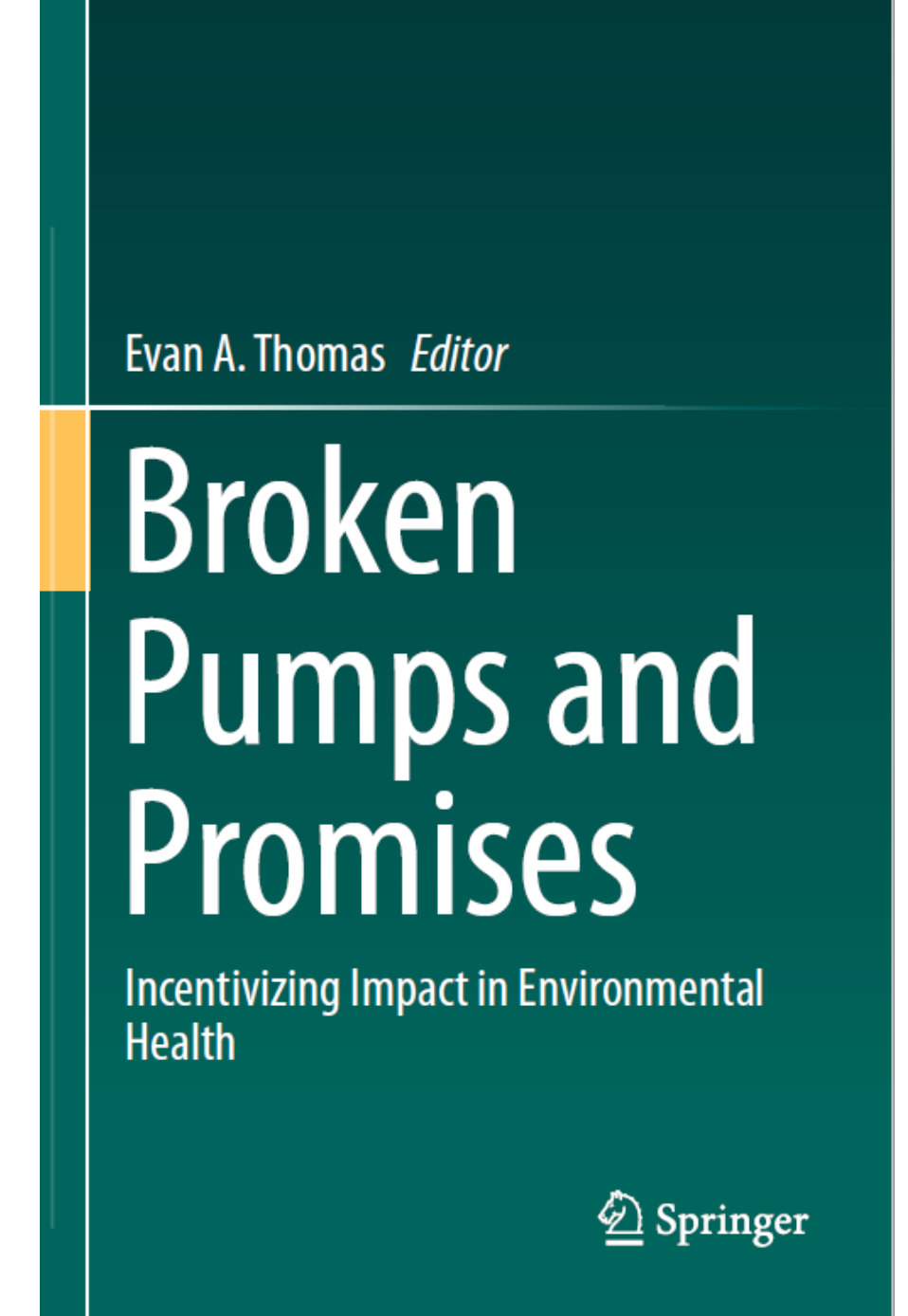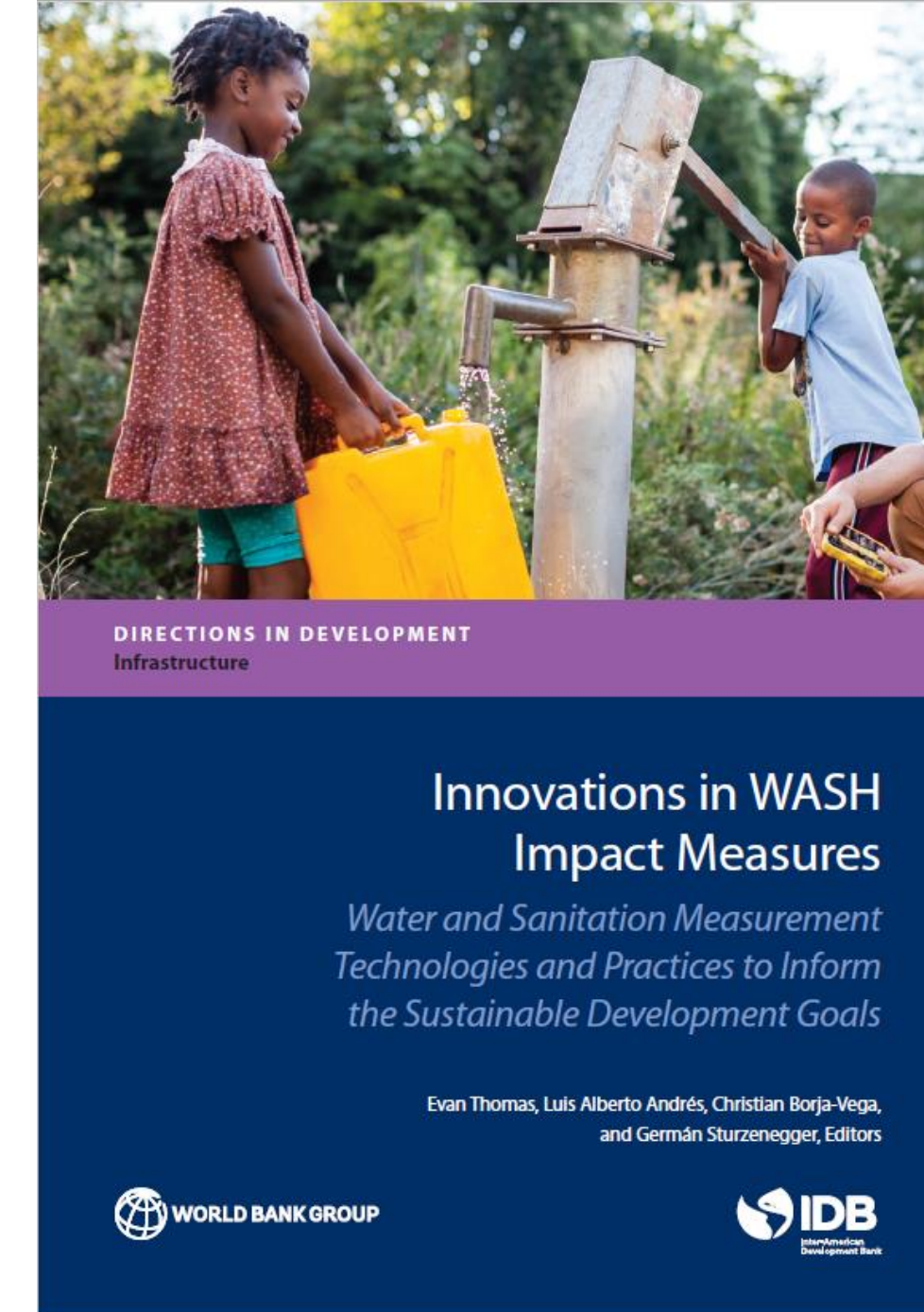
Sierra Leone DWM Distributed Water Management

SERVICE DELIVERY PROJECT

Drinking water tank & reservoir measurements to inform the local utility, PPP operations

Partners: Guma Valley Water Authority, Water4

Funding: MCC

Publications

SYNTHESIS PROJECTS

Among other topics, these books address the importance of good data collection and monitoring practices to improve the impact of international development projects

TOOLS

Place the magnet dial at the end of the slowest dial's sweep

Distance Design

Distance Design
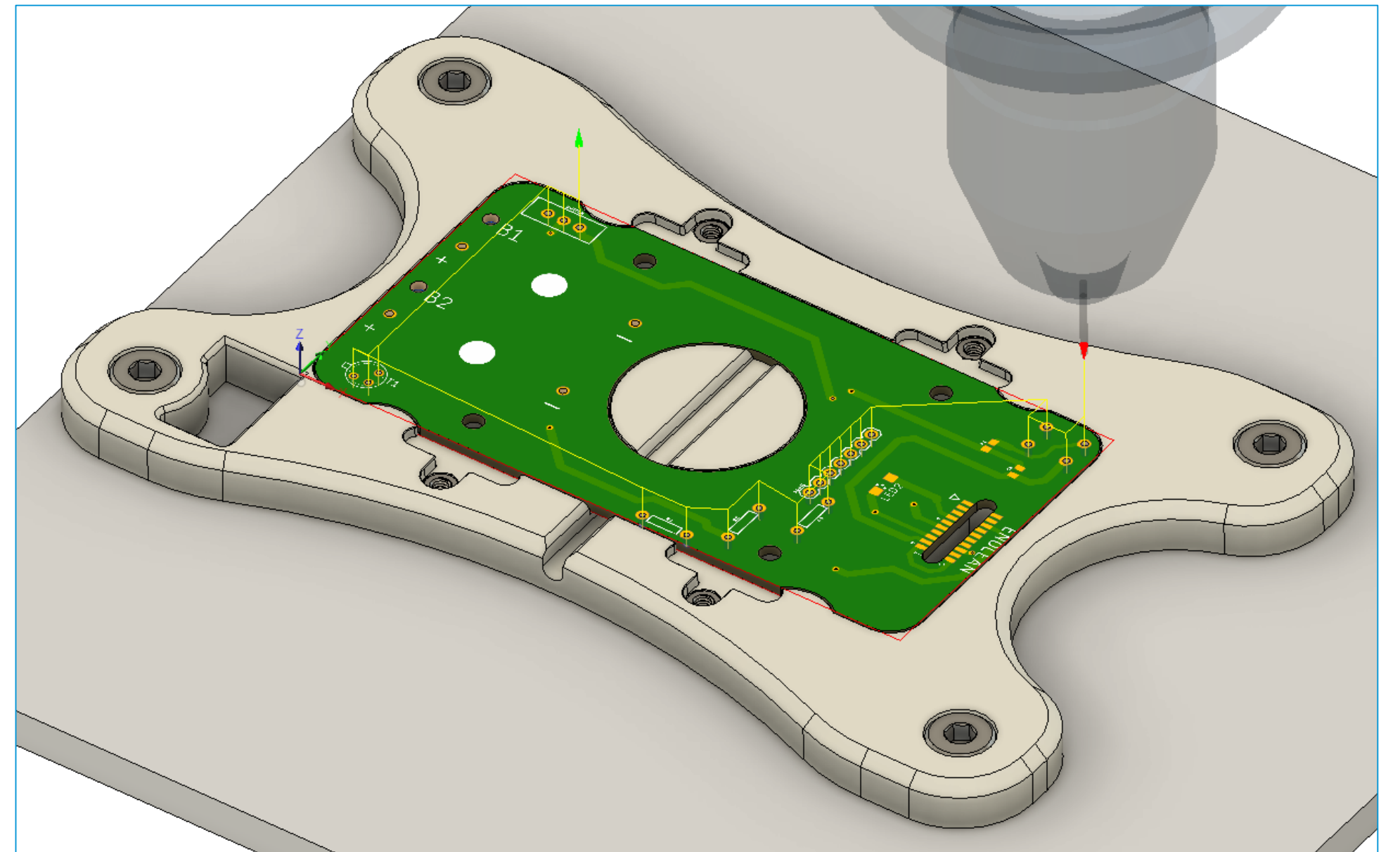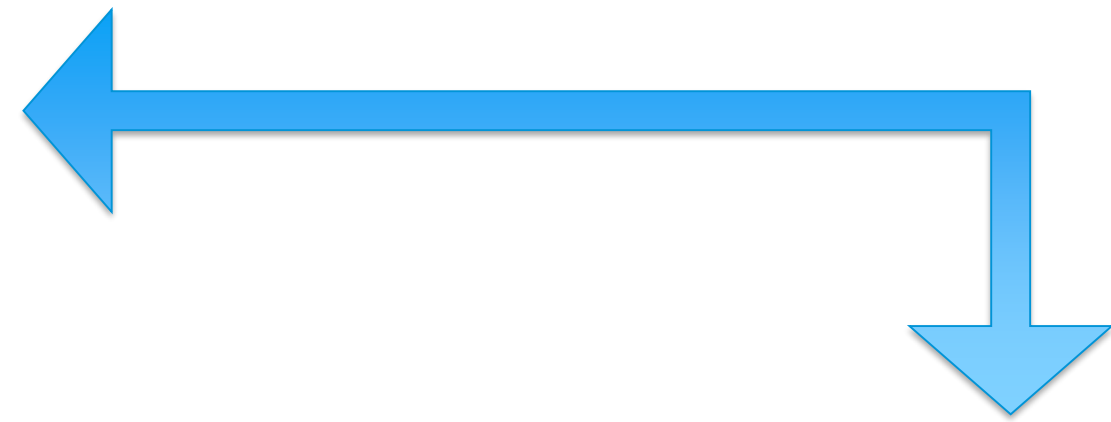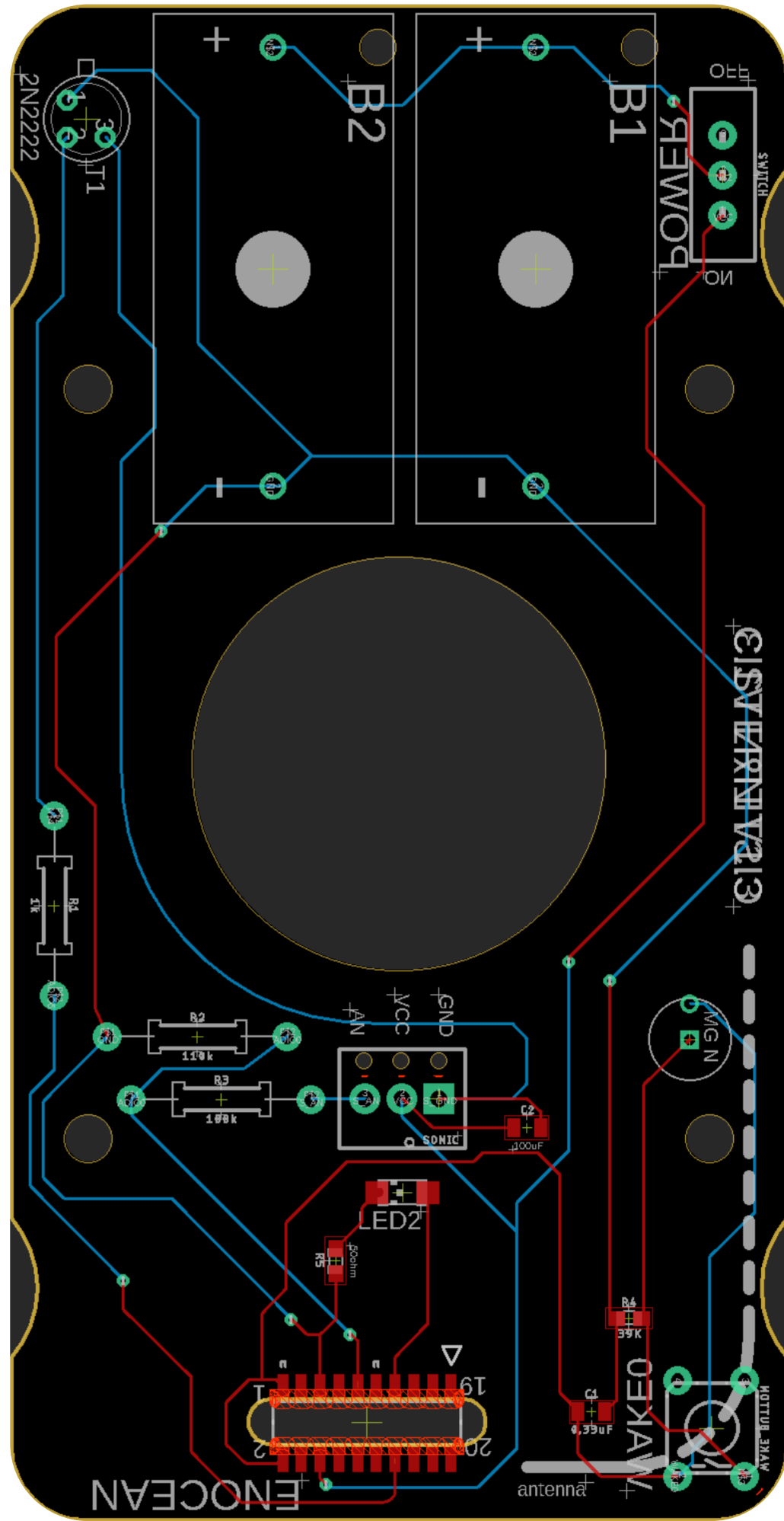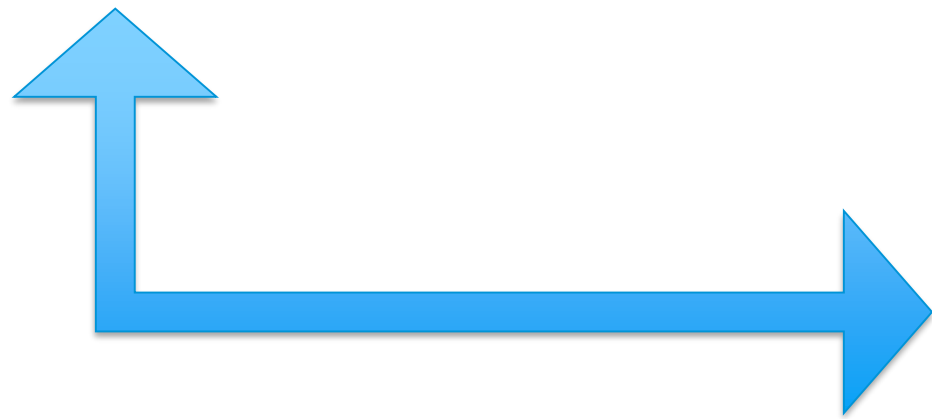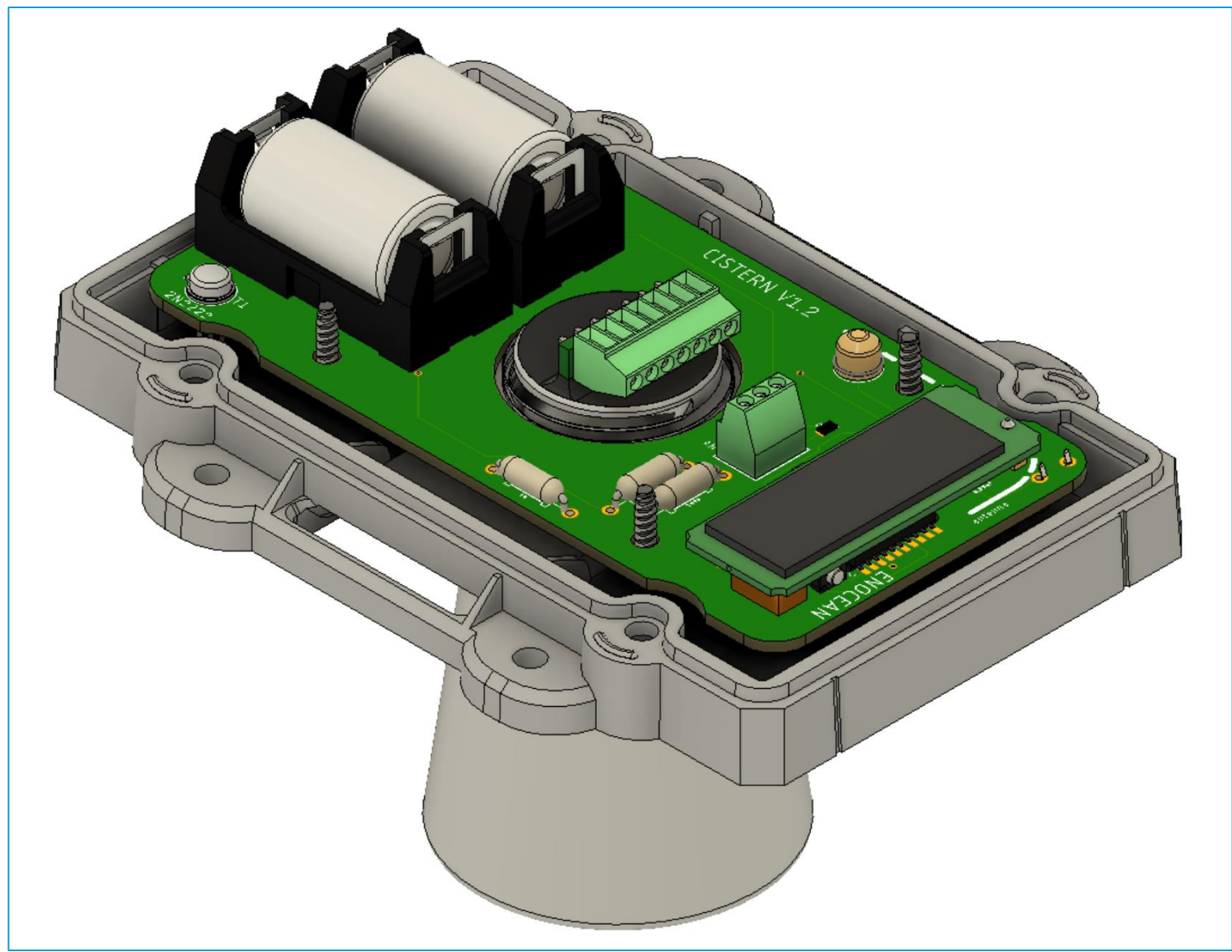
eCAD / mCAD / CAM Integration

3D-printed WAKE
Key

Desktop CNC-
Modified Enclosure

3D-printed component
brackets on PCB

Desktop CNC-
Modified Enclosure

3D-printed TPU
Gasket

Non-traditional Manufacturing

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Rwanda Feedback System

Developed as ancillary HAPIN (Household Air Pollution Intervention Network) Study

Human-centered co-design process with Rwandan colleagues and focus groups

California/Colorado CEAQL

"Collaboratively Engineered Air Quality Lamp"

Developed in collaboration with Pier 9 team:

Jonathan Odom – Fusion 360 Community Manager

Arthur Harsuvanakit – Senior Designer at Pier 9

Context

Concept

Sonete mu nzu
September 18, 2017 · Rwanda | Messages Card Sort · A | 02

Ubutumwa bugaragarira mu mabara
September 18, 2017 · Rwanda | Messages Card Sort · A | 03

Ibimenyetso bishushanyije
September 18, 2017 · Rwanda | Messages Card Sort · A | 04
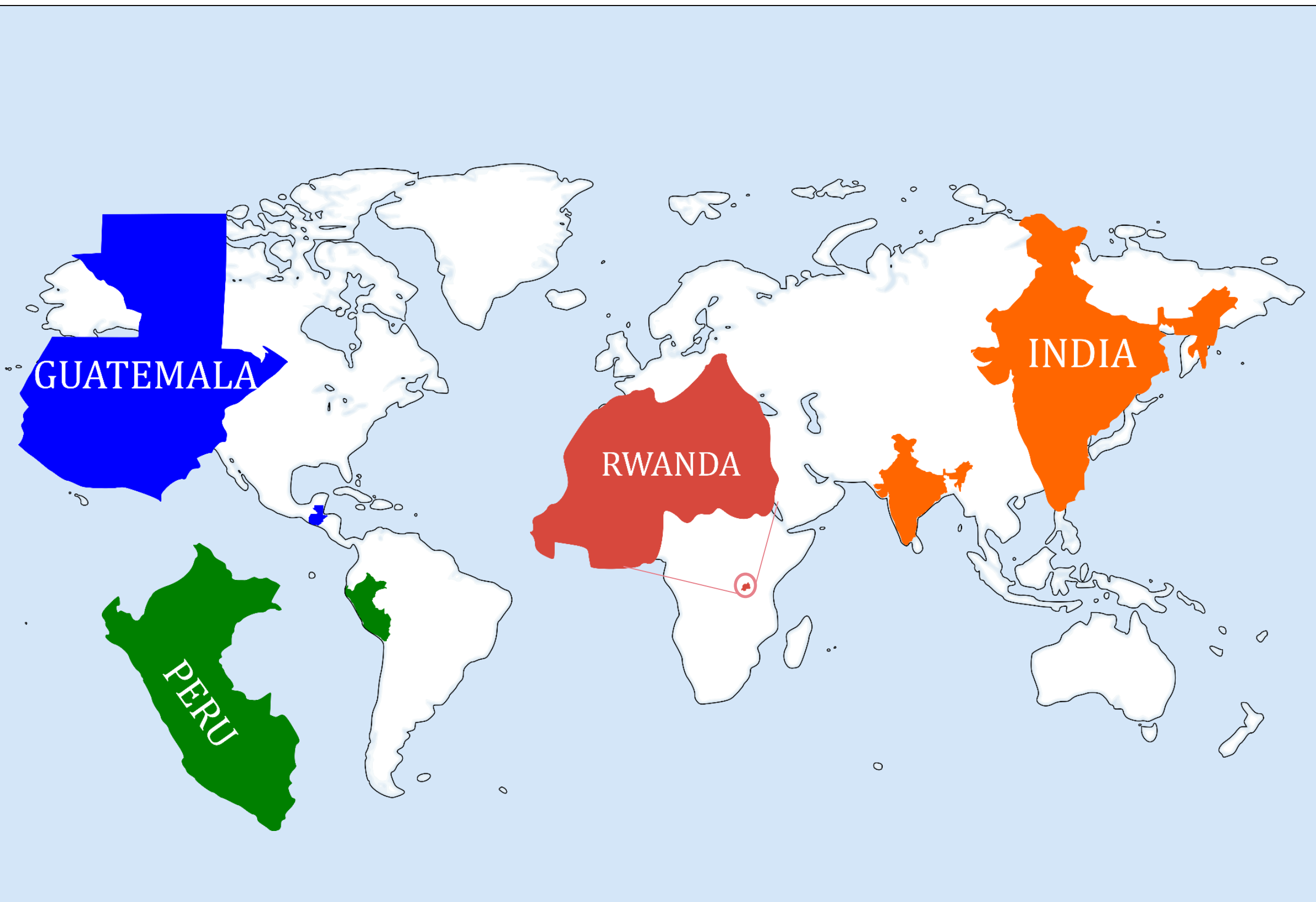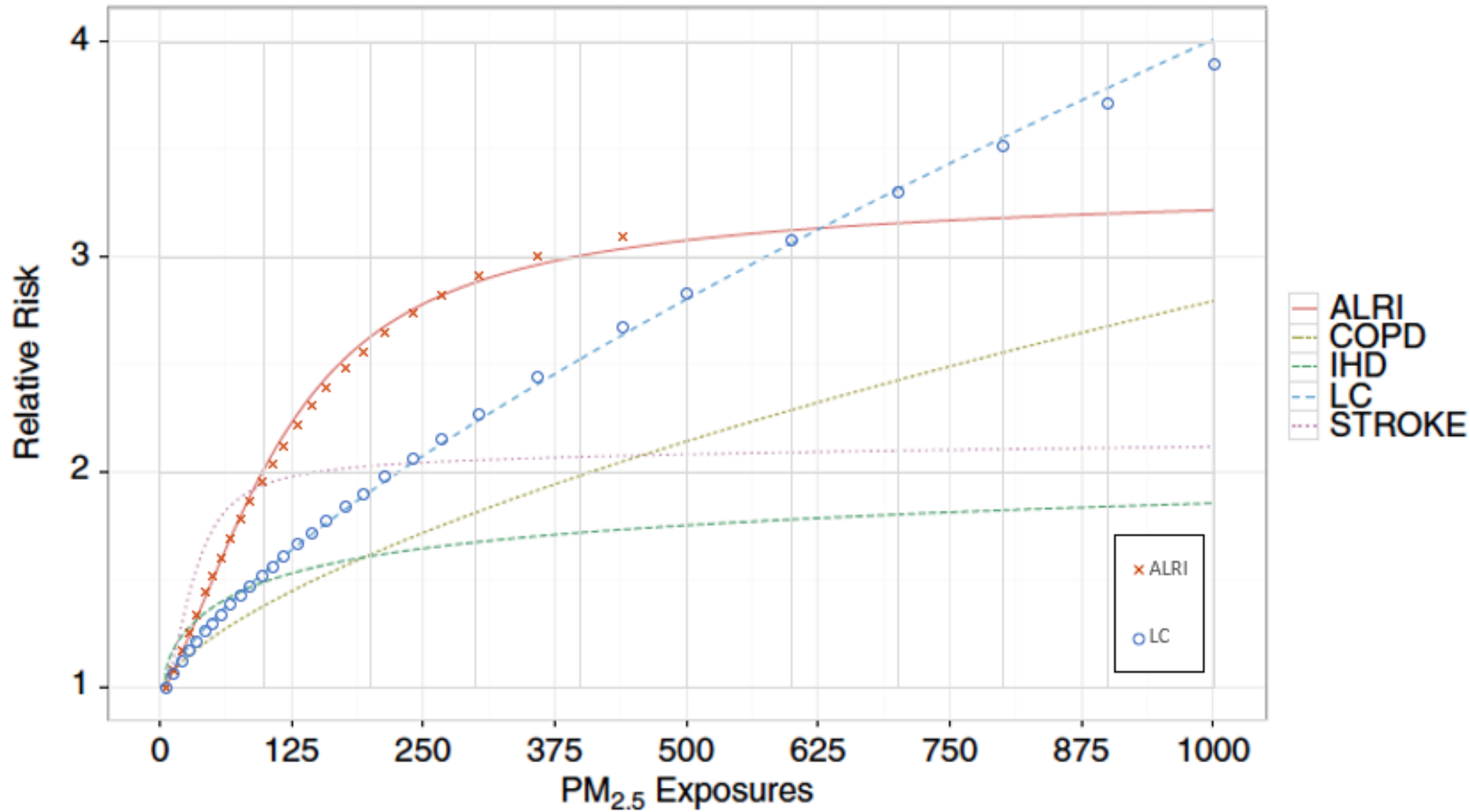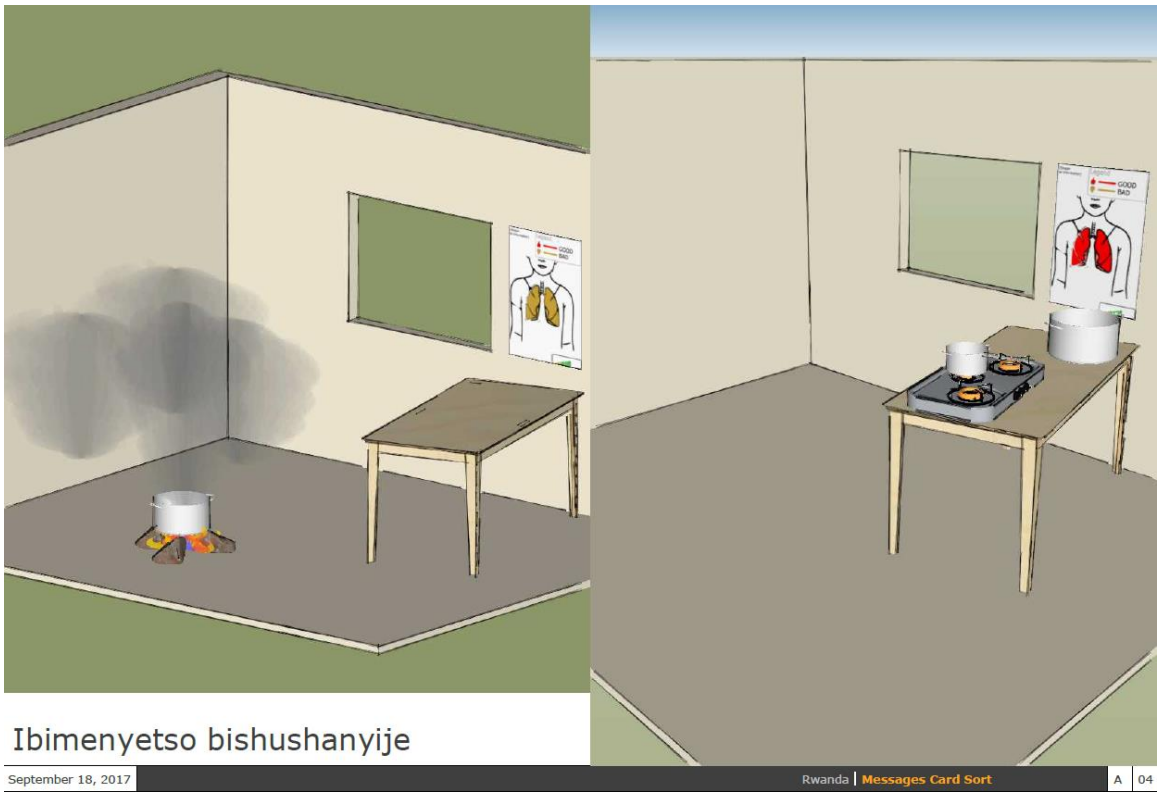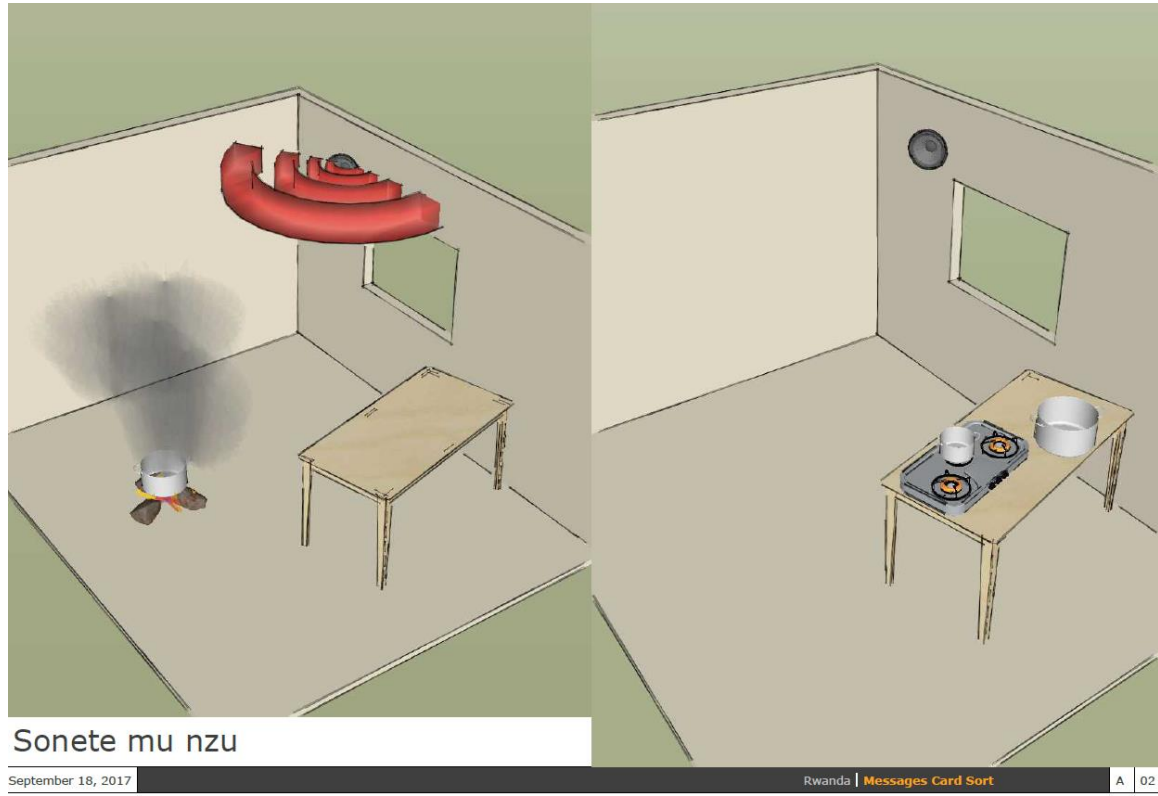
LED meter feedback   lamp mode
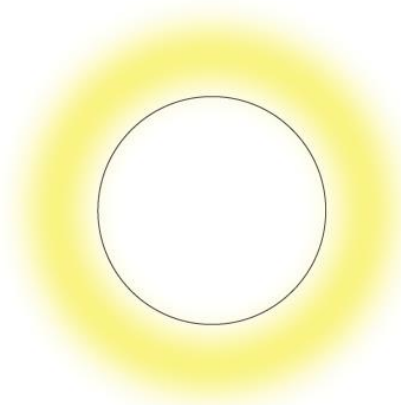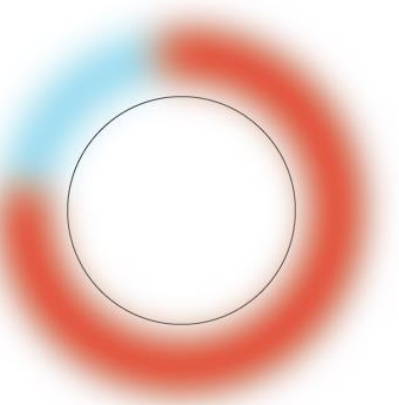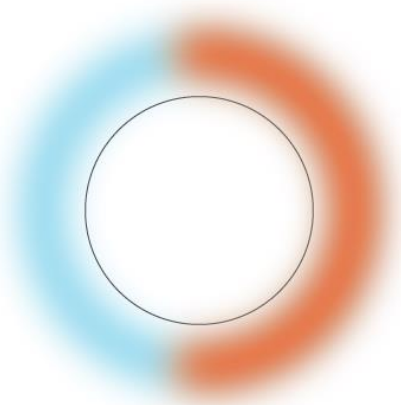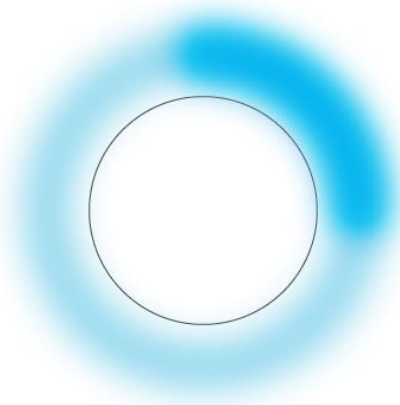
safe   unsafe

Collaboration

TRIGGERS

Friends, 21
Smoke, 36
Infant, 39
Walls, 27
Kids, 39
Trees, 43
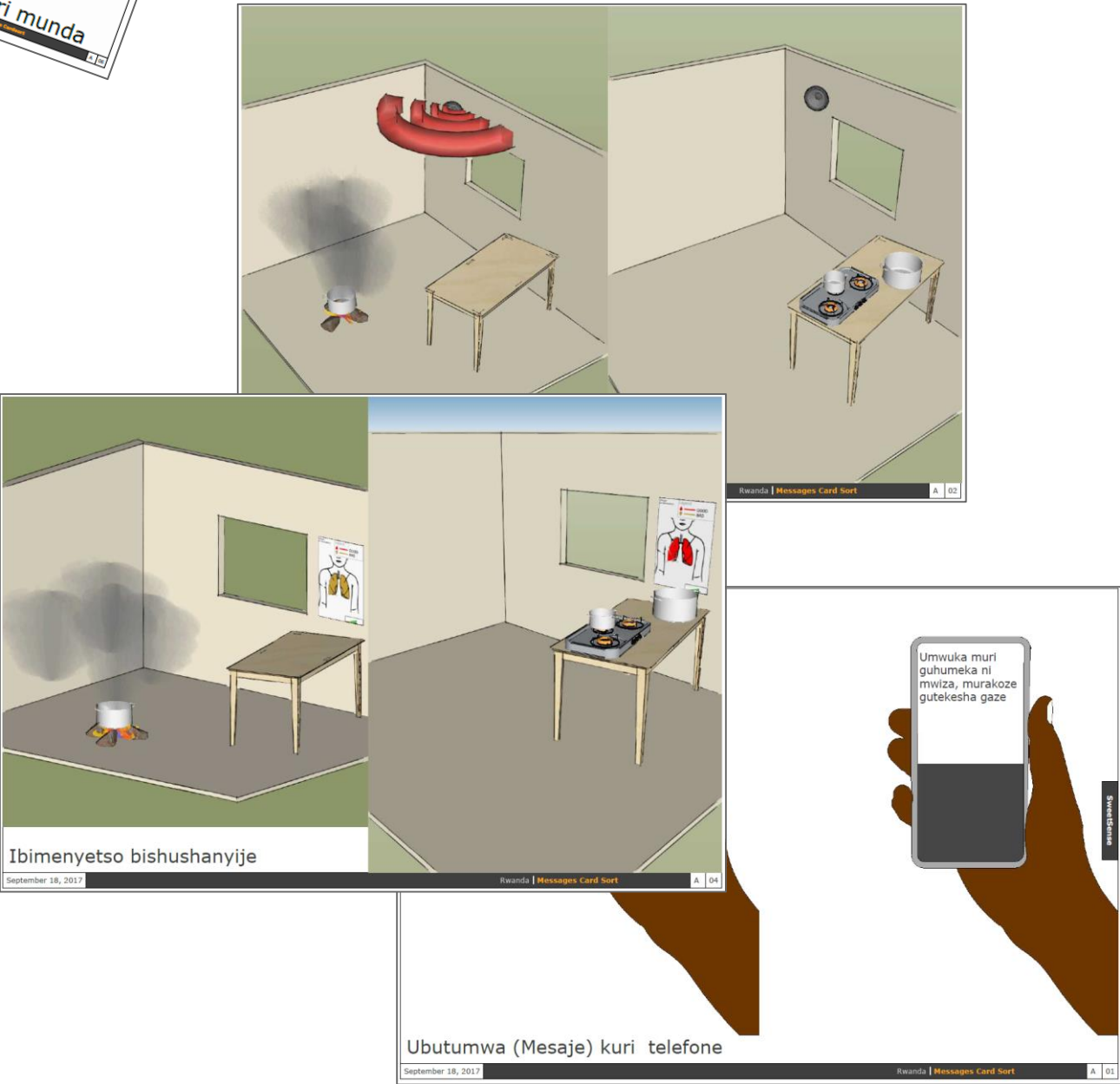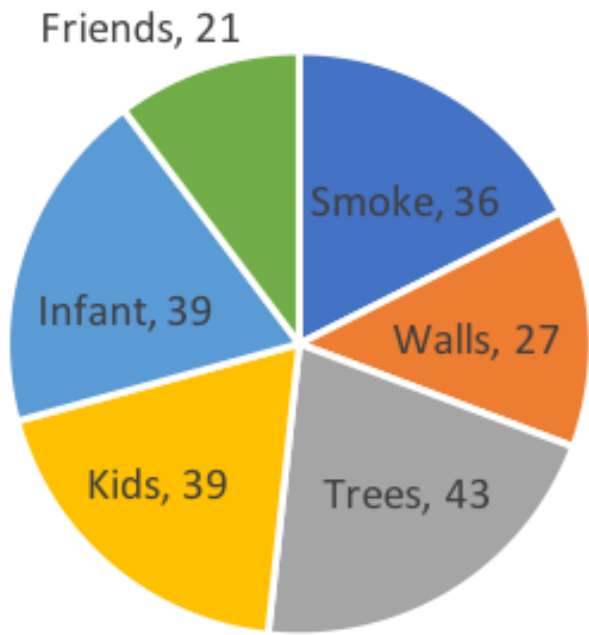
MESSAGING
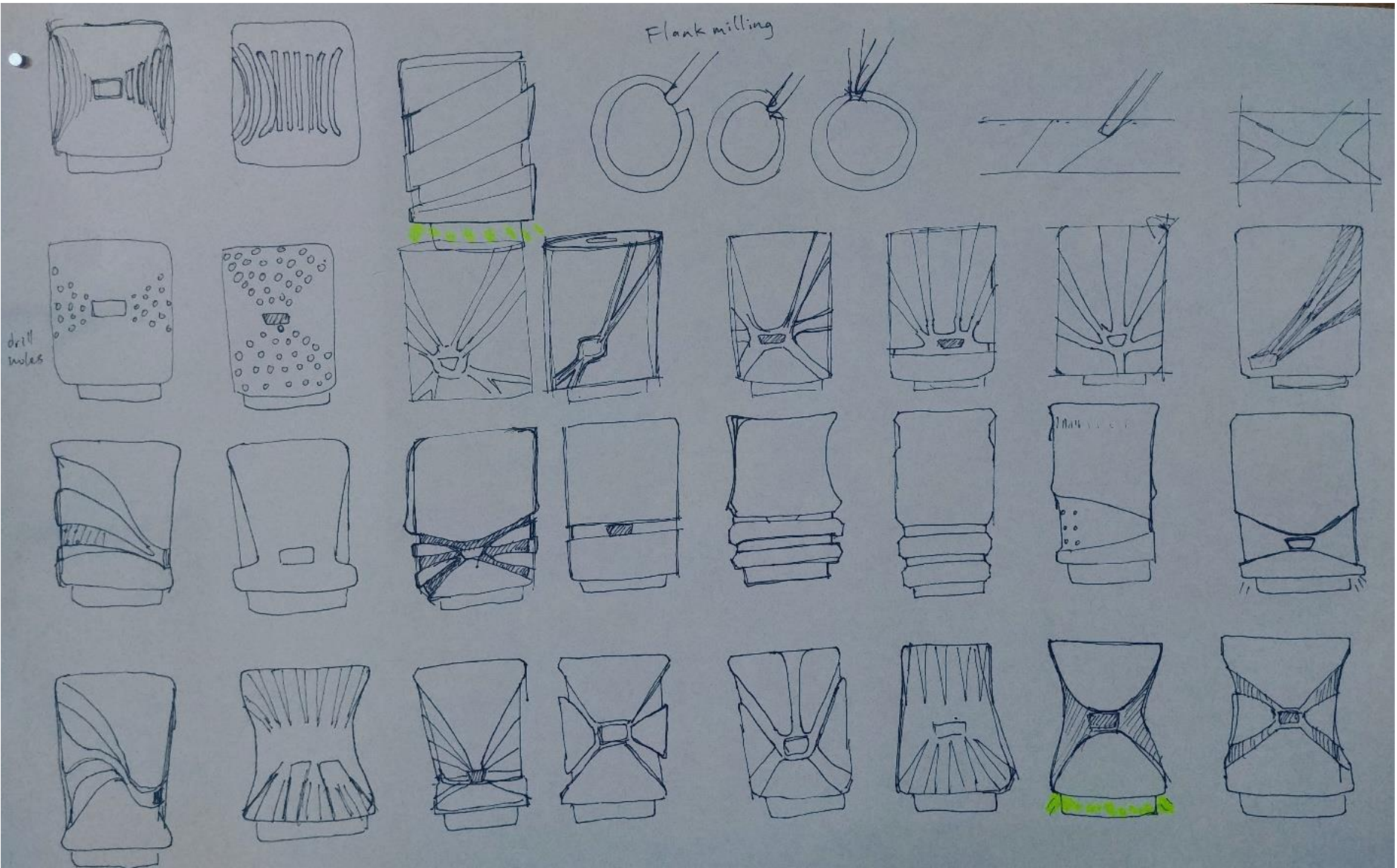
Collaboration

SONE HAMWE N'IGISHUSHANYO

Feedback Controls
Rwanda Group Session, 9.20.17
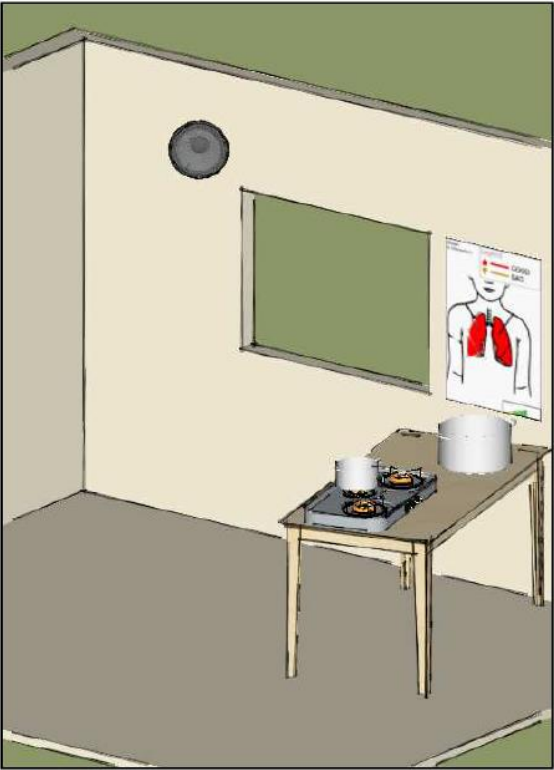
Iyo nta myotsi ihari, igishushanyo kirasa ibara ry'umutuku

Iyo hari imyotsi mike, igishushanyo gihinduka ikijuju

Iyo hari imyotsi myinsh, igishushanyo kirahinduka kijuju, hanyuma na sone ikavuga

Mounting Stand Concept

Created by Taylor Sharpe 3/18/2019

All dimensions in mm

Dimensions are not final, and should be adjusted to the size of locally-available timber

Wood screws to hold display in place

MATERIAL: Timber, fastened with wood screws

AU Lamp LED Segments (Log-log)

AU Lamp LED Segments (Linear)

Relative Risk of ALRI in Children

PM₂.₅ Exposure (µg/m³)
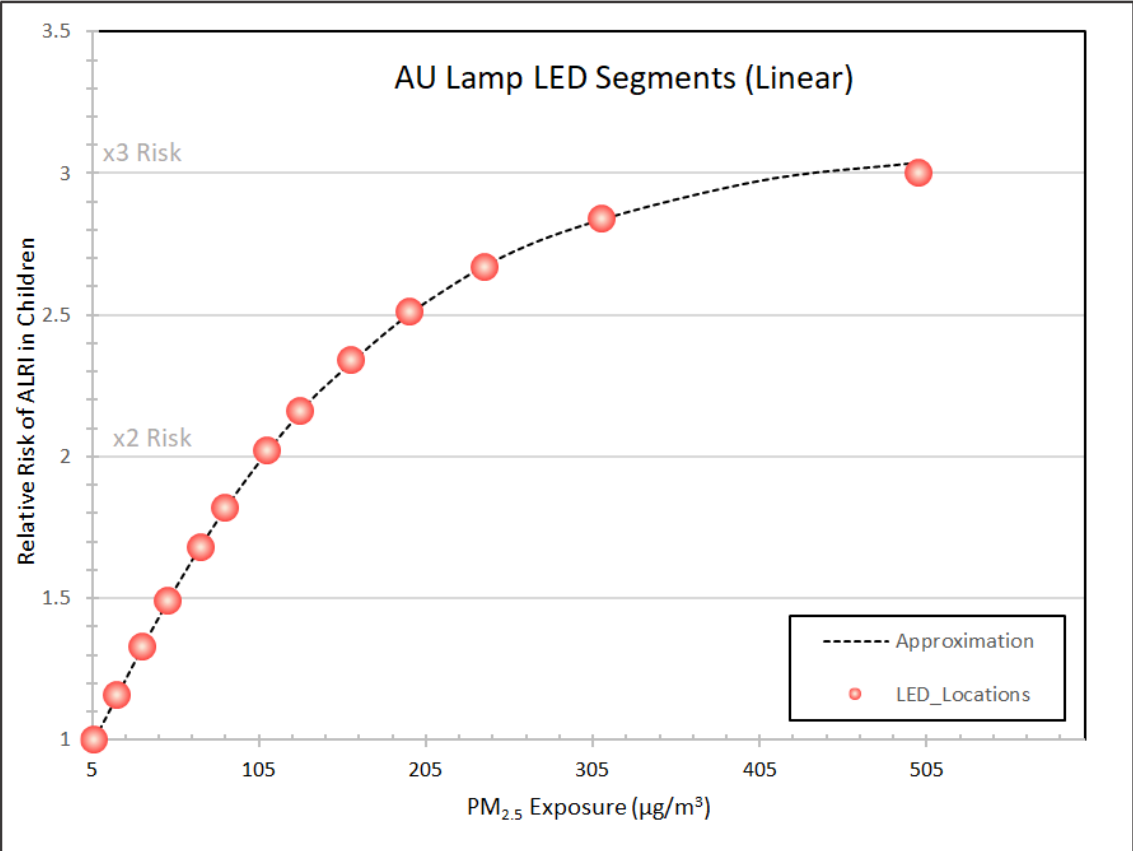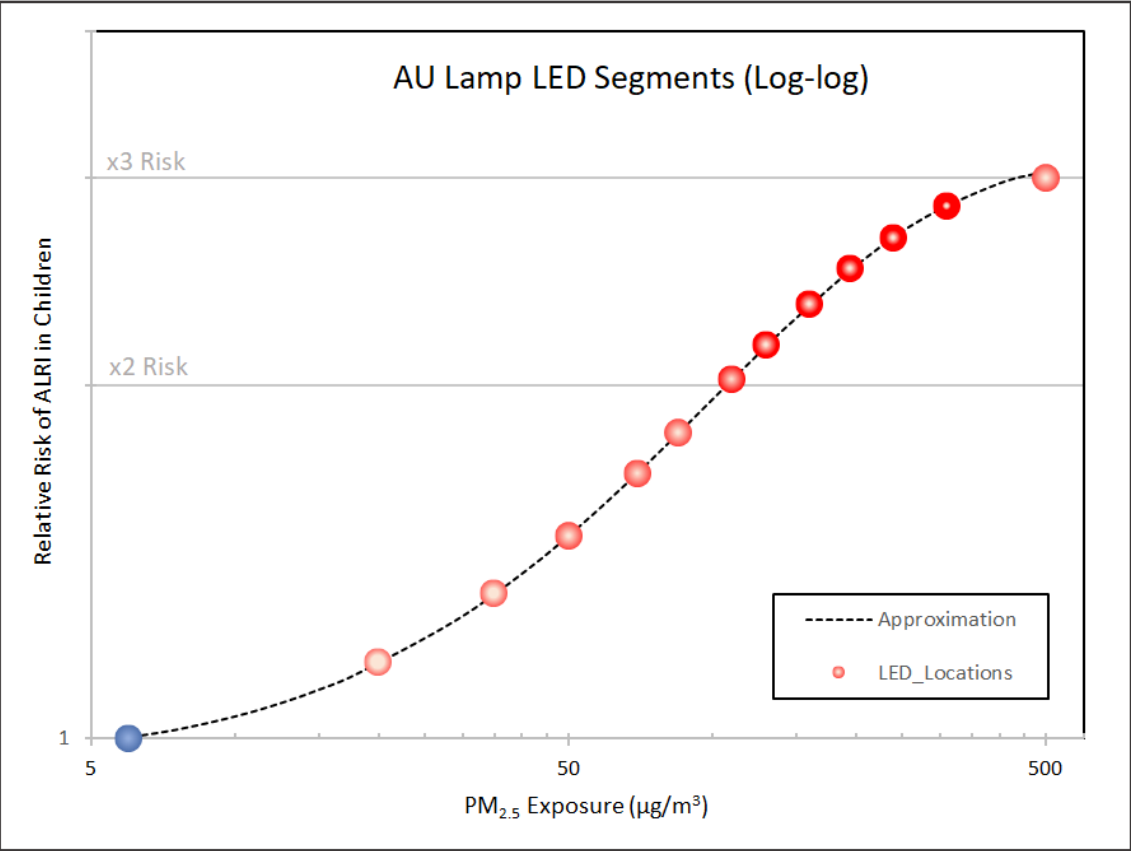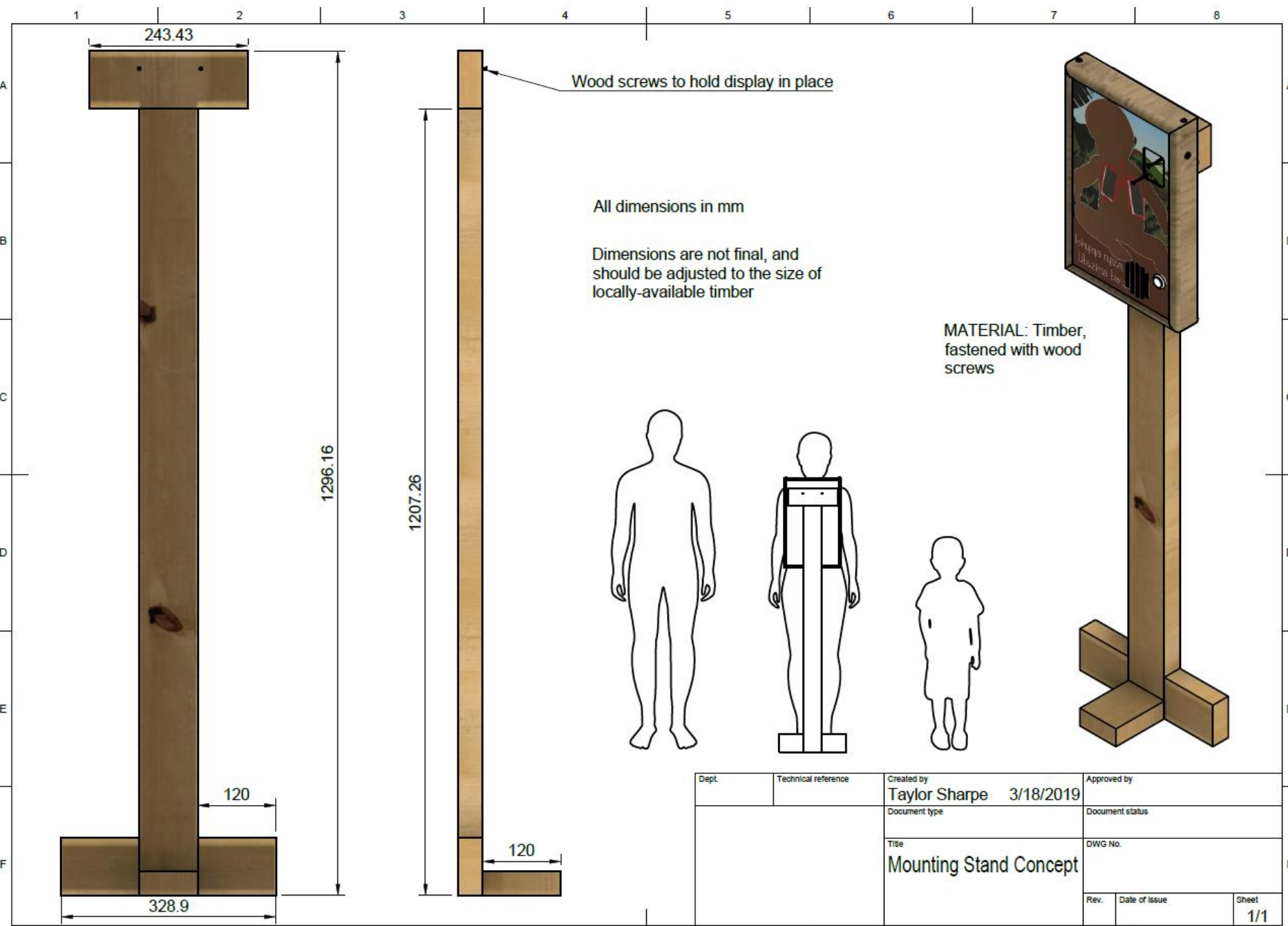
0-10: safe

0-50: low risk

51-100: moderate risk

101-150: unhealthy (sensitive groups)

151-200: unhealthy

201-300: very unhealthy

301-500: hazardous

units: PM2.5 in µg / m3

risk factor: exposure of 24 hours or less *per year.*

CAD
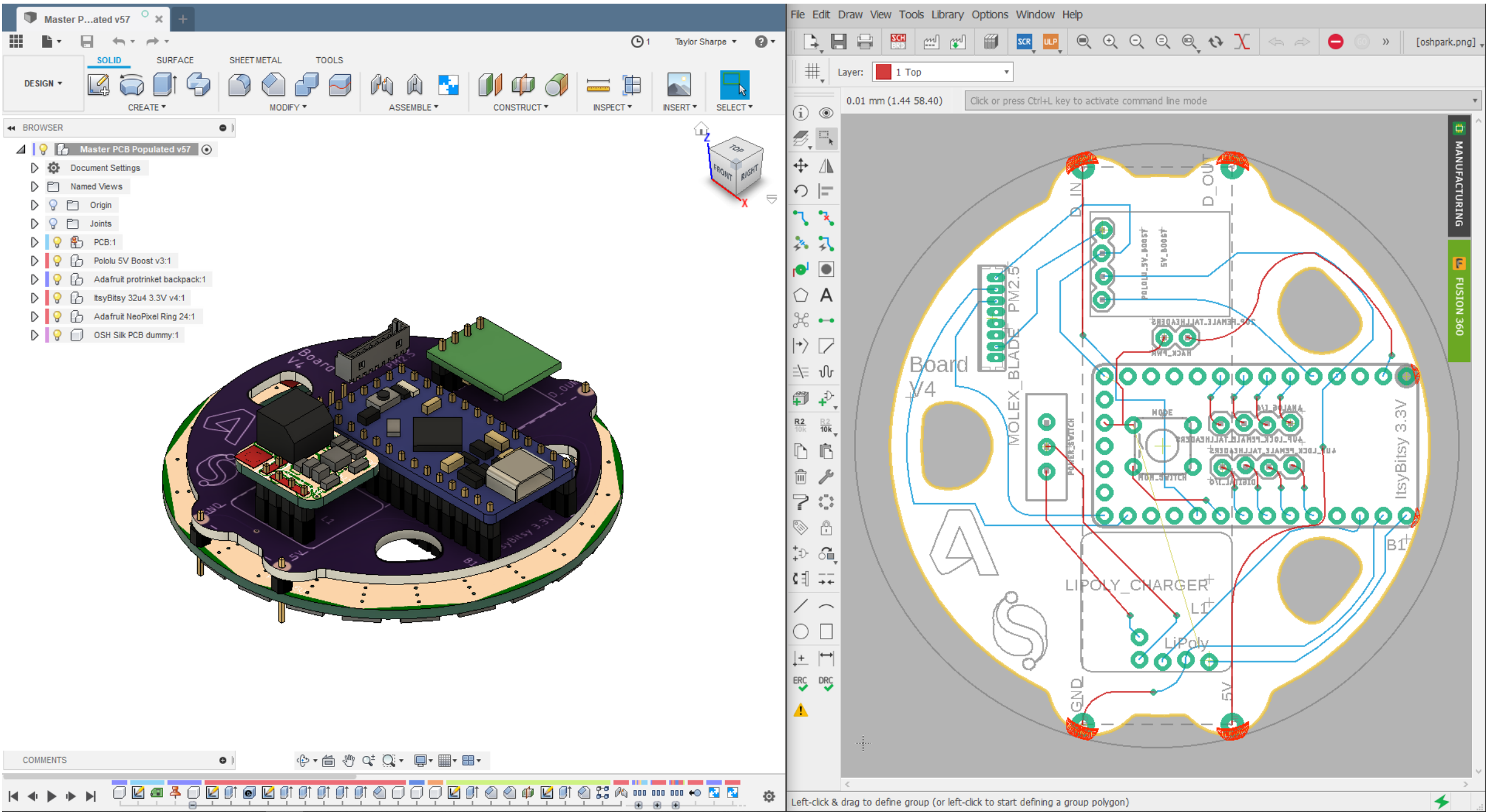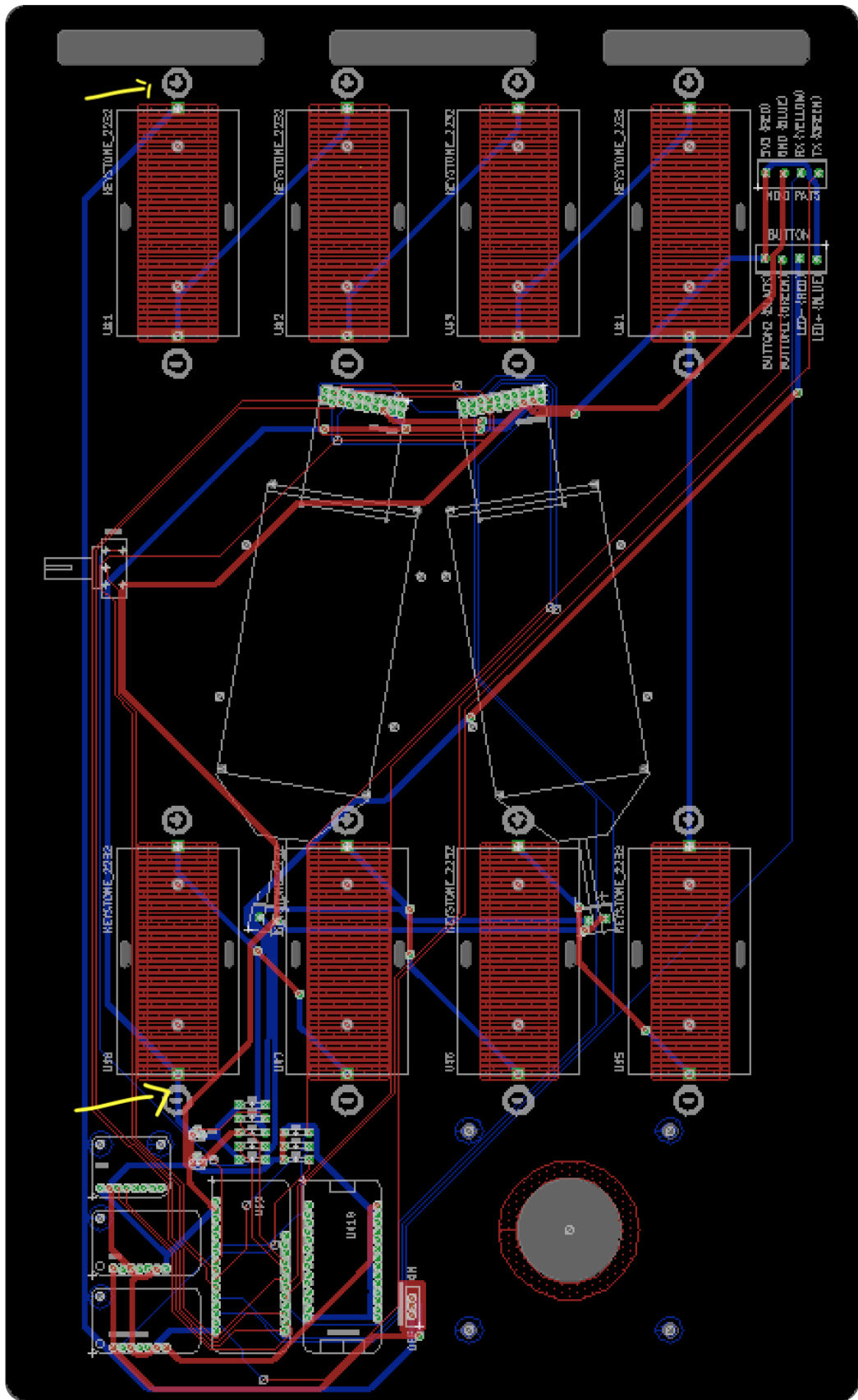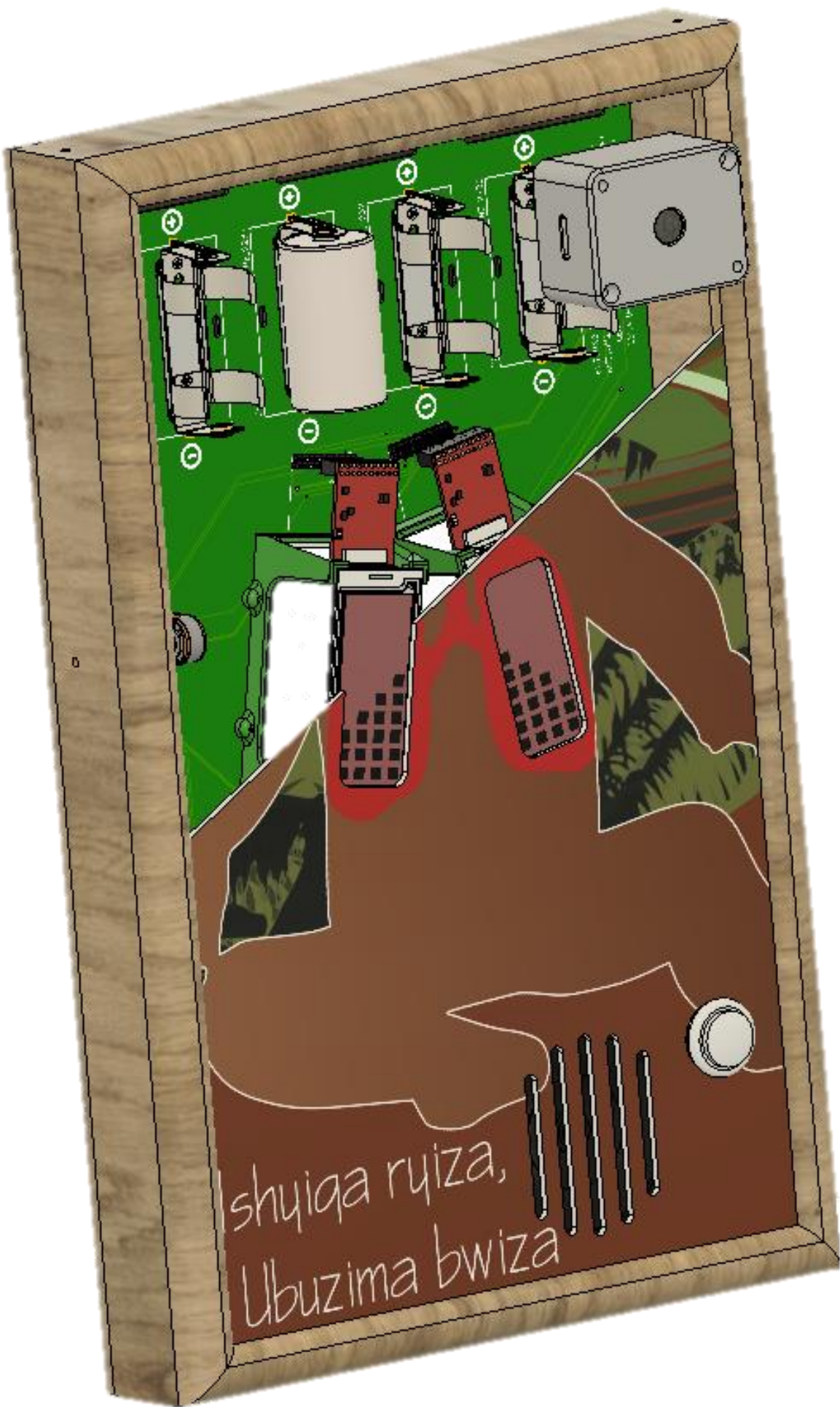
Prototyping
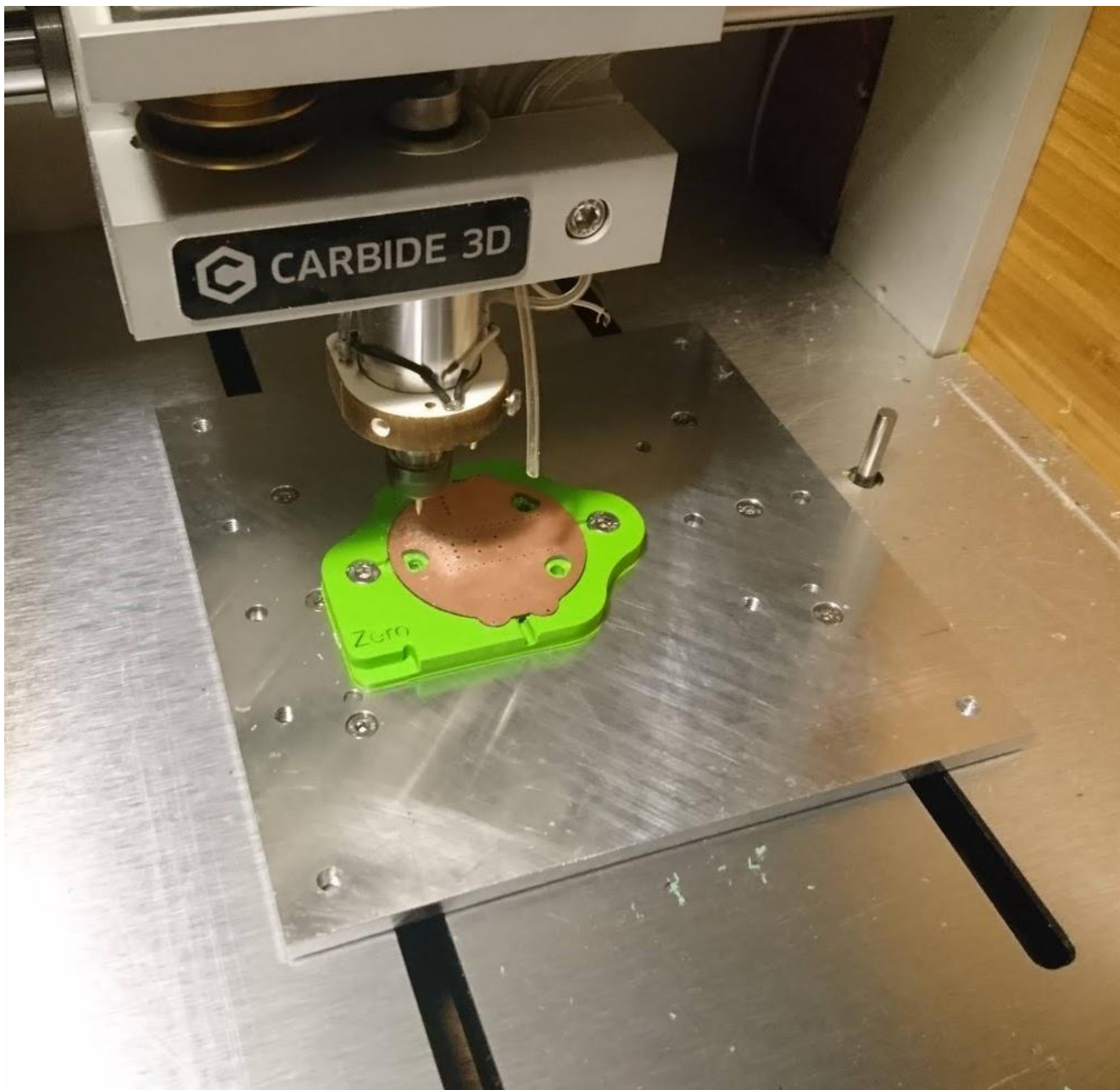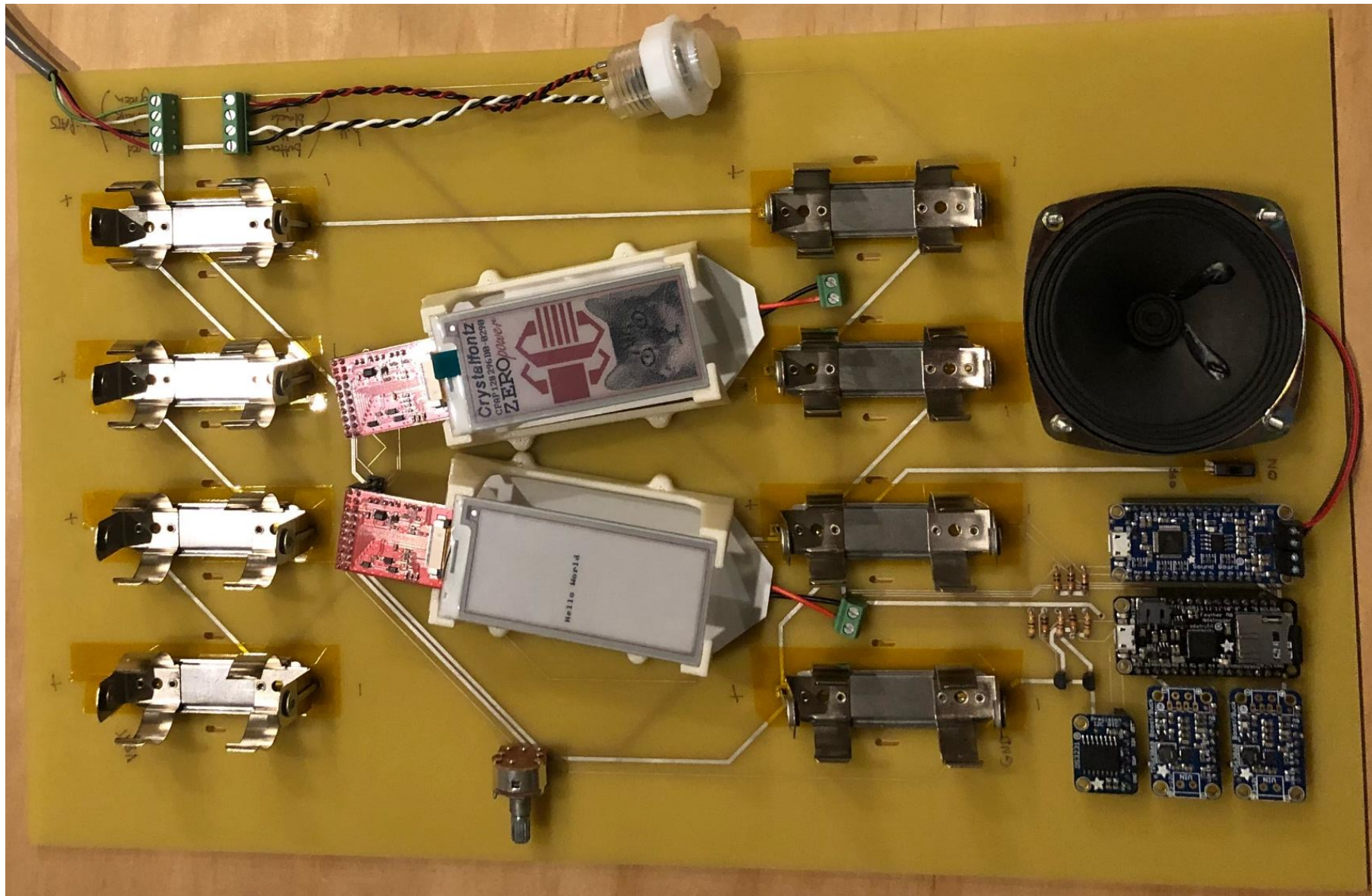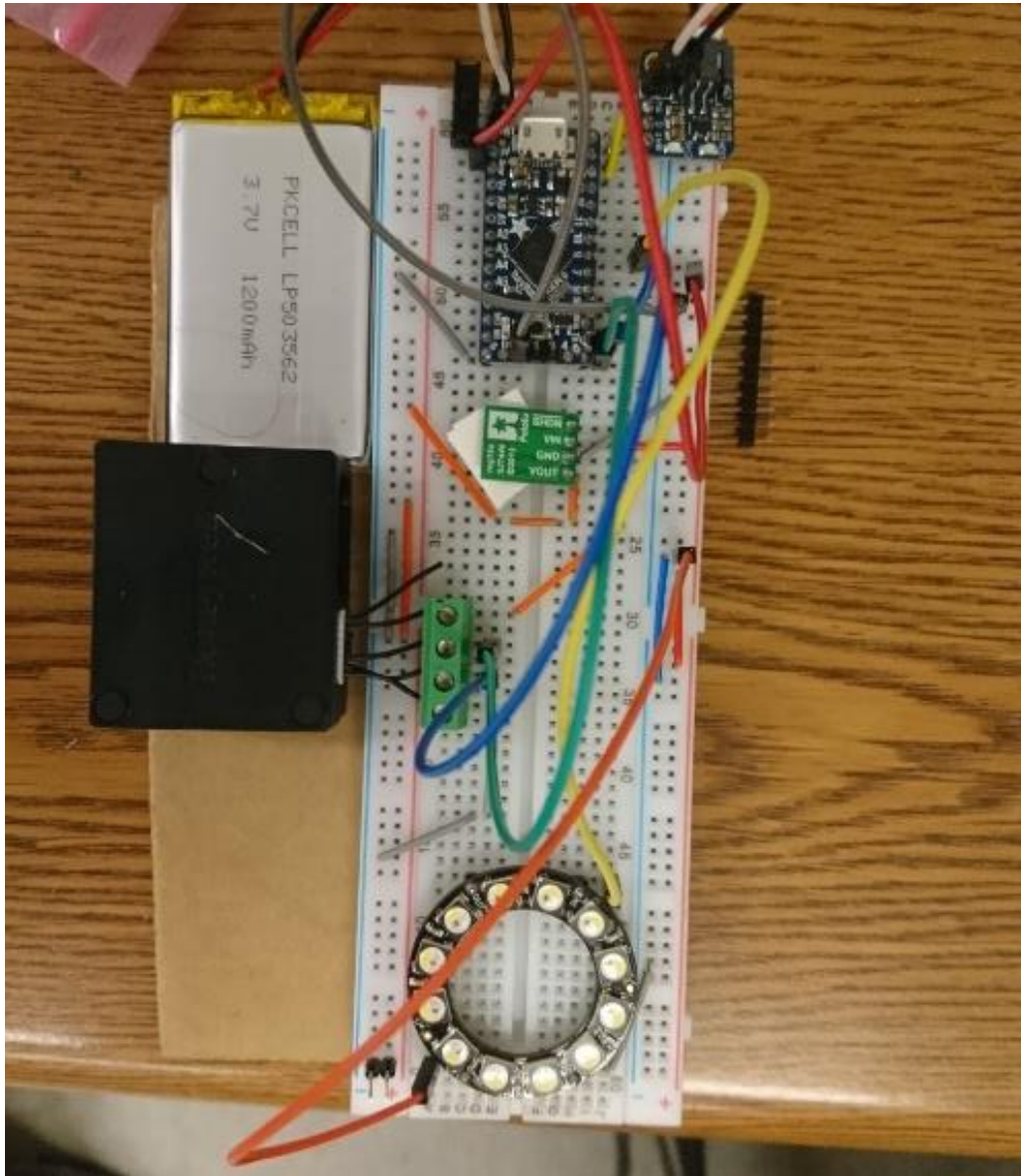
Testing

Production

Project

Air Quality Poster

- Co-designed with Potential Users
- Provides real-time environmental health data
- Provides time-series data for research

Air Quality Lamp

- Co-designed with Autodesk Designers
- Provides real-time environmental health data
- Provides open-source platform for mods

Learning Objectives

(1) BROAD: GLOBAL ENGINEERING

What global challenges are being tackled by Global Engineering?

How does Global Engineering aspire to function on the World Stage?

(2) DEEP DIVE: AIR QUALITY

What are the public health impacts of air pollution?

Who is most at risk?

Where is this an issue?

(3) IOT AS A GLOBAL ENGINEERING TOOL

Why do we use IoT as a Global Engineering tool?

What does this look like in our Rapid Prototyping Space?

What contributions have we made so far?

(4) AIR QUALITY SENSOR CASE STUDIES

What does this process look like in partnership with low-income countries?

What does this process look like in partnership with Autodesk engineers & designers?

Curriculum

Air Quality Sensor Enclosures designed by CU Boulder GE students

Used for air quality measurement lab

- 70 graduate students in 30 countries
  - EDE program monitoring critical water supplies for 2.5m
    - Faculty from Engineering, DevEcon, Public Health

What is the Engineer's role in International Development Projects?

AUTODESK.
Make anything.