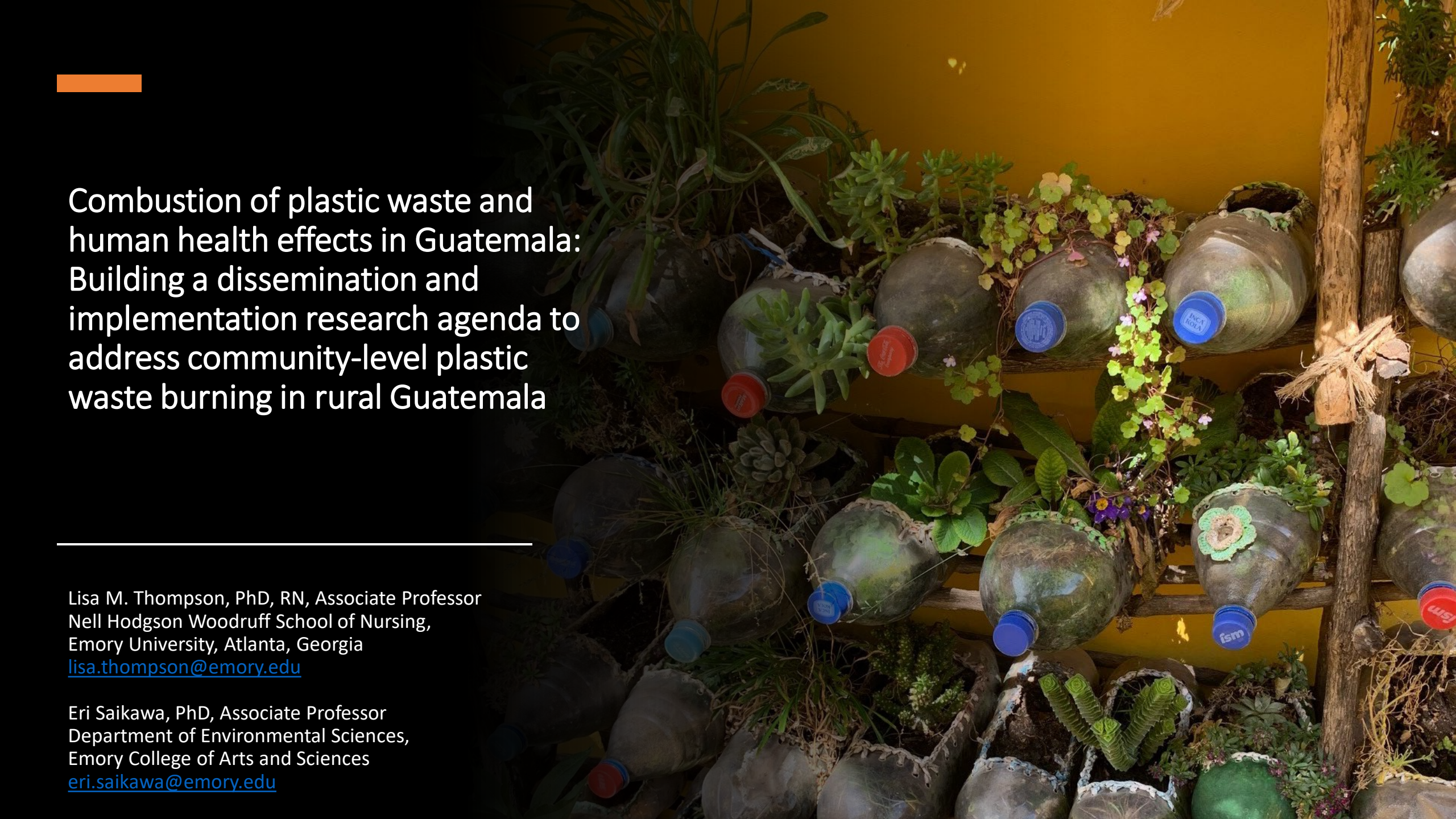
Combustion of plastic waste and human health effects in Guatemala: Building a dissemination and implementation research agenda to address community-level plastic waste burning in rural Guatemala



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The problem-globally

Ambient and household air pollution represent the single largest environmental risk factor for ill health.

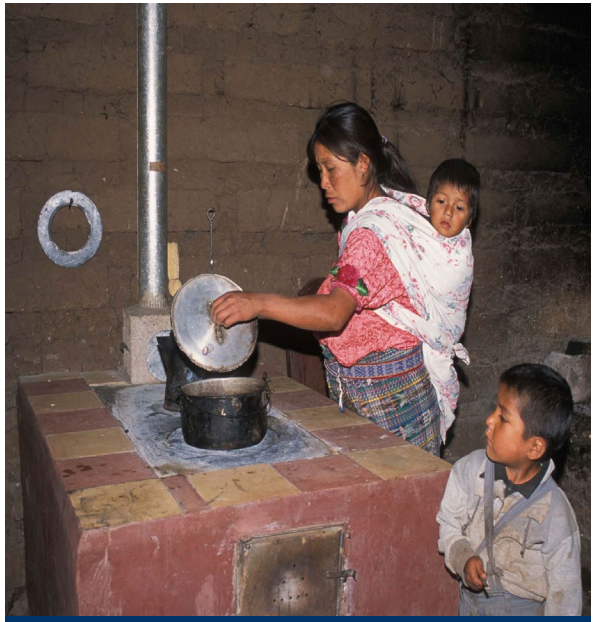
Air pollution contributed to nearly 7 million global premature deaths in 2019

Most of these deaths occur in low and middle-income countries

Health Effects Institute. *State of Global Air.* https://www.stateofglobalair.org/ (2020).

Motivation for study

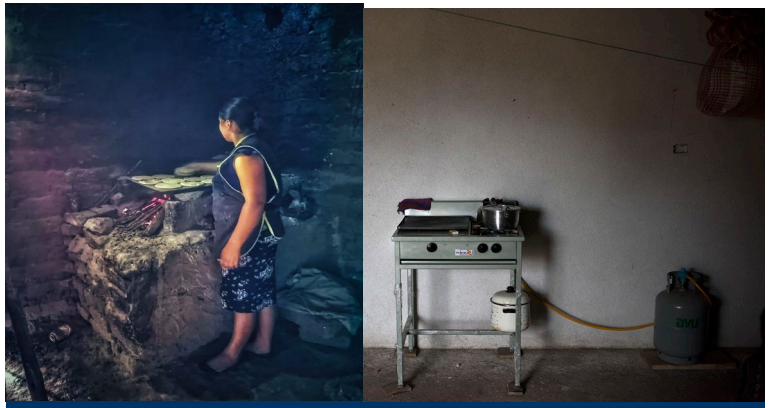
- 71% of Guatemalan households burn waste as the primary means of disposal *(Guatemalan Ministry of Health census, 2018)*
- While clean cookstove programs have focused on the health consequences of HAP, programs that address waste burning, specifically the burning of plastics, are absent



RESPIRE trial (2002-2005)

Chimney stove intervention

Kirk R. Smith (PI)



HAPIN trial (2018-2021)

Gas stove intervention

Clasen; Peel; Checkley (MPIs)

Figure 1 Plastic trash in outside fire (left) and inside kitchen stove (right)

Photo credits: Nigel Bruce; Josh Rosenthal

PLASTIC

2 billion people lack solid waste collection services

Some studies done on pollutants released from open burning of mixed solid waste

Lack of studies on hazardous pollutants specific to plastic burning in household fires (indoor and outdoor)


Rural Dump, Jalapa

Why is this an equity problem?

- Plastic is derived from petrochemicals; production of single use plastic is growing exponentially
- Plastic waste is a global problem, but problem varies locally based on appropriate waste management
- Marine litter comes from land litter (if it is not burned)
- When burned, plastic produces many atmospheric pollutants, including greenhouse gases, black carbon, reactive trace gases, particulate matter, and toxic compounds, such as polycholorinated and polybrominated dioxins and furans
- Rural and urban poor experience the burden of this problem. In Guatemala, many of these rural communities are indigenous and have been marginalized and discriminated against for centuries.

Wood and plastic fuel indoor cookstove

Study Overview

ECOLECTIVOS
CONTRA CONTAMINACIÓN POR PLÁSTICOS

Evaluate implementation strategies to reduce household-level plastic burning in rural Guatemalan indigenous communities.

- Advance the adoption, implementation, and sustainability of community-driven actions in intervention villages
- Develop an approach for policy-relevant solutions that combine evidence from effective implementation strategies, exposure assessment, and atmospheric emissions.
- Address environmental and health equity

1R01ES032009-01A1 (NIEHS: Thompson/Saikawa MPIs)

NIEHS Strategic Plan – Theme Two
Promoting Translation – Data to Knowledge to Action)

- "Develop, test, and validate evidence-based prevention and intervention strategies to reduce or avoid exposures and their resulting health impacts"

"Implementation science is focused on the "HOW" question: how can we move interventions, practices, and policies into real-world settings like health care systems, schools…and communities impacted by environmental exposures?"

NIEHS: Implementation Science in Environmental Health:
https://www.niehs.nih.gov/research/supported/translational/implementation/index.cfm

What is Dissemination & Implementation Science?

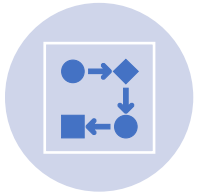
- Efficacy research focuses on *if* an intervention works under ideal conditions.
- Effectiveness research focuses on *whether* an intervention works under real world conditions.
- Dissemination and implementation science (DIS) focuses on *how* an intervention works in a real-world setting
- Definitions:
  - **Dissemination Research:** the *scientific study* of the targeted distribution of information and intervention materials
  - **Implementation Research:** the *scientific study* of the use of strategies to adopt and integrate evidence-based health interventions
  - **Implementation Science:** the *scientific study* of methods to promote the uptake of research findings into routine practice
- DIS is an essential step along the pathway of translating research into practice

DIS Research Questions

- DIS questions assess factors influencing implementation of evidence-based practices
  - *Context* is critical
  - Focus on *implementation outcome*

- Example of DIS questions:
  1. What are the *barriers* and *facilitators* to effective implementation of the evidence-based practice or intervention?
  2. How can an effective evidence-based practice or intervention be *scaled up* to a larger population?
  3. What are effective strategies to *de-implement* ineffective or harmful practices?

Implementation Science in one slide



The intervention/ practice/innovation is THE THING

Effectiveness research looks at whether THE THING works

Implementation research looks at how best to help people DO THE THING

Implementation strategies are the stuff we do to try to help people DO THE THING

Main implementation outcomes are HOW MUCH (extent) and HOW WELL (quality) they DO THE THING

Curran, G.M. Implementation science made too simple: a teaching tool. *Implement Sci Commun* **1,** 27 (2020). https://doi.org/10.1186/s43058-020-00001-z

A complex intervention in a low-resource settings: key ingredients

Theories, Models and Frameworks

Interdisciplinarity of team

Stakeholders/community engagement

Context “real world”– needs/resources assessment

Integrity/standardization of the intervention

Process evaluation/ supportive feedback mechanism

Hawe, P. (2004); Ramaswamy, R. (2018).

Theories, Models and Frameworks (Nilsen 2015)

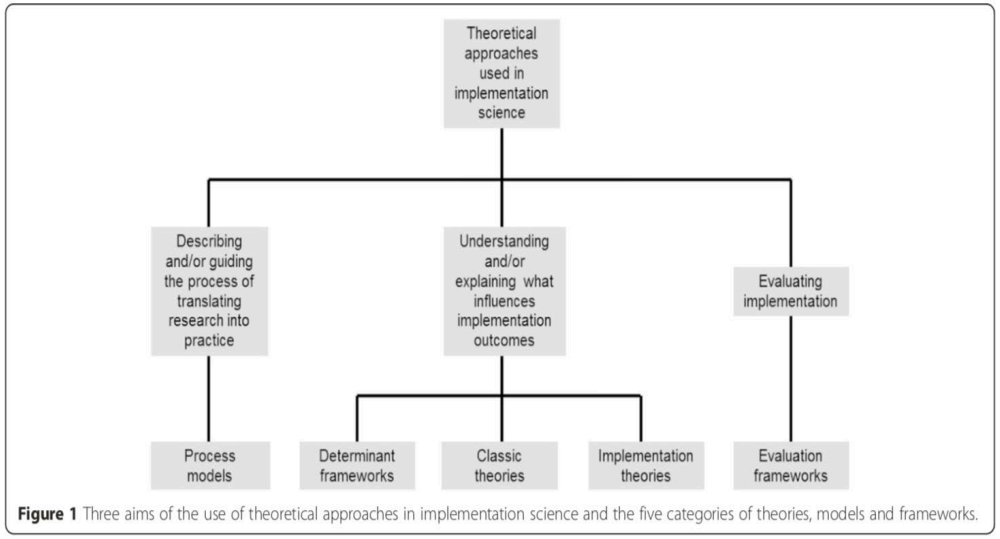


Figure 1 Three aims of the use of theoretical approaches in implementation science and the five categories of theories, models and frameworks.

- **Process Models**
  - Guide the implementation process (e.g., Exploration, Preparation, Implementation, Sustainment (EPIS) Framework https://episframework.com)

Determinant Frameworks

- Implementation outcomes are impacted by barriers and facilitators (e.g., Consolidated Framework for Implementation Research (CFIR) https://cfirguide.org/)

Evaluation Frameworks

- Help researchers frame implementation success (e.g., Reach, Effectiveness, Adoption, Implementation & Maintenance [RE-AIM] https://www.re-aim.org/)

Behavior occurs as an interaction between three conditions

The ability to enact the behavior

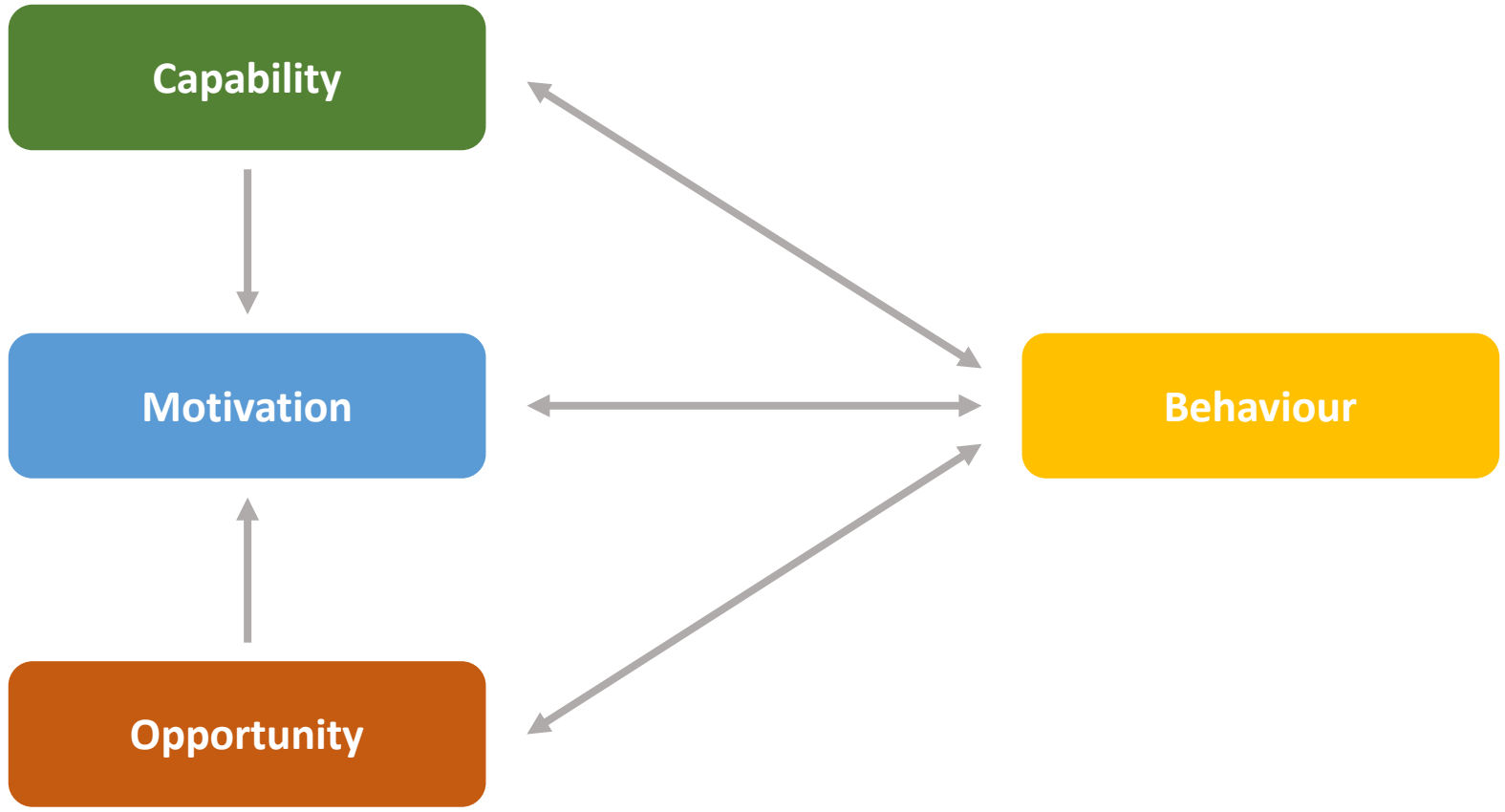
Can be psychological or physical

Mechanisms that activate or inhibit behavior

Can be reflective or automatic

Environment that enables behavior

Can be physical or social

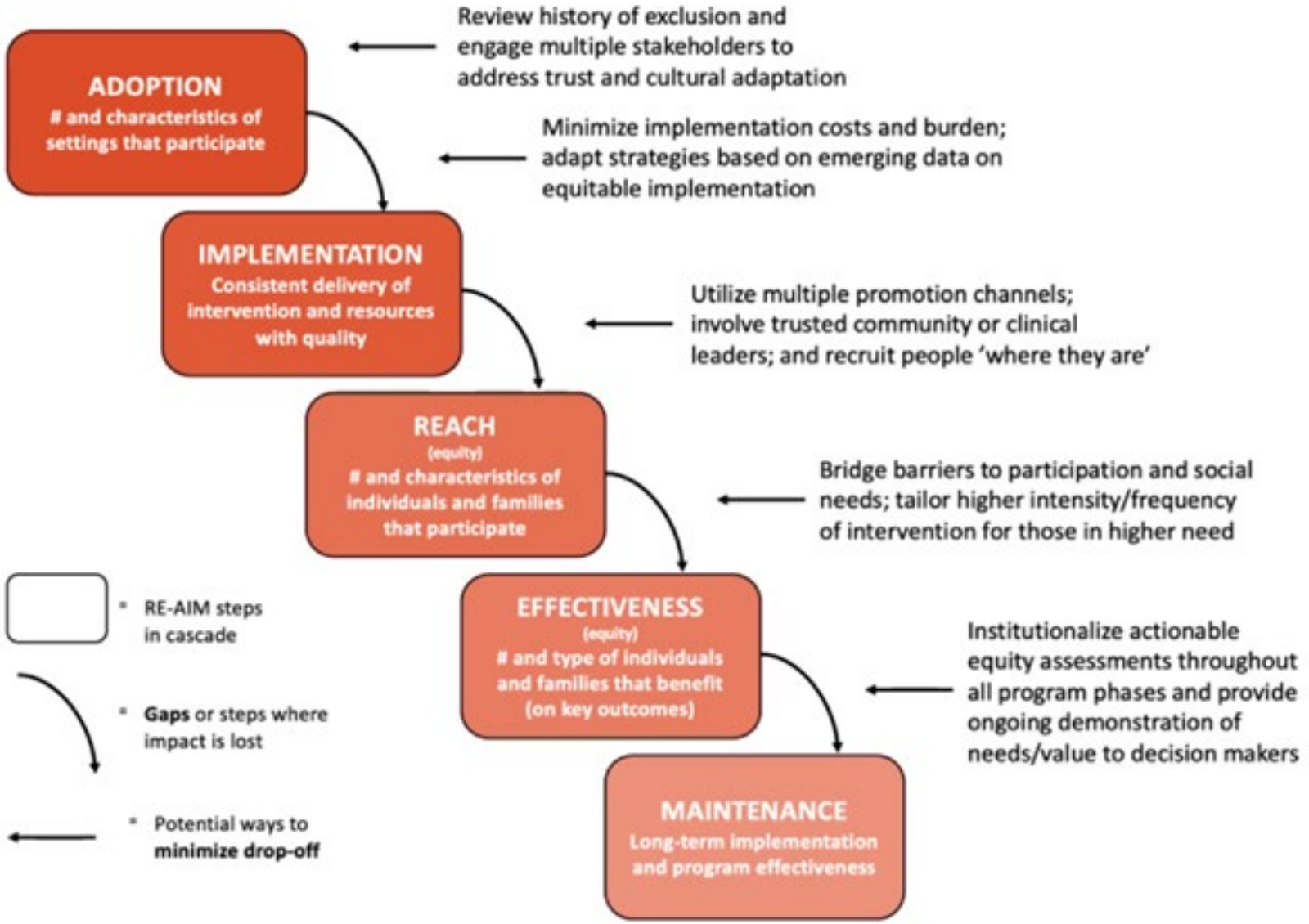


Michie, van Stralen, and West, “The Behaviour Change Wheel/COM-B model.”

COM-B	Theoretical Domains Framework
Physical capability	Physical skills
Psychological capability	Knowledge
	Cognitive and Interpersonal skills
	Memory, Attention and Decision processes
	Behavioural regulation
Reflective motivation	Professional/Social Role & Identity
	Beliefs about Capabilities
	Optimism
	Beliefs about Consequences
	Intentions
	Goals
Automatic motivation	Reinforcement
	Emotion
Physical opportunity	Environmental Context and Resources
Social opportunity	Social Influences

Atkins et al., "A Guide to Using the Theoretical Domains Framework of Behaviour Change to Investigate Implementation Problems."

RE-AIM

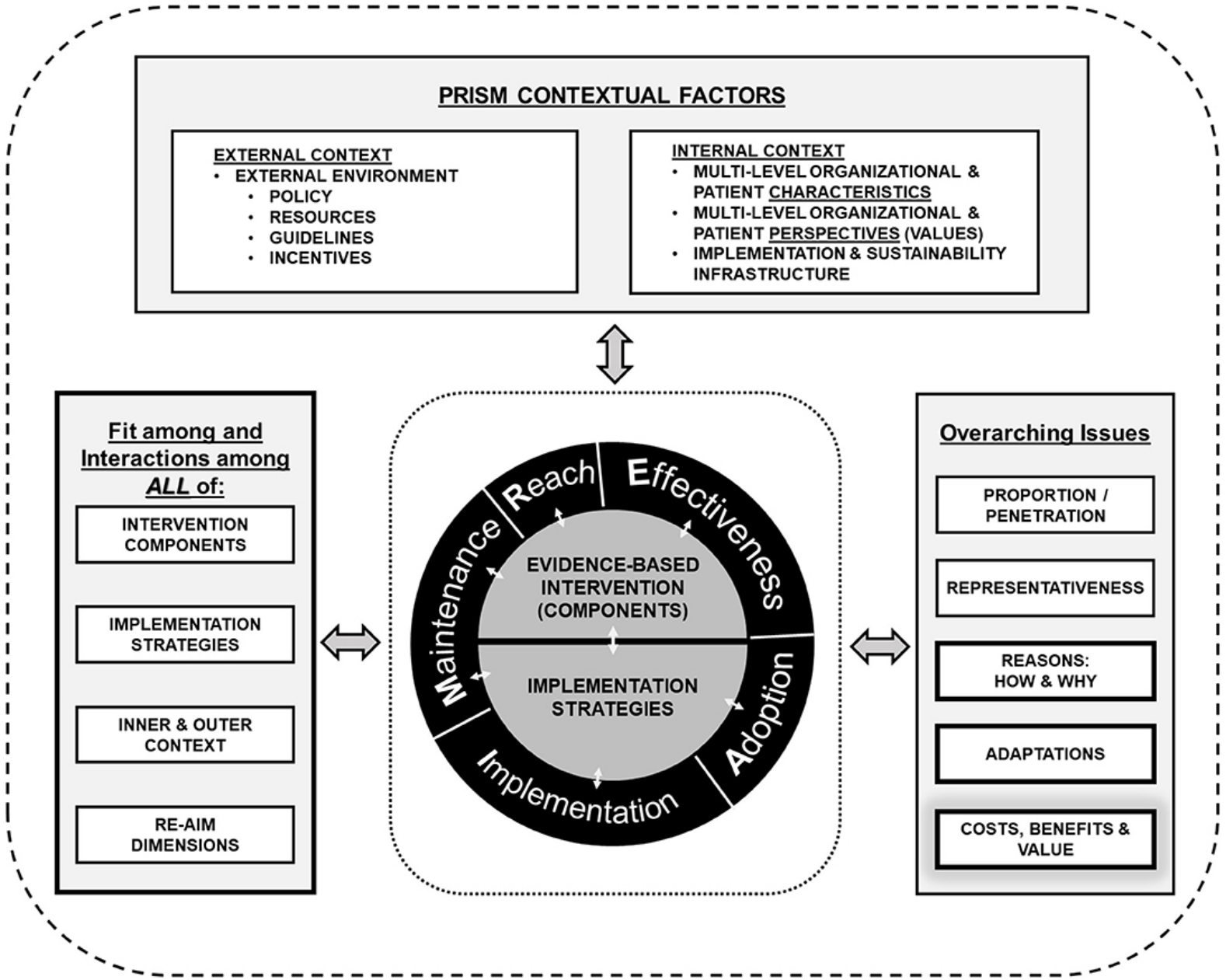


http://www.re-aim.org/

RE-AIM Model - Predominantly used to compare interventions

Dimension	Definition	Level
Reach	Absolute number, proportion, and representativeness of individuals who are willing to participate in a given initiative, intervention, or program, and reasons why or why not.	Individual
Effectiveness	Impact of intervention on important individual outcomes, including negative effects, and broader impact including quality of life and economic outcomes; variability across subgroups (generalizability or heterogeneity of effects)	Individual
Adoption	Absolute number, proportion, and representativeness of settings and intervention agents (people who deliver program) who are willing to initiate program, and why	Organization
Implementation	Intervention agents' fidelity to various elements of an intervention's key functions or components, including consistency of delivery as intended and the time and cost of the intervention. Importantly, it also includes adaptations made to interventions and implementation strategies.	Organization
Maintenance	Extent to which a program or policy becomes institutionalized or part of the routine organizational practices and policies.	Individual & Organization

http://www.re-aim.org/

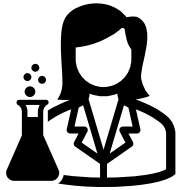


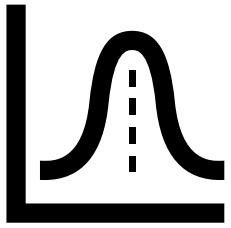
PRISM = Pragmatic Robust Implementation and Sustainability Model.
Feldstein & Glasgow (2008). *Joint Commission Journal on Quality & Patient Safety*, 34: 228-243.

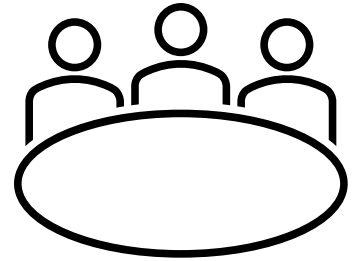
Glasgow et al, 2019

Interdisciplinary team:

implementation scientists, medical anthropologist, atmospheric chemist, environmental epidemiologist, biostatistician, analytic chemistry, air pollution technicians, laboratory technicians, information technology specialist, teachers, nurse(s) and a graphic designer







Formative phase (Year 1)

Formative phase

1. Pilot and refine essential elements of the dynamic working group curriculum (12 weeks) in one village as a practice run for the Main Trial
2. Randomize 8 intervention and 8 control sectors, launch main trial

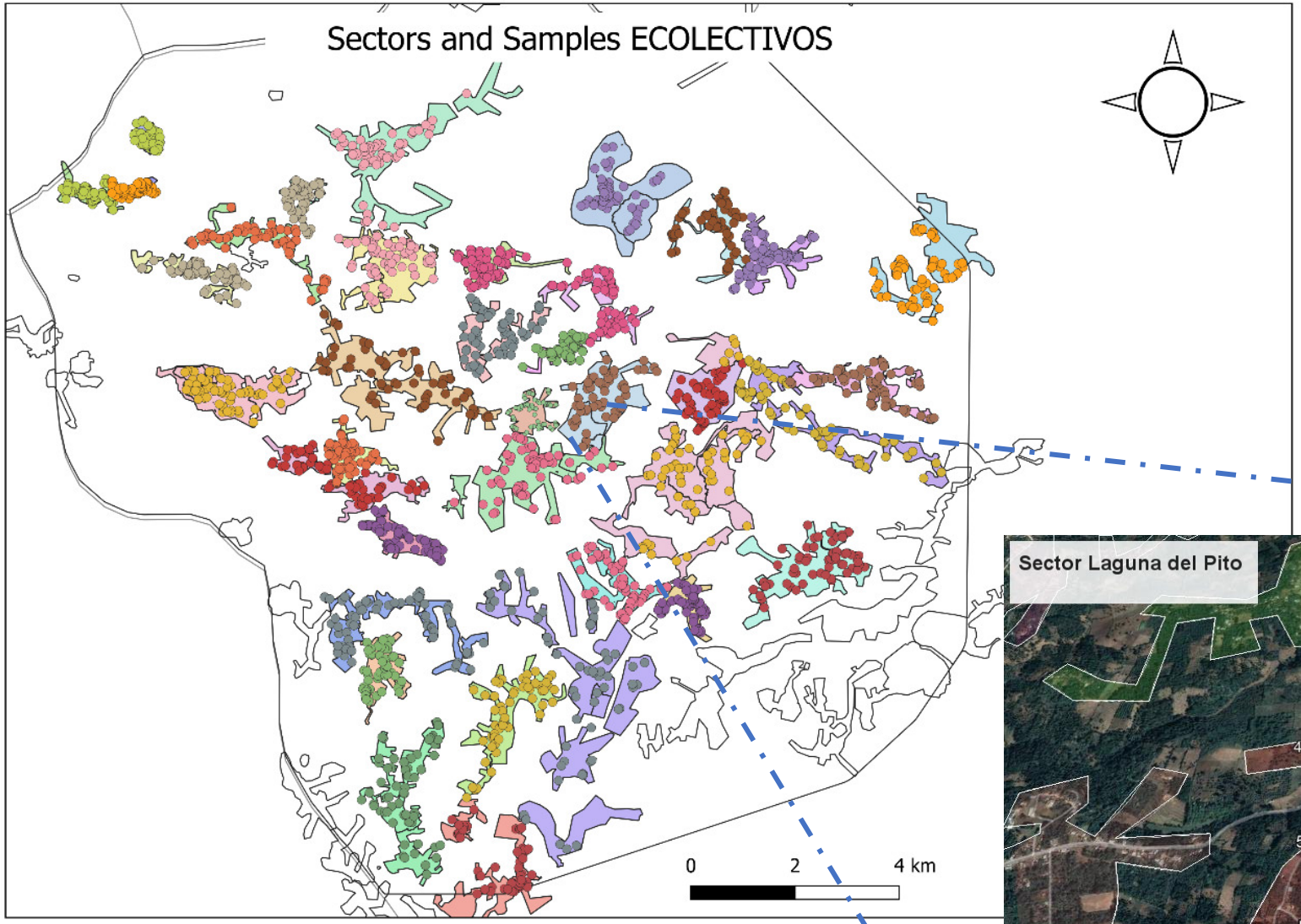
Community Engagement

- Permission from indigenous communities of Xalapam (COCODES, community coodinators)
- Present and work with regional and municipal officials and relevant ministries
- Form Community Advisory Board (CAB) with 15 members
- Village champions identified in each community (typically the COCODE)
- Field workers come from these communities

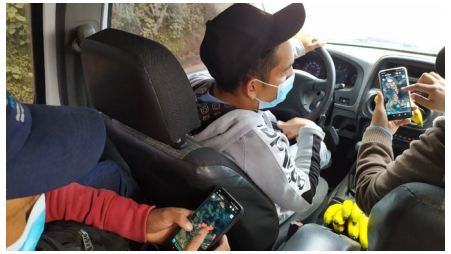
Context “real world”– needs/resources assessment

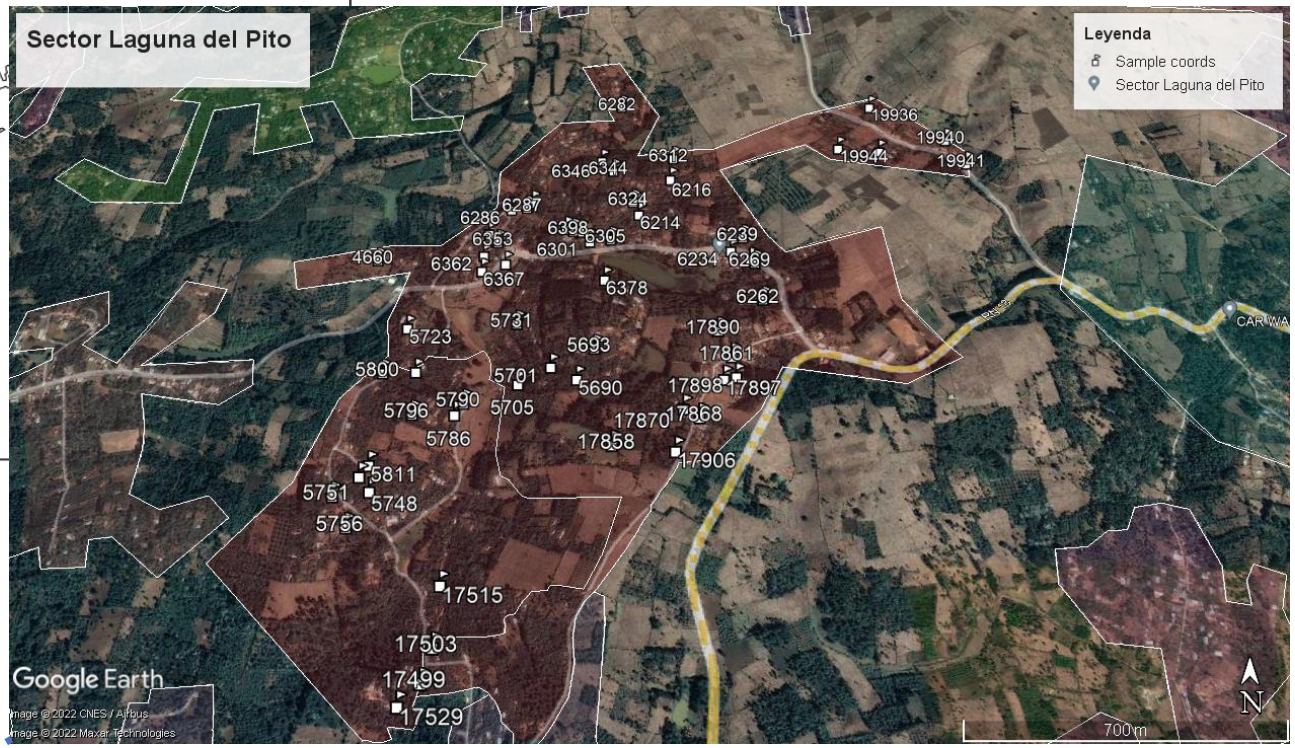
1. Baseline assessment of 1630 households in 37 Xalapam sectors in Jalapa, Guatemala
   - Simple random sampling of 60 households in each sector, oversample to achieve 44 households per sector
   - Assessment of demographics, household energy, waste management, and capabilities, opportunities and motivations to change behaviors that reduce plastic waste burning
   - Identify 400 women of reproductive age (25 from each village) who report burning plastic trash as a primary form of waste disposal at the rapid assessment


Gallo



Google satellite identification of structures using gpx viewer on cellphones to locate house coordinates from the last Guatemalan census (2018)





Integrity/standardization of the intervention

1. Refine dynamic working group curriculum
   - 10-20 participant observations on waste management practices, including people who burn plastic trash
   - 50 open-ended surveys focusing on feasibility and acceptability of capabilities, opportunities and motivations to reduce plastic waste burning
   - 10-20 key informant interviews with community stakeholders who recycle, dispose or repurpose plastic trash
2. Pilot and refine essential elements of the dynamic working group curriculum (12 weeks) in one village as a practice run for the Main Trial

MAIN TRIAL YEARS 2-4

Aim 1: Implement dynamic working groups In 8 intervention villages

75 persons in each village, n=600; Includes 200 women from Aim 2



8 intervention villages

Dynamic working group sessions (3 months) + 9 months maintenance visits

25 women in each village, n=200

8 control villages

25 women in each village, n=200

Hypothesis: Biomarkers and exposures to plastic burning will decrease in women in intervention villages compared to women in control villages between baseline, 4 and 12 months.

Aim 2: RCT ITT analysis (n=400)

PILOT IN FORMATIVE PHASE TO DEVELOP INTERVENTION USING COM-B

	Week	Theme	Components
ESSENTIAL ELEMENTS	1	Solid waste management problems	Plastic use and disposal; Alternatives to plastic burning, like recycling
	2	Plastic waste practice	Sources of contamination (air, land, food)
	3	Plastics in waterways and oceans	River-ocean flow of plastic; ban in Guatemala
	4	Exposure to burning plastic	Dangers of burning plastics in household fires
	5	Sustainable alternatives to plastic litter	Alternatives to avoid plastic litter
	6	Recycling plastic	Discuss recycling, sorting recyclable materials
	7	Reusing and repurposing plastic	Community clean-up/collecting recyclables Ideas and activities reusing/repurposing plastics
	8	Outline potential interventions	Brainstorming projects to reduce plastic burning.
CUSTOM	9-12	Dynamic group work selects community activities. CAB, stakeholders and external resources develop & support reduced plastic burning by reducing use, reusing or recycling.	
	12-52	Weekly meeting with village champion(s), project fieldworker(s) & stakeholders to support activities. Evaluate activities and address bottlenecks to success using **RE-AIM**.	

Do community working groups reduce plastic waste burning? Target capability, opportunity, and motivation domains for key behaviors guided by Michie's COM-B/TDF framework. Assess fidelity, reach and potential for scale-up guided by Glasgow's RE-AIM framework.

Aim 3: Model emissions from plastic burning on regional scale

Using filter-based tracers of plastic burning, estimate emissions of air pollutants from plastic incineration. Assess effects of potential emissions reduction on air quality using a chemical transport model.

Specific Aims (1)

Using dynamic working groups, implement and evaluate strategies that address household level plastic waste burning, targeting barriers and enablers identified within the capability, opportunity, and motivation domains, for key behaviors (guided by **Michie's Behavior Change Wheel** framework), focusing on assessment of implementation fidelity, reach and potential for scale-up (guided by **Glasgow's RE-AIM framework**).

Dynamic Working Groups, the “Thing”

Eight core modules – the “essential ingredients” and four periphery modules -- that we posit will reduce plastic waste burning – will be implemented.

PILOT IN FORMATIVE PHASE TO DEVELOP INTERVENTION USING COM-B

	Week	Theme	Components
ESSENTIAL INGREDIENTS FOR ALL VILLAGES	1	Solid waste management problems; sources of plastic contamination	Plastic use and disposal; alternatives to plastic burning, like recycling Activity: Groups discussion concerning waste management and plastic burning as a way of disposal
	2	Personal, family, and community practices on solid waste management, focus on plastics	Sources of contamination (air, land, food) Activity: Documentaries concerning plastic production, use and disposal/Groups discussions
	3	Plastics in waterways and oceans Plastics in the ocean, harmful effects on marine life, plastic islands, plastic ban in Guatemala	Activity: Workshop to repurpose plastic materials and fabrication of more environmentally friendly products to avoid plastic use
	4	Contaminants in burning plastic and health implications of exposure	Dangers of burning plastics in household fires Activity: Community compost
	5	Sustainable alternatives to plastic and reducing plastic litter in the community	Activity: community clean-up/collecting of non-recyclable plastics in the community and fabrication od products using these materials
	6	Recycling plastic	Discuss recycling Activity: sorting recyclable materials
	7	Reusing and repurposing plastic	Methods of reusing plastics Activity: Making of organic soaps to avoid products that come in plastic packages
	8	Wrap-up. Formation of groups to outline potential interventions	Group activity: brainstorming community projects to reduce plastic burning.
CUSTOMIZED	9-12	Dynamic group work to select intervention(s) for the community. Includes bringing in CAB, other stakeholders and external resources to develop and support community intervention(s) that reduce plastic burning by reducing use, reusing or recycling.	
	12-52	Weekly meeting with village champion(s), project fieldworker(s) and stakeholders to support activities that community chooses. Evaluate activities and address bottlenecks to success using **RE-AIM**.	

ECOLECTIVOS

CONTRA CONTAMINACIÓN POR PLÁSTICOS

Guía de apoyo para formación y capacitación
para el manejo adecuado de los desechos plásticos.

PLÁSTICOS:
Riesgos a la salud y problema ambiental

ACTIVIDAD DE REFLEXIÓN

- ¿Cuáles son las razones por las que hay mucha basura plástica en la comunidad?
- ¿Cómo ha ido cambiando el paisaje en la comunidad con la introducción de los plásticos?
- ¿Qué materiales plásticos consumen ahora que no consumían anteriormente?
- ¿Qué pueden hacer en sus hogares para lograr vivir en un ambiente libre de contaminación por plásticos?
- ¿Qué pueden hacer en su comunidad para lograr vivir en un medio ambiente libre de contaminación por plásticos?

Huella Ecológica

La huella ecológica es un indicador que se utiliza para medir el impacto ambiental que una persona, grupo o sociedad genera a través de la demanda de los recursos naturales existentes en todo el planeta, con relación a la capacidad que existe para que esos recursos se regeneren.

Aim 1: community working groups

Making natural botanical soap

Community composting

Aim 1: Community recyclers

Recyclers pay neighbors for materials received and sell materials to the central recycler

1. Meeting with recyclers

2. Training recyclers to buy materials

3. Sign hanging in store

4. Explaining recycling program to neighbors

5. Central recycler buying materials

Aim 1: Forestation and home composting (vermiculture)

Using RE-AIM Implementation Measures at each Plastic Risk Reduction Step

	Engagement with Risk Reduction Behaviors (Behavior Change Activities that Reduce Plastic) ***(Step 1)*** →	**Adaptation/Implementation** of Risk Reduction Behaviors ***(Step 2)*** →	**Maintenance/Sustainment** of Activities for either original or adapted Risk Reduction behaviors ***(Step 3)***
Reach *Who engages with behavior change activities?*	***Women:*** Number, proportion and type of women who come to working groups; #/range/types of behavior changes attempted within intervention group; intensity of change per behavior; assessed at weekly working group sessions ***Household:*** Number, proportion and type of household members engaged? ***Village:*** Who else in village engaged?	***Women:*** Number, proportion and type of women who made adaptations to behaviors they changed; level of change per behavior, assessed at 4 months ***Household:*** Number, proportion and type of household members who adapted behaviors? ***Village:*** Who else in village adapted behaviors?	***Women:*** Number, proportion and type of women who maintained any adaptation 1+ behavior; level of sustained activity per behavior, assessed at 12 months ***Household:*** Number, proportion and type of household members who maintained behaviors? ***Village:*** Who else in village maintained behaviors?
Effectiveness *Did the level of behavior (high/low) effect health outcomes?*	***Women:*** Total change across behaviors (effectiveness); What is the effect of the behavior changes on collective efficacy? General self efficacy? Health-related quality of life? urinary biomarkers of exposure (e.g., bisphenols, phthalates, polycyclic aromatic hydrocarbons, and volatile organic compounds)? Collect at baseline	***Women:*** Total change across behaviors (effectiveness); What is the effect of the behavior changes on collective efficacy? General self efficacy? Health-related quality of life? urinary biomarkers of exposure (e.g., bisphenols, phthalates, polycyclic aromatic hydrocarbons, and volatile organic compounds)? Compare baseline to 4 months	***Women:*** Total change across behaviors (effectiveness); What is the effect of the behavior changes on collective efficacy? General self efficacy? Health-related quality of life? urinary biomarkers of exposure (e.g., bisphenols, phthalates, polycyclic aromatic hydrocarbons, and volatile organic compounds)? Compare baseline to 12 months
Adoption* *Did participating household and village members complete behavior change activities?*	***For each participating household/village:*** level of change per behavior and range of behaviors within households and intervention village.	***For each participating household/village:*** range of behaviors that were adapted within households and intervention villages who engaged and at what level?	***For each participating household/village:*** range of behaviors that were maintained within households and intervention villages who engaged and at what level?

*Assess barriers/enablers to adoption and sustainment with original and/or adaptation of behavior changes

Specific Aims (2)

Compare urinary biomarkers of exposure to plastic combustion (bisphenols, phthalates, polycyclic aromatic hydrocarbons and volatile organic compounds) and personal airborne fine particulate matter (PM2.5) and black carbon (BC) in reproductive age women. ***Hypothesis:*** Biomarkers and exposures will decrease over time in 200 women from 8 intervention villages compared to 200 women from 8 control villages at 4 and 12 months.

Aim 2

Collected at baseline (before randomization, at 4 months and 12 months (n=400; 25 women per village)

Urinary biomarkers

- 8 PAH and 6 VOC analytes
- 9 phthalate and 2 bisphenol analytes

24-hours personal air pollution monitoring

- Particulate Matter ($PM_{2.5}$): PTFE and quartz filters
- Black carbon (SootScan)
- Metals/Elements: Subset of 600 37-mm PTFE filters (300 at baseline and 300 at 4 months; 150 each from intervention and control), including antimony (Sb)
- PAHs: Subset of 120 37-mm quartz filters (60 at baseline and 60 at 4 months; 30 each from intervention and control) analyzed to assess the composition and mass of TPB and 25 PAHs, as done in previous studies

Table 3. Target analytes and method specifications (ng/mL)	
Target Analyte	**Parent Toxicant**
Phthalates	
Mono-ethylphthalate	Diethylphthalate
Mono-n-butylphthalate	Benzylbutylphthalate; Dibutylphthalate
Mono-i-butylphthalate	Dibutylphthalate
Mono-benzylphthalate	Benzylbutylphthalate
Mono-2-ethylhexylphthalate	Di-2-ethylhexylphthalate
Mono (2-ethyl-5-oxohexyl) phthalate	Di-2-ethylhexylphthalate
Mono (2-ethyl-5-hydroxyhexyl) phthalate	Di-2-ethylhexylphthalate
Mono (2-ethyl-5-carboxypentyl) phthalate	Di-2-ethylhexylphthalate
Mono (2-carboxymethylhexyl) phthalate	Di-2-ethylhexylphthalate
BPX	
Bisphenol A	BPA
Bisphenol S	BPS
PAHs	
1-naphthol	Naphthalene
2-naphthol	Naphthalene
2/3-OH-fluorene	Fluorene
1-OH-phenanthrene	Phenanthrene
2-OH-phenanthrene	Phenanthrene
3-OH-phenanthrene	Phenanthrene
4-OH-phenanthrene	Phenanthrene
1-OH-pyrene	Pyrene
VOCs	
N-acetyl-S-(2-hydroxy) cysteine	Acrylonitrile; vinyl chloride; ethylene oxide
N-acetyl-S-(1-phenyl-2-hydroxy)-L-cysteine	Styrene
N-acetyl-S-(benzyl)-L-cysteine	Toluene
N-acetyl-S-(phenyl)-cysteine	Benzene
N-acetyl-S-(n-propyl)-L-cysteine	1-bromopropane
N-acetyl-S-(3-hydroxypropyl)-L-cysteine	Acrolein

Specific Aim (3)

Using filter-based antimony (Sb) and 1,3,5-Triphenylbenzene (TPB) as tracers of plastic burning and collecting household plastic waste, apportion PM2.5 and quantify emissions estimates of air pollutants from plastic incineration and assess effects of potential emissions reduction on air quality with a chemical transport model.

Aim 3

- For a subset of 120 women, apportion sources based on Sb and TPB concentrations on PTFE and quartz filters, respectively.
- Ask 400 women to collect plastic waste they would have burned over a 1-week period, at baseline and at 4 months.
- Measure change in plastic waste weight across two time points for households in the working groups, as well as differences between control and intervention households.
- Estimate kg/person/day of plastic waste, and adjust for household and socioeconomic indicators that may explain patterns of plastic waste.
- Estimate Emission Factors (EFs) for various chemical species from plastic burning, using the air pollution exposure data from Aim 2
- Forecast future emissions from plastic burning, creating four emissions (as usual—plastic ban) scenarios for year 2030.
- Use Weather Research and Forecasting (WRF) model coupled with Chemistry version 3.7.1 (WRF-Chem) to simulate the regional air quality over Guatemala and Central America to assess the impacts of different plastic emissions on air quality at the local and regional level.

Year 5 (Dissemination)

- Evaluate program
- Disseminate results to all participating communities, to regional and national policy makers
- Capacity building on issues related to household and ambient air pollution, as well as climate change

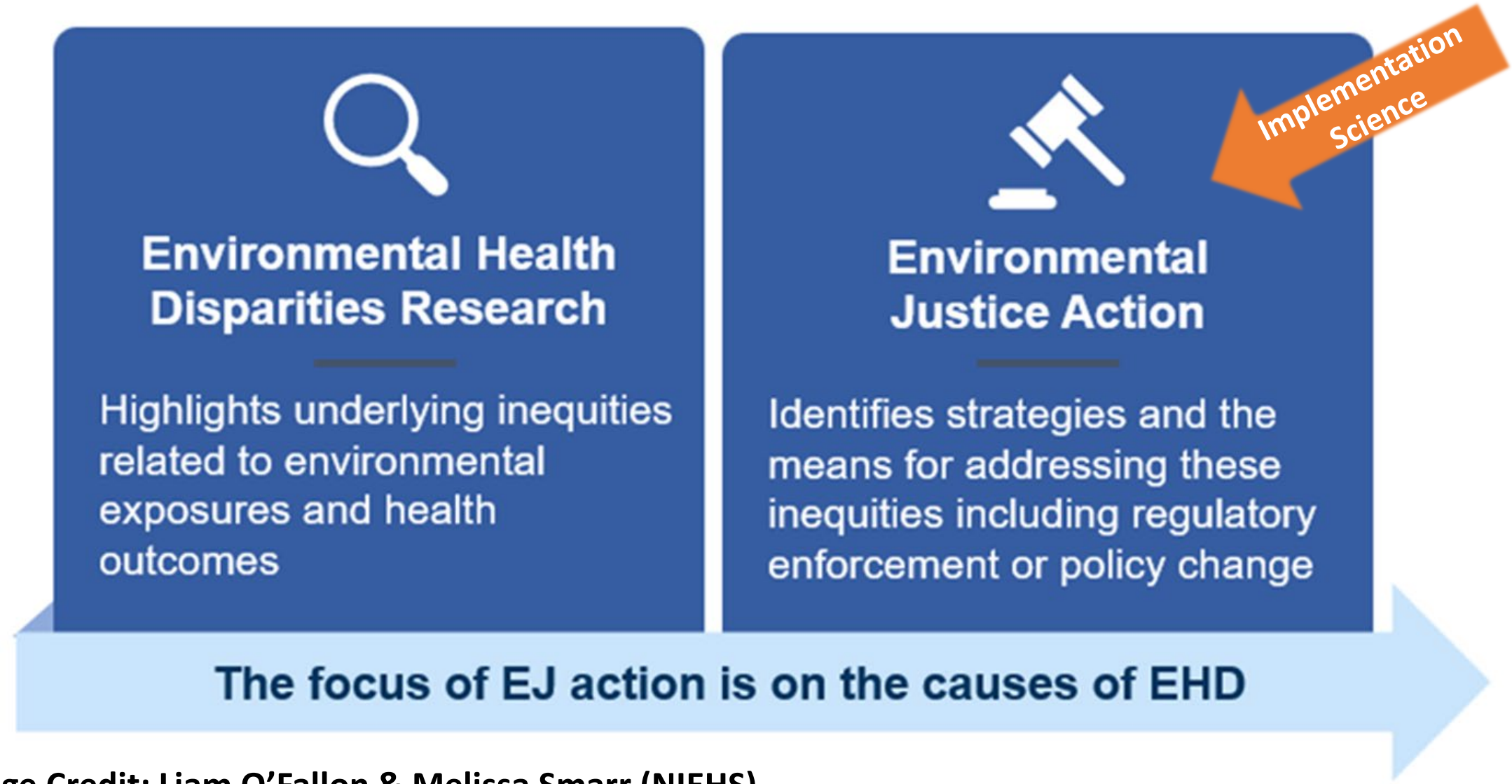


Image Credit: Liam O'Fallon & Melissa Smarr (NIEHS)

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1R01ES032009-01A1 (NIEHS: Thompson/Saikawa MPIs)

ClinicalTrials.gov NCT05130632

Our team

References

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