

## Synopsis

I am an applied environmental economist with a primary focus on the use of water and energy resources and its broader implications, for human societies and for the planet. My scholarly goal is to advance understanding of the drivers of resource management behavior, of the impacts of that behavior on a wide range of outcomes, and of the interventions or policies that can help mitigate harmful consequences and leverage development synergies. My work is interdisciplinary and action-oriented, and aims to create teams and networks of productive researchers working alongside practitioners and policy-makers, to better identify and tackle the practical challenges arising in the natural and social system “problemsheds”.<sup>1</sup> Moreover, this work is comparative and global, but most directly focused on settings in least-developed countries (LDCs) or low-income settings, given the connections between poverty and environmental degradation.

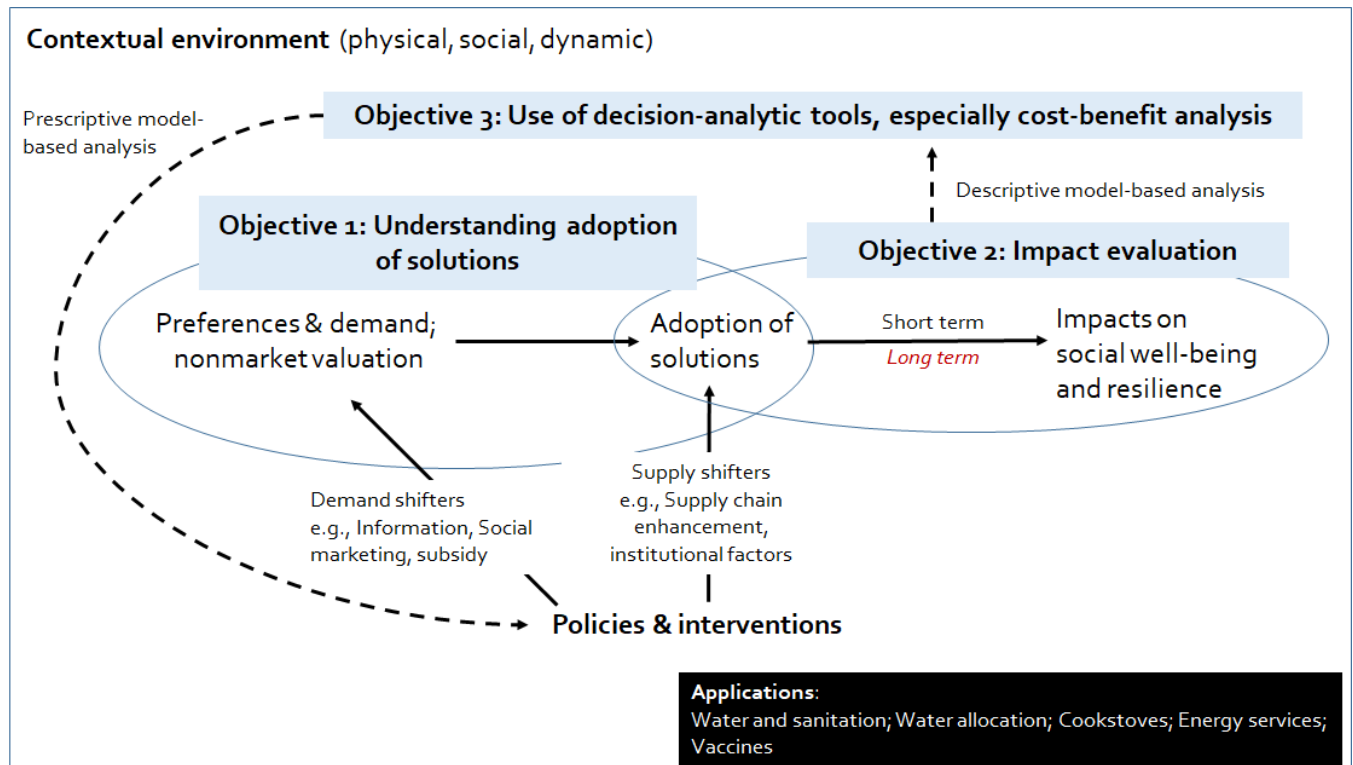
Nuanced analysis of the environmental and economic development problems facing the poor requires a perspective that accommodates a variety of methods and disciplinary traditions. My work embraces such pluralism, actively engaging with multiple fields including economics, public health, decision science, and civil and environmental engineering. In particular, I make wide use of micro-surveys to generate knowledge from the bottom-up, elucidating how perceptions of, and preferences for, environmental goods and services contribute to individual and household decisions, which may or may not advance social welfare. Impact evaluations leverage similar data to examine changes in those behaviors in the face of policy interventions, and to assess their relative contributions to individual and social well-being. My review work then aims to uncover consistencies in the patterns of such behaviors and impacts that extend beyond single and isolated study settings. Finally, model building (of both simulation and optimization types) endeavors to make predictions, informed by theory and empirical evidence, which apply to different geographies, populations, future conditions, and cover a wider range of hypothetical policies. My work spans individual-, household-, community-, and resource-level scales, and has remained consistent in its general orientation and objectives (Figure 1).

Over the past 5 years, even as a consistent framing and many prior interests have been maintained, the project that has most captured my attention has been at the interface of energy access and development. I co-lead an international group of scholars (called SETI<sup>2</sup>) that aims to foster a more sustainable global energy transition by a) creating a space for network-building and North-South collaboration; b) producing research that fills critical knowledge gaps; c) meeting to share knowledge on what works and d) establishing researcher and policy-maker interactions to enhance the relevance of such scholarship. As part of that work, I have led the Energy Access Project (EAP) that is specifically based at Duke in the Energy Initiative and is an integrated research-teaching-engagement program working to end global energy poverty. As part of my work with SETI and the EAP, I manage and work with teams in dozens of countries on a rich and stimulating array of research and policy questions.

<sup>1</sup> Kneese, A. 1968. “The ‘Problem Shed’ as a unit for environmental control.” *Archives of Environmental Health: An International Journal* 16(1): 124-127.

<sup>2</sup> In the first phase of this Sustainable Energy Transitions Initiative (SETI), I shared the leadership with Subhrendu Pattanayak, who first secured the funding to establish this group. I have led the transition to a new phase, where SETI is housed administratively in Chile at the Universidad de Concepcion, and where my co-lead is Marcela Jaime.

My publication strategy targets a wide variety of outlets (including general interest, public health, water policy, energy policy, and environmental economics journals). In my teaching and mentoring, my goal is to equip future practitioners and scholars with theoretical frameworks and tools that they can apply to solve complex problems and evaluate solutions, especially in the domain of environmental policy.



**Figure 1.** Schematic representation of my research interests and scholarly activities

**Notes:** Solid arrows denote the relationships that my work aims to elucidate; and dotted arrows denote model-based analyses I conduct.

### Detailed Research Statement

I organize the presentation of my research contributions around the three objectives described in my synopsis, and then discuss how these threads connect and offer opportunities for applied, policy-focused scholarship. In an addendum, I group my publications in a thematic CV (rather than the conventional chronological ordering), since this presentation may aid review of the key domains represented in my portfolio of work.

#### 1.1. Understanding adoption of environmental and health solutions

**The first major axis of my work focuses on better understanding preferences for, and adoption of, environmental goods and services.** As someone who is broadly interested in tackling challenging environment and development problems, I see better knowledge of individuals’ technology and behavioral adoption in this domain as a critical first step towards global sustainability and enhanced human well-being. My work aims to identify not just solutions to environmental management problems facing society, but also to better understand when and where these solutions do (or do not) work. The technologies and behaviors on which I

focus typically confer important private benefits, but also have other impacts that are not fully internalized, or sometimes have under-recognized costs.<sup>3</sup> As a result, adoption of such solutions tends to fall well below the social optimum, even in the face of rather severe risks, with critical implications for social welfare.

For example, technologies and behaviors that provide safe water and sanitation or that reduce solid fuel use and household air pollution have important environmental spillovers that reduce others' exposures to contamination and health damages, and that also help preserve healthy ecosystems. Households may even fail to fully account for their own private benefits, if decision makers do not fully bear costs, for example when women are responsible for domestic chores but have little say in purchasing decisions for labor-saving durable goods. Overall, my work has considered demand for a range of such technologies: vaccines, water quality, sanitation, air quality, and, most recently, an increasing set of energy services.

The study of technology adoption and behavior change is broad and multi-disciplinary; **my own work in this domain starts from an economic theory of boundedly-rational consumer behavior, while also engaging with other perspectives.** This leads me to heavily apply nonmarket valuation methods – both stated and revealed preference – as empirical tests of how different individuals see alternative solutions' relative pros and cons. In practice, such an approach accommodates deviations from fully rational decision-making because those "violations" of rationality are still reflected in real and survey responses to situations where agents can make choices (and researchers can observe them). One need only accept that there is some basis for the choices made, i.e., that they are not arbitrary. Psychological, socio-cultural, economic, and heuristic rationales can be reconciled, and my work engages with such aspects.

Much of my research is in context- and technology-specific applications and thereby endeavors to inform local decision-making, usually working collaboratively with local researchers and practitioners, as well as scholars from other disciplines. My collaborative philosophy – which can be seen in the large set of longstanding and productive research collaborations with both junior and senior scholars in my publication record – serves as a means of a) improving research relevance and nuance (are we even asking the right questions?); b) expanding the set of problems and locations studied with an eye towards what does and does not generalize; and c) building local researchers' (or their teams') capacities – see also overlapping comments on service. As a development scholar with views on service-oriented work that were molded by Peace Corps service and my own experience as a "privileged outsider", I am keenly aware that most of these collaborators begin from a much harder starting point, and that the most impactful work I can do is often to empower their research careers.

If I had to highlight what I see as my most notable contributions in this domain, I would emphasize several aspects. **First**, and perhaps surprising to social scientists who see this as obvious, **I am often the one in the room noting that heterogeneous preferences must be acknowledged.** Thus, silver bullet solutions are exceedingly rare, especially where private and social net benefits diverge. An empirical test of the importance of this latter point can be found in my 2020 paper in JAERE, where I show that some individuals' low valuations for improved cooking technology, measured *ex ante* of a multi-pronged promotion intervention that relaxed numerous adoption constraints, inhibit adoption even under heavy subsidies, or that individuals from similar villages and cultural contexts may nonetheless may prefer very different solutions. Such preference

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<sup>3</sup> For example, taste problems associated with higher quality drinking water, as explored in B.64 on my CV.

heterogeneity challenges effective government action in many domains, and governments or implementers simply multiplying choices may not help. This provides a motivation for trying instead to foster supply chains and markets that more naturally evolve to accommodate varying and dynamic demands, and then intervening to make those markets work better (which some of my work described under theme 2 attempts to inform).

**Second, much of my work aims to better characterize that very preference heterogeneity and to understand its implications for adoption behavior.** I do not wish to oversell this contribution; such characterization is largely correlational, and many aspects will remain unexplained or are unstable over time (and therefore subject to change). Typical determinants, explored in my and others' work, include higher wealth, education, demographic factors that influence risks, time preferences, and risk aversion. Nonetheless, I have spent considerable effort trying to better understand – leveraging survey methods and information experiments – how hard to measure perceptions, e.g., of water quality, might inform demand for improved technology, e.g., for water treatment. The idea behind the experimental methods I deployed in that study example was to use exogenous information to shift perceptions and examine impacts on purchases of chemical treatment technology.

**Third, some of my work is methodological and considers the reliability of nonmarket valuation methods,** engaging in comparisons of different methods (examining so-called *convergent validity*), or using split-sample experiments designed around testable hypotheses (e.g., assessing the idea that willingness to pay (WTP) will be inferior to willingness to accept (WTA), owing to income effects as well as asymmetries in individuals' weighting of gains vs. losses) with Joe Cook and others, I have similarly tested whether allowing respondents' time to reflect on a valuation scenario affects estimates of demand; we show that "time to think" decreases both the magnitude and uncertainty of stated WTP.

### 1.2. *Evaluating interventions to improve environmental quality and resource management*

**The second major axis of my work, closely related to the study of preferences and demand, is on evaluating interventions and policies aiming at enhanced environmental sustainability and social welfare.** Such interventions may act on individuals' knowledge (or perceptions) of the benefits of environmental and health technologies and behaviors; or on b) suppliers ability to provide these reliably and at affordable prices. The evaluations then focus on rigorous measurement of impacts relative to a non-intervention counterfactual, accounting for the often complex causal chain linking cause and effect in the environmental domain. Importantly, and in contrast to much work in development and public health, I also feel that these evaluations must also be guided by a lens that ensures the measurement of policy relevant quantities or parameters. That is, they must provide the inputs needed for policy analysis that speaks to whether the interventions are worthwhile (the subject of my third research aim, described in Section 1.3). Here I am particularly critical of research that aims to ever more precisely measure specific effect sizes (like the effect of water treatment on diarrheal disease prevalence in young children), without understanding why those effects are meaningful. Such useful research requires multi-disciplinary teams, because a variety of skills and perspectives are required.

Interventions on the demand side. **Besides characterizing preferences and the demand for environmental technologies and services, my research has tested interventions aimed at stimulating adoption, in an effort to get nearer to a socially efficient level.** Theory suggests that an obvious way to raise private investments in environmental protection is to lower their cost to individuals; as such, my work has focused on relaxing or counteracting money, knowledge, and preference-related constraints. Across several specific

environmental domains, I have examined the effects of capital subsidies for community-level technology, and subsidies for acquisition, as well as use, of household-level equipment on both adoption of preventive behaviors. These findings collectively support a wide body of evidence that shows that demand for environmental and health technologies is highly price elastic, and that affordability and liquidity constraints also greatly inhibit their adoption by the global poor.

A second, common way of stimulating demand is to provide potential beneficiaries with information about environmental risks. The logic behind information interventions is that risks are uncertain and imperfectly unobservable, especially in low-income settings where multiple risks are present. **My experimental work** in this domain **shows that households in low-income settings respond to information about water contamination, by seeking out safer sources, or by purchasing and using chemical treatment to disinfect water, especially when such information is surprising.** Specifically, my colleagues and I find that initially optimistic households with contaminated water are much more likely to respond to information provision by purchasing and using the treatment products than are other types of households.

Interventions on the supply side. This focus on demand-stimulating interventions is also completed by consideration of the supply side, again with quasi-experiments or experiments as well as econometric analysis. **Given the potential importance of supply issues where there are thin markets for preventive goods, I have worked on supply aspects of interventions as well.** Because rigorous evaluation designs are more difficult in this domain relative to demand-side studies, I am particularly proud of this strand of my work. It examines aspects such as a) the role of different forms of post-construction technical assistance (e.g., provision of spare parts, training of mechanics, regular visits to monitor infrastructure function) in enhancing the sustainability and performance of rural water supply interventions, b) the value of trusted community implementers in promoting new energy technologies, and c) the need for cash grants to small entrepreneurs in a context of building from small, information-poor, and risky rural markets (the latter is work in progress). Moreover, this work also brings mixed methods and modeling methods to bear in order to better incorporate features of the supply and demand context. Indeed, the most critical limiting factors to scale-up sometimes cannot always be easily assessed using experimental methods, and call for a more pluralistic approach to research.

Downstream impacts. In addition to effects on supply and demand, my work also examines downstream impacts on outcomes emerging from the adoption of improved technology and behaviors that contribute to welfare (health benefits, time savings, resource use, etc.), using **experimental, quasi-experimental, econometric methods, and systematic reviews.** Thus, I examine the conditions under which interventions can be effective, and how behavioral adjustments sometimes reduce or negate anticipated impacts via predictable compensating mechanisms and feedbacks. Such adjustments include insufficient use to achieve health improvements, substitution away from other modes of self-protection, so-called rebound effects, and negative complementarities with other technologies and behaviors. All in all, these add to the complexity of the causal chain that links environmental interventions to impacts.

### *1.3. Applying decision-analytic tools and models to understand environmental problems and guide policy making*

**The third major axis of my work is development and application of decision-analytic tools to aid environmental and development decision-making.** In this domain, I aim to capitalize and synthesize across findings from my own research on drivers and impacts, as well as others', to conduct economic and other

analyses that are useful for policy making. This serves to close the loop in my portfolio and helps me to identify and address critical knowledge gaps. Some of this work tends towards the descriptive and is conducted with the primary purpose of elucidating how key complexities can affect behaviors and outcomes within socio-environmental systems. Moreover, I have used such models to illustrate the implications of heterogeneity for downstream outcomes, offering a counterweight to research that aims to obtain ever more internal validity and precision, at the expense of engaging with generalizability. Other model-based analyses have a more normative bent that focus on the divergence between the private and social benefits of interventions, and on the social efficiency or equity implications of policies that aim to produce enhance social welfare. Below I describe the three main categories of such analyses in my work.

Analyses of the economics of transboundary water resource management. This is an old strand of my work dating back to my dissertation that remains active in my current agenda, especially where it intersects with my energy and climate adaptation thrust. As a doctoral scholar and assistant professor, I **developed simulation and optimization-based methods for analyzing the economics of infrastructure investment and changes in water management in transboundary water systems.** My most significant contributions in the domain of hydro-economics were in **simulating the outcomes of coupled hydrological and economic systems**, in a context of deep climate change and development uncertainties. I developed frameworks for characterizing and guiding decision making in the face of such uncertainties, as demonstrated in two publications in the leading water journal *Water Resources Research*. This work highlights the shadow value of the water-related benefits generated by infrastructure, which increase with scarcity and climate change, and illustrates well my ability to meaningfully engage with methods and theories from economics, hydrology and water resources engineering. It also generated new insights that I believe are important for influencing negotiations over, and relations related to, shared water resources, particularly in the Nile Basin, and has elevated me to being a consistent contributor in high profile work on Nile hydropolitics (B.22). Without use of a systems modeling framework that accommodates the dynamics of socio-hydrological systems and the strategic interactions of riparians, it is easy to miss crucial interdependencies and impediments to progress.

Cost-benefit analysis of environmental health interventions. A related set of decision tools that I have developed are for **cost-benefit analysis of environmental health interventions**, work which connects and intersects with the first and second major themes in my research. I have made two primary contributions in this domain. First, I have **developed and used simulation methods to demonstrate the tremendous variability in ex ante benefit-cost predictions about such interventions in typically targeted (low-income) locations.** As I show in this work, much of the variability in the distributions of costs and benefits arises from real-world spatial and dynamic heterogeneity in benefits as well as costs, which calls for treating external validity as a central policy issue. In addition, selection of effective intervention strategies typically requires sensitivity to local context, and should allow for feedback that incorporates local knowledge that technocrats and decision-makers will usually lack. In a recent commentary and analysis with colleagues, we discuss this in the context of sanitation RCTs, which expended tremendous effort to measure health effects precisely without considering ways to characterize variation across contexts, and developing designs that would shed light on the phenomena underlying that heterogeneity.

Second, I have sought to push decision-makers away from a single-minded focus on narrow outcome metrics (most typically health outcomes measures) as an indicator of the success of an intervention. In several papers

and in developing new decision tools (e.g., the BAR-HAP model for the World Health Organization), I and co-authors have argued that a policy dialogue grounded in welfare-theoretic principles and employing several complementary metrics is essential, specifically: a) social net benefits (an efficiency metric), b) private net benefits to adopters (a behavioral metric), and c) public financing burden (a feasibility metric given budget constraints). This work especially warns against partial accounting. For example, many researchers compare water and sanitation interventions with oral rehydration therapy on the basis of cost per illness avoided, which ignores the fact that many water and sanitation interventions affect time allocation, dignity and privacy, and even offer fundamentally different health benefits (e.g., the avoided pain and suffering and fear of getting ill, that treatment alone cannot remove). Somewhat differently, spillover benefits must be considered carefully in policy analysis.

#### 1.4. *Synthesis and future directions*

Figure 1 in my synopsis provides a schematic perspective on how these research threads fit together. As noted above, my thinking about problems of water resources, energy, and environmental health is grounded in environmental economics theory; I seek to understand and guide policy-making how to manage environmental resources and quality. **My research is heavily influenced by perspectives other than environmental economics, however, relying on extensive, pluralistic, and trusting collaborations.** My own training in environmental engineering, systems analysis, economics, and public health and participation in teams with medical and public health experts, natural scientists, other social scientists, as well as policy makers and implementing organizations, do not cease to provide opportunities for new insights. In brief, multi-disciplinary collaborations enrich my work and allow me to produce better, more nuanced and informative policy analyses. Even more importantly, my work in the Global South would be nothing without contributions from researchers and policy-makers there.

**Looking to the future, I will continue to strengthen my research agenda on the aforementioned themes, applying the conceptual models, tools and methodologies discussed above to a wider array of empirical environment, health, and development problems.** At the same time, **my scholarly goals are increasingly tending towards working to empower other researchers, especially junior scholars and those based in less-advantaged institutions and countries.** In the past 3-4 years, as I have taken the reins of the Energy Access Project (EAP) research program at Duke and served as thought leader for the Sustainable Energy Transitions Initiative, I have become ever more passionate, though not always fully successful, in my attempts to create equitable collaborations with others. I also see this as the linchpin for magnifying my own impact. I owe much to my colleagues, who never cease to open my eyes to problems and challenges that are worthy of attention.

There are a few new directions in my portfolio that I feel are worth highlighting briefly here. Most emerge out of my current role in the EAP. The first concerns the nexus of energy and gender; one of our EAP workstreams is focused on equitable and sustainable energy transitions for the Global South, and emphasizes gendered dimensions as a key aspect of that. Working with a team of researchers, we have reviewed theoretical frameworks and empirical evidence on the bidirectional relationship between access to modern energy and women's empowerment (C.4), and identified a rich set of research questions on which empirical work is needed. One set of questions around which I am leading fieldwork concern the time savings conferred by adoption of clean energy technology, how that time is reallocated across productive and welfare-enhancing activities, and implications for what that tells us about the shadow value of time in contexts with variable wage-

earning opportunities (e.g., subsistence agriculture, casual labor, or complementary productive use interventions).

A second area of burgeoning interest relates to this first domain but extends over a broader set of climate adaptation benefits. Rural households in low- and middle-income countries (LMICs) working in the agriculture sector feed much of the world, bear little responsibility for climate change, and yet are coping with major and increasing risks from climate-related shocks. In much of the developing world, smallholder farmers, who produce 80% of food and who are responsible for 40% of all jobs, are highly exposed to these challenges, especially given entrenched rural poverty and vulnerability. Climate finance represents a critical opportunity to bring a range of innovations to agricultural settings, improve resilience, and drive new and more inclusive low-carbon development, but agriculture value chains for smallholders and the financing institutions serving them currently account for a paltry amount—just 0.2%—of the roughly \$600 billion in annual climate-related financing globally. Our team at EAP hypothesizes that this is partly due to measurement challenges; we are now working with researchers, donors, and climate investors to try to develop new and rigorous techniques to fill this gap. This work also offers opportunities for considering **household demand for a set of energy services that enhance household productivity and livelihoods**, which my team's work is spotlighting.