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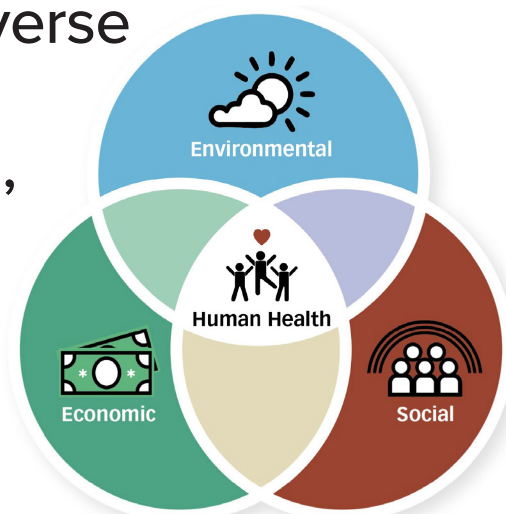
Roadmap to Health: Assessing Adverse and Beneficial Environmental, Social, and Economic Cumulative Exposures



HEI Special Panel on Cumulative Impact Assessment

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Roadmap to Health: Assessing Adverse and Beneficial Environmental, Social, and Economic Cumulative Exposures

HEI Special Panel on Cumulative Impact Assessment

Special Report 2

Health Effects Institute

Boston, Massachusetts

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ABOUT HEI ENERGY

The Health Effects Institute's Energy Research program (HEI Energy) was formed to identify and conduct high-priority research on potential population exposures and health effects from the development of oil and natural gas in the United States. Since 2022, HEI Energy has supported population-level exposure research in multiple oil and gas regions. This research followed an extensive planning process that included preparing reviews of the scientific literature, hosting multisector workshops to learn about research priorities, and developing an online curated database and spatial bibliography to advance both public and scientific understanding. The research scope of HEI Energy is expanding beyond oil and gas to other forms of energy development, with an overarching goal of providing impartial knowledge about the benefits and drawbacks associated with various technologies.

The scientific review and research provided by HEI Energy contribute high-quality and credible science to the public debate about unconventional oil and natural gas development and provide needed support for decisions about how best to protect public health. To achieve this goal, HEI Energy has put into place a governance structure that mirrors the one successfully employed for nearly 40 years by its parent organization, the Health Effects Institute (HEI), with several critical features:

- Balanced funding from the US Environmental Protection Agency under a contract that funds HEI Energy exclusively and from the oil and natural gas industry, with other public and private organizations periodically providing support
- An independent Board of Directors consisting of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization
- A research program governed independently by individuals having no direct ties to or interests in sponsor organizations
- An HEI Energy Research Committee, consisting of internationally recognized experts in one or more subject areas relevant to the Committee's work, that has demonstrated the ability to conduct and review scientific research impartially and has been vetted to avoid conflicts of interest
- Research that undergoes rigorous peer review by HEI Energy's Review Committee, which is not involved in the selection and oversight of HEI Energy studies
- Staff and committees that participate in open and extensive stakeholder engagement before, during, and after research and communicate all results in the context of other relevant research.

In addition, HEI Energy publicly shares all literature reviews and original research that it funds, along with summaries written for a general audience. Without advocating policy positions, it provides impartial science targeted to make better-informed decisions.

HEI Energy is funded separately from the Health Effects Institute's other research programs (*www.healtheffects.org*), with financial support from the US Environmental Protection Agency, the oil and gas industry, and private foundations.

CONTRIBUTORS

In 2023, HEI Energy appointed the Special Panel on Cumulative Impact Assessment to inform the set of considerations for assessing cumulative exposures outlined in this roadmap. The Special Panel included individuals with expertise and experience in environmental health, epidemiology, sociology, strategic planning, leadership, communication, and community organizing, and was chaired by Julia Haggerty at Montana State University.

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EXECUTIVE SUMMARY

The health of people living in any community can be affected by a range of environmental, social, and economic factors. The purpose of this roadmap is to build on and contribute to ongoing efforts to advance the practice of assessing cumulative exposures and their impacts in the United States using a tool referred to as cumulative impact assessment. Cumulative impact assessments have and continue to occur in the context of national, state, and local regulatory decisions, but they can also be used for nonregulatory, educational, and research purposes.

To date, cumulative impact assessments fall short of addressing the totality of impacts in a truly cumulative way, at least in part because of the complexity of such assessments. Nonetheless, cumulative impact assessments, designed such that they can be completed in a useful time frame, can help to reframe scientific and policy discussions so that they encompass the full spectrum of factors that can affect human health, and in so doing, position decision-makers to capitalize on beneficial impacts while avoiding adverse impacts. This roadmap and accompanying checklist aim to facilitate taking the first steps toward realizing this goal. They provide a set of considerations that can be used by local and state decision-makers, nonregulatory actors such as industry and planning agencies, and other scientific and technical researchers to inform a cumulative impact assessment, alongside example contexts for how these considerations might be applied in real-world settings.

Roadmap to Health: Assessing Adverse and Beneficial Environmental, Social, and Economic Cumulative Exposures

HEI Special Panel on Cumulative Impact Assessment

I. INTRODUCTION TO THE ROADMAP

A. PURPOSE OF THE ROADMAP

The health of people living in any community can be affected by an array of environmental, social, and economic factors. Numerous studies throughout the scientific literature document how exposures associated with one or even a few factors might affect human health. The same is not true for understanding how the integrated (or cumulative) exposure to all factors can affect health. The purpose of this roadmap and accompanying checklist (Appendix B) is to build on and contribute to ongoing efforts to advance the practice of assessing cumulative exposures and their impacts in the United States (using a tool referred to as cumulative impact assessment,[1] hereafter, CI assessment) by providing a set of considerations that can inform a CI assessment process, alongside example contexts for how these considerations might be applied in real-world communities. CI assessment processes are highly context-specific. As such, this roadmap is not intended to provide prescriptive guidance on the implementation of a CI assessment.

To date, CI assessments fall short of addressing the totality of impacts in a truly cumulative way, at least in part because of their complexity. Nonetheless, CI assessments designed such that they can be completed in a useful time frame can help to reframe scientific and policy discussions so that they encompass the full spectrum of factors that can affect human health, and in so doing, position decision-makers to capitalize on beneficial impacts while avoiding adverse ones. Leveraging what is already known from Health Effects Institute Energy (HEI Energy) through its currently funded research and what has been learned about the various types of impacts on communities over the past two decades, this document illustrates CI assessment concepts and potential methods using the context of any community affected by unconventional oil and gas development (UOGD)[2] in the United States. UOGD is used as the example context for the application of this set of considerations because the literature is relatively large on potential exposures and impacts that describe environmental, social, and economic factors. However, the considerations are meant to be broadly applicable to other environmental contexts in addition to those involving UOGD, such as the development of new infrastructure in a locality or other energy-related developments, such as power plants.

Although this Special Report was produced with partial funding by the United States Environmental Protection Agency under Contract No. 68HERC19D0010 to the Health Effects Institute, it has not been subjected to the Agency's peer and administrative review and may not reflect the views of the Agency; thus, no official endorsement by the Agency should be inferred. This report also has not been reviewed by private party institutions, including those that support HEI Energy, and may not reflect the views or policies of these parties; thus, no endorsement by them should be inferred.

B. INTENDED USERS OF THE ROADMAP

The roadmap is intended for use by anyone interested in using CI assessment to understand and assess how cumulative exposures to environmental, social, and economic factors can affect human health. The roadmap consists of a flexible set of considerations that can be adapted or applied in educational, research, regulatory, and other decision contexts, although they are primarily intended for application in the United States context. As such, they are likely to be most useful to local and state decision-makers, nonregulatory actors such as industry and planning agencies, and other scientific or technical researchers in the United States.

C. CUMULATIVE IMPACT ASSESSMENT PRACTICE TO DATE

Several approaches are available to assess cumulative exposures, including cumulative risk assessment, CI assessment, and cumulative effects assessment.[3] CI assessment and cumulative effects assessment are largely described interchangeably and have often been conducted within the framework of environmental impact assessment. Although a detailed review of these approaches is beyond the scope of this document, additional resources include Blakley and Franks 2021, Callahan and Sexton 2007, Gunn and Noble 2009, IAIA 1999, Rish et al. 2024, and US EPA 2003.

Assessments intended to assess cumulative impacts have primarily been conducted and initiated at local to regional scales under regulatory contexts — for example, for the National Environmental Policy Act (NEPA) and similar state rules. However, no widely accepted model exists for conducting CI assessments in other decision contexts (Rish et al. 2024; Verweil and Rish 2025). Several frameworks for CI assessment (e.g., US EPA 2024) and comprehensive reviews of frameworks and methods for CI assessment (e.g., Rish et al. 2024, Verweil and

Rish 2025) have been published. An observation made in these publications (e.g., US EPA 2022, 2024) is that the methods and approaches used in CI assessment depend on the decision context under which the CI assessment is being conducted. CI assessment has and can inform a variety of national, state, and local regulatory decisions about new or ongoing projects and development, and it can be used for nonregulatory, educational, and research purposes. See **Table 1** for a matrix of examples of decision contexts and other contexts in which CI assessment might take place (broadly, as well as within the context of UOGD). It should be noted that the majority of CI assessments are initiated as part of a regulatory decision-making process. In addition, the Tishman Environment and Design Center (2025) provides another resource that consists of a comprehensive evaluation of state policies that require assessment of cumulative impacts in permitting decisions.

In September 2024, HEI Energy released a research brief[4] that presented a scoping review of the peer-reviewed and gray literature that assesses or describes what is known about CI assessment, cumulative impacts of chemical and nonchemical stressors (i.e., exposures and effects associated with environmental, social, and economic factors), and methods for assessing the cumulative impacts experienced by populations affected by UOGD in the United States and Canada. The scoping review revealed a variety of analytical frameworks and decision contexts for conducting CI assessments and various methodologies primarily as practiced in the field of environmental impact assessment. Few studies specifically analyzed cumulative impacts in populations affected by UOGD. Moreover, there remain several questions related to both theoretical and methodological aspects of CI assessment. Challenges cited throughout the literature include a lack of widely accepted guidance and terminology, limitations in data availability and quality, the need to establish new methods and refine existing methods for combining quantitative and qualitative data, and the need for strengthening community engagement in CI assessment processes and implementation. More broadly, although CI assessment processes fall short of wholly assessing cumulative exposures, there are many efforts currently under way aiming to advance and improve this practice. These efforts represent an important step in moving toward more comprehensive assessments that address community concerns. To be useful, these CI assessments need clear temporal, spatial, and substantive scopes to ensure that they can be feasibly completed within the time frame required for decision-making.

D. DECISION CONTEXT FOR THE ROADMAP

This CI assessment roadmap can be adapted for various decision contexts. To illustrate the general steps that might be conducted within a CI assessment, the roadmap incorporates several example communities in US oil and gas regions where HEI Energy is funding research[5] (**Figure 1**). See **Box 1** for a brief description of the HEI Energy-funded study locations and communities that will be referenced throughout the roadmap.

E. THE SPECIAL PANEL'S APPROACH TO INFORM THIS ROADMAP

In 2024, HEI Energy formed a Special Panel on Cumulative Impact Assessment to inform the set of considerations for assessing cumulative exposures outlined in this roadmap. The

Table 1. Examples of Educational, Research, and Decision Contexts for CI Assessment

Context for CI Assessment	Examples
Educational contexts	• Raising awareness (Saha et al. 2024) • Educating community members and policymakers (Ellickson et al. 2024)
Research contexts	• Community-driven and other types of scientific research (Lam et al. 2022) • Theoretical framework formulation (Jones 2016)
Regulatory contexts	
Federal	• Cumulative effects analysis required under the National Environmental Protection Act (NEPA) (CEQ 1997)
State	• State-level environmental assessment mandates (e.g., California Environmental Quality Act (CEQA) (P.R.C. § 21000 et seq), Massachusetts Environmental Policy Act (MEPA) (M.G.L. Ch. 30, §§ 61-62L), Montana Environmental Policy Act (MEPA) (75-1-102 M.C.A)) • Permitting regulations (e.g., permitting of facilities in New Jersey (N.J.A.C. 7:1C); approval of air permits in Massachusetts (310 C.M.R. 7.00); solid waste management in New Mexico (20.9.3 N.M.A.C); approval, changes to operations, and filing fees for oil and gas operations in Colorado (2 C.C.R. § 404-1))
Local	• Permitting decisions (e.g., construction or modification of stationary sources in Albuquerque-Bernalillo County, New Mexico (20.11.72 N.M.A.C)) • Land use and zoning decisions (e.g., applying for commercial or industrial developments within Newark, NJ (Title XLI § 41:20))

Figure 1. HEI Energy-funded study locations used as example contexts for illustrating the application of this roadmap. UOGD basins are shaded in gray, and the portion of the basin associated with each study location is shaded in blue.

Box 1. Description of HEI Energy-Funded Study Locations Used as Example Contexts for Illustrating the Application of This Roadmap

HEI Energy funded the “Tracking community exposures to air emissions and noise from oil and gas development” (TRACER) collaboration to better understand population exposures to air emissions and noise from oil and gas development in multiple US regions. The regions differ with respect to environmental, social, and economic conditions as well as the types of oil and gas resources, and the collaboration was designed to quantify the variability in exposure that stems from these differences. More information about the studies can be found at https://www.heienergy.org/. The study locations used as example contexts in this roadmap include a subset of those studied as part of the TRACER collaboration: the Denver-Julesburg region in Colorado, the Marcellus region in Pennsylvania, and the Permian region in New Mexico.

Governance of oil and gas operations in some study locations includes requirements for CI assessment. Although Colorado, Pennsylvania, and New Mexico do not have formal state-level rules similar to NEPA, some agencies in these states require or have proposed environmental impact assessments or similar procedures that may include consideration of cumulative impacts (EJC 2022).

- In ***Colorado***, the Energy and Carbon Management Commission adopted the “Cumulative Impacts and Enhanced Systems and Practices Rules” in 2024 (2 C.C.R. § 404-1). Under this regulation, oil and gas operators who are seeking new drilling permits are required to assess cumulative impacts and implement community outreach protocols. The rules’ adoption follows the requirement to address cumulative impacts as outlined in Colorado Senate Bills 19-181 and 24-229 and Colorado House Bill 24-1346. Colorado House Bill 21-1266 additionally mandates the Colorado Air Quality Control Commission to adopt and implement regulations aimed at reducing greenhouse gas emissions from oil and gas.
- In ***Pennsylvania***, draft legislation was introduced in 2023 in the Pennsylvania Senate that would require an assessment of cumulative environmental impacts for permits (including air, waste, and oil and gas injection wells) issued for facilities located within areas with populations defined by the state as vulnerable and experiencing high levels of pollution (S.B. 888).
- In ***New Mexico***, the state senate introduced a bill in 2007 that would include consideration of cumulative impacts pertaining to environmental permitting processes (S.B. 880). The bill was unsuccessful, but state-level regulations related to permitting solid waste facilities include provisions for conducting a community impact assessment in certain cases (20.9.3 N.M.A.C.).

Special Panel included representation from individuals with expertise and experience in environmental health, epidemiology, sociology, strategic planning, leadership, communication, and community organizing (see Appendix C for biographies of panel members); additional oversight was provided by the HEI Energy Research Committee.

HEI Energy and the Special Panel conducted a multistep approach to identify potential adverse and beneficial impacts on the health and well-being of communities located near and affected by UOGD. They also formulated a flexible set of guiding questions and resources that can inform a CI assessment and be adapted for various decision contexts. Broadly, this multistep approach consisted of gathering information to inform the roadmap, deliberating to conceptualize and draft the roadmap, and reviewing the roadmap. In the information-gathering phase, HEI Energy hosted a series of three educational webinars between February and June 2024, with speakers discussing (1) an introduction to CI assessment, (2) regional and local perspectives on assessing cumulative impacts, and (3) methods for CI assessment. The webinar recordings are publicly available on HEI Energy's website.[6] HEI Energy also produced a research brief (published in September 2024 and available on the website) that summarized the results of a scoping review that described what is known about cumulative impacts experienced by populations affected by UOGD and outlined methods for assessing them. Throughout spring and summer 2024, HEI Energy project staff conducted various one-on-one consultations with individuals who work on cumulative impacts, and along with the Special Panel on Cumulative Impact Assessment, consulted additional literature on related topics, including community perspectives, engagement, and benefits; risk assessment, cumulative risk assessment, and health impact assessment; as well as UOGD research methods. The Special Panel met periodically from spring 2024 to spring 2025 and contributed to all phases of the project (information gathering, drafting of the roadmap, and responding to review of the roadmap). This roadmap was reviewed by a total of seven external reviewers representing the US EPA, state government, the oil and gas industry, academia, and community and nonprofit groups.

F. ROADMAP STRUCTURE

The considerations for assessing cumulative exposures outlined in this document are structured as a flexible roadmap that can be adapted for various decision contexts. The structure for the roadmap reflects a four-phase, generic process for CI assessment (**Figure 2**): (1) a developing partnerships and community engagement phase, to identify and build relationships in the community who are interested in or affected by the prevailing decision context; (2) a scoping phase, to define and prioritize values and impacts and to set boundaries for the assessment; (3) an analysis phase, to assess trends and cumulative impacts, which includes data collection, data generation, and data analysis; and (4) a management phase, to implement strategies for preventing, minimizing, or monitoring impacts or outcomes. Each of the roadmap's phases is explored in detail in the sections that follow. Importantly, strong communication and engagement among all assessment participants, as well as those interested in or affected by the assessment, should occur throughout all phases of the CI assessment.

It should be noted that CI assessments might not include every phase, depending on the decision context (except the analysis phase, which provides the foundation for any CI assessment and is therefore always included). For example, analyses of cumulative impacts in some state-level environmental decision-making processes focus on visualization and analysis of the multiple impacts experienced by communities to inform permitting or funding decisions (N.J.A.C. 7:1C, S.B. 535; A.B. 1550). In that context, the management phase is not necessarily included if the outcome of the assessment process is the denial of a permit or funding. A CI assessment might also include iteration within and across phases. For example, as part of its cumulative impacts rulemaking, the Minnesota Pollution Control Agency held several public working sessions on the scoping phase to iterate on identifying and prioritizing impacts and datasets to use in the assessments (MPCA 2024). In addition, depending on the prevailing decision context, the analysis and management phases might include an iterative process to maximize benefits while minimizing or preventing adverse impacts on human health and well-being of individuals in an affected population (IFC 2013).

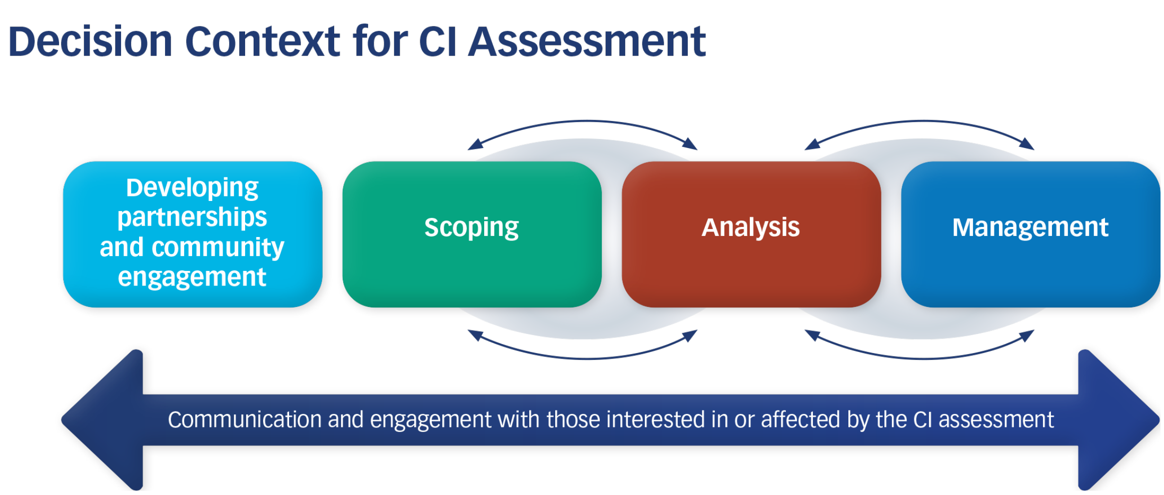

Figure 2. Overview of the four-phase, generic process for CI assessment described in this roadmap, including communication and engagement throughout the CI assessment process (large arrow) and the potential for iteration between phases (shown using thin arrows).

Each section of this roadmap includes an overview of the CI assessment phase, and a set of guiding questions, potential resources,[7] and example contexts drawn from HEI Energy-funded study locations that are specific to the UOGD experience.

G. KEY CONCEPTS AND TERMINOLOGY

The set of considerations for assessing cumulative exposures outlined in this document is presented using terminology associated with cumulative impacts. The scoping review of the literature on CI assessment generally and CI assessment in the context of UOGD revealed a range of terminology related to cumulative impacts, including both nuanced and distinct differences in definitions. For this reason, Blakley and Russell (2022) noted that basic CI assessment terms and concepts are not well understood. Below, we outline key terminology used throughout this roadmap.

We intentionally define terms for ease of comprehension across a wide audience. This roadmap modifies the definitions of "cumulative impact assessment" and "cumulative impacts" used by the US EPA (2022, 2024):

> **Cumulative impact assessment**: A process of evaluating both quantitative and qualitative data representing cumulative impacts to inform a decision, including strategies to prevent, minimize, or modify cumulative impacts to the extent possible.
>
> **Cumulative impacts**: The totality of impacts that might affect human health and well-being for individuals in an affected population.
>
> **Impacts**: Consequences of adverse or beneficial exposures associated with combinations of environmental, social, and economic factors that can affect human health and well-being for individuals in an affected population.

Other key terms that appear in this roadmap include the following:

> **Community**: A place-oriented process of interrelated actions through which members of a local population express a shared sense of identity while engaging in the common concerns of life (Theodori 2005).[8]
>
> **Health and well-being**: A state of complete physical, mental, and social wellness, and not the mere absence of disease or infirmity for all persons who live, work, or are otherwise active in a defined community or communities (Goodman et al. 2014; WHO 1946).

In this roadmap, CI assessment encompasses a process of evaluating an array of potential impacts that might affect human health and individual and community well-being. Projects or activities that are the subject of a CI assessment may contribute to changes in some factors or a combination of factors (often termed chemical or nonchemical stressors in the literature related to cumulative impacts) that might or might not lead to adverse or beneficial exposures resulting in impacts on human health and individual and community well-being. For ease of comprehension, this roadmap illustrates the CI assessment process in the context of populations affected by UOGD.

II. ROADMAP

A. PHASE 1 — DEVELOPING PARTNERSHIPS AND COMMUNITY ENGAGEMENT

Partnerships and community engagement are defining components of the CI assessment process. Regardless of the decision context, building partnerships and engaging with people in communities across sectors who might be interested in or somehow affected by the decision is essential to a successful, meaningful, and trusted CI assessment. Furthermore, continued communication and engagement are essential throughout and after the CI assessment process. HEI has developed guidance to help its funded investigators conduct effective engagement with individuals and groups who might use or be affected by their research (HEI 2025). The principles for such engagement can be more broadly applied to building effective partnerships and community engagement for a CI assessment in populations affected by UOGD and are modified below for this context.

- Define the value the CI assessment is aiming to create for and with populations affected by UOGD as a basis for continuing partnership and engagement and for promoting ongoing learning by and with communities.
- Work in partnership with local organizations that have strong relationships and ties to [populations affected by UOGD] for all aspects of community engagement.
- Proactively reduce logistical barriers to participation.
- Practice transparency and open communication that considers cultural and language characteristics.
- Commit to continued learning and reflection on community engagement practice.

Building multisectoral partnerships and engaging community members is itself a process and should begin early in the development of the assessment and continue throughout and after the assessment process. Key tasks include identifying multisectoral partners and participants for the assessment, defining the level and form of engagement for all assessment participants, and developing a communication plan that will be used throughout and after the assessment process. Multisectoral partnerships can include collaboration across a range of participants interested in or affected by the CI assessment, including collaboration within and across government agencies, as well as among and between academic researchers and industry.

In the context of populations affected by UOGD, additional consideration needs to be given to the state of "research fatigue" that might be present in a community. Many social science research efforts have been conducted in regions experiencing UOGD to understand the community impacts of energy extraction activities (Walsh et al. 2020), including in the study location communities referenced in this design (in particular, Colorado and the Marcellus region in Pennsylvania). These efforts have resulted in what has been termed "research fatigue," which broadly refers to community sentiment of being over-researched and an unwillingness or disinterest in participating in further research efforts. Additionally, some communities have expressed disinterest in participating in research efforts because of the feeling of being a laboratory experiment as opposed to an individual (Scharff et al. 2010). Any CI assessment in such communities would benefit from careful attention to any efforts that have preceded the assessment and review best practices for better partnerships and community engagement (e.g., Taylor et al. 2021). The following guiding questions are designed to begin this process and to determine which individuals, communities, sectors, or groups should be involved; why they should be included or want to participate; and how the engagement should proceed.

GUIDING QUESTIONS

- Who?
    - Who will be leading the CI assessment?
    - Who might be affected by any decisions related to this CI assessment?
    - Who has expressed interest in participating in the CI assessment process?
    - Who has expertise and experience that might be valuable?
    - Who has been involved in any prior assessments or research efforts?
    - Who has not been involved or under-represented in such efforts?
- What?
    - What is the value of the CI assessment for participating partners, including government, industry, community members, and the general public?
    - What are the roles and responsibilities of assessment participants?
        - How will roles and responsibilities be defined?
    - What other assessments or research efforts have taken place in this community?
    - What type of communication plan is best suited for the CI assessment process?
- How?
    - How will participation be facilitated?
    - How will participation be compensated? How will participants' information be protected?
    - How will the general public be involved? How is the general public being defined?
    - How will communication take place throughout and after the assessment process?
        - How will all aspects of the assessment process be communicated between assessment participants?
        - How will all aspects of the assessment process and results be communicated to the general public?

Best practices and principles for effective engagement with communities and other sectors have been developed by various groups and institutions; several potential resources are listed below. The list is not exhaustive, nor should it be interpreted as referring to the optimal resources to consult.

POTENTIAL RESOURCES

- Ipieca Meaningful Engagement Practitioner Guide[9]
- Groundwork USA Best Practices for Meaningful Community Engagement[10]
- Urban Institute Fostering Partnerships for Community Engagement[11]
- American Petroleum Institute Community Engagement Guidelines[12]

B. PHASE 2 — SCOPING

The scoping phase of a CI assessment is intended to both explore and set parameters and boundaries for the breadth of the assessment. The scoping phase lays the groundwork for the analysis phase of the CI assessment through a process of linking sources of concern with potential impacts. The scoping phase might include the following actions: identify potential adverse and beneficial impacts associated with UOGD and which exposures or factors are related to such impacts; define methods for prioritizing impacts; prioritize impacts valued by assessment participants that merit consideration in the assessment; establish flexible geographic and temporal boundaries related to the impacts that will be assessed; and identify other factors unrelated to UOGD that can influence the identified impacts. There are multiple approaches to conducting scoping activities that might partly be dictated by the decision context (US EPA 2024). For example, some state regulations that include CI assessment require the use of a particular template and associated geospatial mapping tool for air permit applications (310 C.M.R. 7.02(14)). Regardless of the methods and approaches chosen, scoping should be conducted in consultation with all CI assessment participants.

i. Identify Potential Impacts and Related Exposures or Factors

The scoping phase of a CI assessment begins with identification of potential impacts to include in the CI assessment. There are a range of adverse and beneficial impacts documented throughout the peer-reviewed and gray literature that might affect individuals and populations affected by UOGD. **Table 2**[13]

Table 2. Summary of Potential Impacts on Individuals and Populations Affected by UOGD in the United States and Canada Identified in Peer-Reviewed and Gray Literature[a,b]

Category	Impacts Identified in Peer-Reviewed and Gray Literature
Natural Environment	
Ambient and hazardous air pollutants	Emissions of the following pollutants: Fine particulate matter ($PM_{2.5}$) Coarse particulate matter (PM_{10}) Nitrogen oxides (NO_x) Ozone (O_3) Hazardous air pollutants (HAPs), including benzene, toluene, ethylbenzene, and xylenes (BTEX) Volatile organic compounds (VOCs) Dust
Water	Discharge and seepage of wastewater Contamination of the following: Freshwater (bromides) Groundwater (BTEX) Surface water
Greenhouse gases	Methane emissions
Noise	Noise and vibration pollution
Other emissions	Light pollution Odor emissions Soil pollution
Environmental degradation	Biodiversity and habitat loss Changes in greenspace Increases in invasive species Land use change, physical and sensory changes to landscapes
Accidents	Spills, leaks, blowouts
Built Environment	
Transportation	Changes in traffic
Infrastructure	Road damage Changes in walkability
Socioeconomic	
Employment	Changes in employment conditions Increased employment opportunities Increases in unemployment during busts
Income	Changes in personal income Changes in poverty levels Redistribution of wealth
Cost of living	Changes in housing value Increases in cost of living
Public revenue and local government services	Strains on local public services and infrastructure (such as emergency services, doctors, hospitals, clinics) Increases in local government revenue

continued

Table 2. (continued)

Category	Impacts Identified in Peer-Reviewed and Gray Literature
Health Outcomes	
General	Decreases in happiness and life satisfaction, quality of life Decreases in self-rated health Decreases in self-rated sleep
Morbidity/mortality	Increases in rates of cancer outcomes Increases in rates of adverse cardiovascular outcomes Increases in rates of adverse pregnancy outcomes Increases in rates of adverse respiratory outcomes Increases in rates of adverse mental health outcomes Increase in other rates of other adverse outcomes Changes in mortality
Psychosocial and Spiritual	
Psychosocial	Increases in psychosocial stress Increases in symptoms of anxiety Increases in depressive symptoms Changes in feelings of safety
Powerlessness	Feelings of powerlessness Differences in access to information about UOGD
Identity and values	Changes in civic engagement Changes in attitudes toward environmental concerns and exposure Feelings of disenfranchisement Changes in political identity Loss of sense of place and attachment
Spiritual	Loss of attachment to the land and local environment
Community	
Quality of life	Changes in neighborhood quality Increases in cultural erosion Changes in perceptions of equity Decreases in social cohesion, social capital Increases in social disruption, displacement Changes in population Increases in crime

[a] The set of reviewed literature was not exhaustive and might not have identified impacts in all categories. Lack of identified impacts in a category should not be interpreted as meaning that such impacts do not exist or are not important.

[b] References are listed in Appendix A, Table A-1.

summarizes the range of potential impacts identified in peer-reviewed literature in the context of populations affected by UOGD. Peer-reviewed literature was identified using a search strategy similar to that in Romitti and colleagues (2024) and using HEI Energy's spatial bibliography.[14] The list does not constitute a comprehensive review of all such peer-reviewed literature regarding potential impacts in the context of populations affected by UOGD.

The relevance of these impacts will vary by decision context and across communities. Identifying impacts necessarily includes consideration of what associated exposures or factors could lead to such impacts. In addition, it is important to consider what intrinsic (such as individual biology and genetics) and extrinsic (such as socioeconomic status, access to healthcare, housing quality) characteristics at both the individual and community levels might interact and modify impacts on the human health and well-being of individuals in an affected population. Approaches to identifying and prioritizing impacts vary (as discussed below in the *Prioritizing Impacts* section).

The following set of guiding questions is designed to help identify and prioritize potential impacts and their associated exposures or factors.

GUIDING QUESTIONS

- Which impacts on the natural environment, built environment, socioeconomic conditions, health, psychosocial factors, spiritual well-being, and community-level dynamics can be identified as affecting the human health and well-being of individuals in an affected population?
- Which impacts (natural environment, built environment, socioeconomic, health, psychosocial, spiritual, and community level) are being experienced in the community that are potentially related to UOGD?
  - What has been identified in scientific literature?
  - What has been identified by the community?
- What exposures or factors are associated with the identified impacts?
- Which, if any, of the impacts are not uniformly distributed across individuals or populations of interest?

POTENTIAL METHODS

- Literature reviews
- Ethnographic research methods, including surveys and focus group interviews
- Community-based participatory research methods, including community group discussions, forums, town halls, and other meetings
- Multisector forums and meetings

Studies on environmental health and studies of community perceptions and concerns throughout the study location regions in this design have identified multiple potential exposures and impacts related to the health and well-being of individuals or community members that might be associated with UOGD, some of which are listed in **Table 3**. Peer-reviewed literature was identified using a search strategy similar to that in Romitti and colleagues 2024 and using HEI Energy's spatial bibliography. The list does not constitute a comprehensive review of all the peer-reviewed literature regarding potential impacts in the three study locations.

ii. Prioritize Impacts

After identifying potential impacts to include in the CI assessment, the scoping phase generally includes a process of prioritizing which impacts (and thus their associated exposures or factors) to include in the assessment. Although there will typically be a wide array of impacts of concern to a community or population affected by UOGD, it is not always necessary, feasible, or desirable to attempt to assess an unwieldy number of potential impacts. Prioritizing which impacts to assess will partly be determined by the decision context. For example, assessment of cumulative impacts for air quality permit applications in Massachusetts requires consideration of impacts on air quality, health, socioeconomics, and state-defined susceptible groups, as well as consideration of whether there are nearby regulated facilities (310 C.M.R. 7.02(14)); in this case, the state regulation determines which impacts to prioritize. Prioritizing impacts can also be determined through a valuation judgment process that is based on a set of criteria agreed upon by all assessment participants. These criteria can be subjective or identified using, for example, a conceptual modeling exercise that explores relationships among identified impacts and their associated exposures or factors. Often, prioritizing impacts is largely determined by the availability and quality of information and data on identified impacts in a community, as well as time and resources available for the CI assessment.

The prioritization process involves consideration of not only causal and associational relationships among the various impacts, but also potential interactions between impacts (e.g., are the impacts additive, synergistic, antagonistic?) to determine which impacts to prioritize for assessment. Consider the example of increased truck traffic in a community affected by UOGD. Truck activity can increase noise in a neighborhood and potentially contribute to psychosocial stress (Adgate et al. 2014; Klasic et al. 2022). It can also increase traffic-related air pollution, likely contributing to changes in local air quality (Adgate et al. 2014; Klasic et al. 2022). In addition, increased truck traffic might require changes to local infrastructure, such as building new roads, which might contribute additional jobs and local revenue for the community (Mayer 2017). Not only does increasing truck traffic have multiple impacts, but the impacts can interact: the combination of increased psychosocial stress and changes in air quality might adversely affect

Table 3. Summary of Potential Impacts Associated with UOGD in the Example Context Study Locations for This Roadmap That Have Been Identified in Peer-Reviewed and Gray Literature of Studies on Environmental Health and Studies of Community Perceptions of UOGD[a]

	Denver-Julesburg Region, Colorado	Marcellus Region, Pennsylvania	Permian Region, New Mexico
Natural Environment			
Ambient and hazardous air pollutants	Emissions of HAPs, NO_x, and VOCs	Emissions of HAPs, O_3, $PM_{2.5}$, VOCs	Emissions of black carbon, BTEX, HAPs (polycyclic aromatic hydrocarbons [PAHs]), NO_x, $PM_{2.5}$, O_3, VOCs
Water	Water use in UOGD Contamination of groundwater (e.g., BTEX)	Contamination by methane, BTEX, and other toxic pollutants	Water use and availability from UOGD and wastewater management
Greenhouse gases	Methane emissions	Methane emissions (including from abandoned wells)	Methane emissions
Noise	Noise pollution	Noise pollution	Not identified in the set of reviewed literature
Environmental degradation	Perceived environmental degradation associated with UOGD	Perceived degradation of air and water quality	Perceived environmental degradation associated with UOGD
Accidents	Surface spills and leaks	Spills, leaks, blowouts	Not identified in the set of reviewed literature[b]
Built Environment			
Transportation and infrastructure	Stress on local infrastructure: increase in road traffic	Stress on local infrastructure: increase in road traffic and congestion, road damage, and safety concerns	Not identified in the set of reviewed literature
Socioeconomic			
Employment	Fluctuating employment	New employment opportunities Changes in job types and availability	Increases in unemployment during busts New employment opportunities
Income	Changes in income and poverty levels Unrealized monetary benefits to homeowners due to conflicts between mineral rights and surface owner rights	Changes in wage inequality	Increases in local economic growth Changes in income across boom-bust cycles
Cost of living	Housing shortages and increased housing prices due to the increased population	Housing shortages Increases in local prices	Housing shortages during boom cycles
Public revenue and local government services	Increases in public revenue and local economic growth	Social service strain due to population growth and the influx of migrant workers	Increases in public revenue and local economic growth

continued

Table 3. (*continued*)

	Denver-Julesburg Region, Colorado	Marcellus Region, Pennsylvania	Permian Region, New Mexico
Health Outcomes			
	Increases in noncancer outcomes Increases in cancer outcomes Changes in self-rated health	Increases in physical health problems Increases in collective trauma related to industrial accidents Increases in noncancer outcomes Increases in cancer outcomes Decreases in self-rated health	Not identified in the set of reviewed literature
Psychosocial and Spiritual			
Stress	Increases in psychosocial stress Feelings of complicity or guilt for those dependent on the UOGD industry	Increases in psychosocial stress	Environmental distress associated with changing landscapes
Powerlessness	Feelings of powerlessness and mistrust Changes in access to information about UOGD and a subsequent reduction in decision-making capacity	Feelings of powerlessness and anger regarding industry accountability Feelings of powerlessness in negotiations with the UOGD industry due to dependence on the industry for income Frustration due to a lack of access to tools and information related to UOGD	Not identified in the set of reviewed literature
Identity and values	Changes in political identity	Loss of rural way of life Loss of attachment to land due to industrial development	Changes in attitudes toward environmental change
Spiritual	Not identified in the set of reviewed literature	Not identified in the set of reviewed literature	Not identified in the set of reviewed literature
Community			
Quality of life	Changing neighborhood conditions	Changing community dynamics Increased crime	Changing community dynamics

[a] References are listed in Appendix A, Table A-1.
[b] The set of reviewed literature was not exhaustive and might not have identified impacts in all categories across study locations. Lack of identified impacts in a category should not be interpreted as meaning that such impacts do not exist in that study location or are not important.

individual health, but changes to local infrastructure and the economy might benefit community health broadly.

The prioritization process also includes considering what metrics are needed to assess cumulative impacts. Building on the example discussed above, what would be the most useful metrics to assess changes in noise, air quality, infrastructure, and jobs in a community? Are there measures that are specific to truck traffic? Metrics can be used to assess changes from a baseline point in time and progressively over the course of time. As noted above, the availability and quality of information and data often determine which impacts are prioritized (i.e., selected) and what metrics are included in a CI assessment.

GUIDING QUESTIONS

- Which impacts are of specific value to the community?
- How do these impacts relate to one another?
    - What causal and associational relationships between identified impacts and their associated exposures and factors can be identified? Which relationships are strongest?
    - Do certain impacts occur together? Similarly, do certain exposures and factors that result in impacts of concern occur together?
    - What potential interactions between impacts can be identified?
- What information and data are available on the identified impacts?
    - Are critical data or information missing?
    - Are additional data collection efforts needed?
    - What is the temporal and spatial scale of available information and data?
- What metrics (whether qualitative or quantitative, or a combination of the two) will be used to assess impacts, and what criteria will be used to determine which impacts will be included in the assessment?
- What impacts can feasibly and practically be assessed within the scope, time, and resources of the CI assessment?
- How and where do we incorporate the concept of “value of information”? In other words, we can study countless impacts, but the time and money might be better spent addressing an impact rather than studying it.

POTENTIAL METHODS

- Literature reviews
- Ethnographic research methods, including surveys, focus groups, and in-depth interviews
- Community-based participatory research methods, including community group discussions, forums, town halls, and other meetings
- Local, state, and federal publicly available data
- Local, community, and industry data sources or data collection
- Multisector forums and meetings

iii. Geographic and Temporal Boundaries

The scoping phase of a CI assessment also includes consideration of the geographic and temporal boundaries of the impacts that will be prioritized in the assessment. The geographic and temporal boundaries will likely be determined by the decision context. For example, an air permitting process might require that a source of air pollution be within a certain proximity (e.g., within 1 mile) to be considered. Setting geographic boundaries often includes considering the spatial area directly affected by the sources of concern and the spatial extent of the impacts that will be assessed. In practice, this means that CI assessments are often conducted on local or regional scales, although they can also be used at broader geographic scales, depending on the decision context. In the context of populations affected by UOGD, geographic boundaries for the assessment will likely be based on the proximity to UOGD activities (e.g., setback distances). It might also be based on census geographies (i.e., census tracts, counties, or states where UOGD activities are located). Additionally, local and regional economic impacts might be important in determining geographic boundaries in a CI assessment in the context of UOGD, because the economic impacts of UOGD can extend to nearly 100 miles from development activities (Feyrer et al. 2017).

Temporal boundaries are often determined based on the life cycle of the source of concern and the time horizon for the prioritized impacts. For communities affected by UOGD, this decision includes consideration of whether to assess impacts from both the boom-and-bust cycle of activity.

Overall, determining spatial and temporal boundaries in a CI assessment is an iterative process that should be responsive to professional judgment, risk management, existing conditions, and operational life of a project (Hegmann et al. 1999).

GUIDING QUESTIONS

- Does the decision context predetermine the geographic and temporal scope of impacts?
- What is the spatial extent of UOGD activities for the community?
- Does the set of prioritized impacts extend beyond the identified boundaries of UOGD activities?
- What phase of UOGD activity is the community experiencing?
- How far into the past should the CI assessment look, given the prioritized impacts?
- How far into the future should the CI assessment look, given the prioritized impacts?

Impact Prioritization Across Example HEI Energy-Funded Study Locations

Denver-Julesburg Region of Colorado

Studies that include surveys of communities in Colorado have identified several potential impacts in the region. These studies have highlighted impacts on the environment (including changes to air quality, potential water contamination, and increased noise levels) in this region. Other impacts that have been documented include socioeconomic impacts such as increased public revenue, changes in employment conditions (including unemployment), and concerns associated with an increasing population in the community (Haggerty et al. 2018; Malin 2020; Newell and Raimi 2018). Other studies have identified concerns about psychosocial stress, guilt, and powerlessness associated with economic insecurity, dependency on UOGD income, and decision-making regarding leasing rights for UOGD or permitting processes (Malin et al. 2023; Malin and Kallman 2024; Marlin-Tackie et al. 2020; McKenzie et al. 2016). One source of information to help prioritize impacts for the CI assessment in this location includes widely accessible databases, such as Colorado EnviroScreen, a publicly available screening tool that combines data on multiple measures related to the environment, demographics, socioeconomics, state-defined susceptible populations, and climate (CDPHE 2024). Other sources of information include industry-provided data related to UOGD, as well as community-based data collection efforts. Additional data collection efforts might be needed to gather metrics on, for example, employment conditions, rates of unemployment, and the impact of a changing population on the community (e.g., housing cost, access to public services, and community dynamics and cohesion).

Marcellus Region of Pennsylvania

Studies surveying community leaders and residents across the Marcellus region of Pennsylvania have identified multiple potential impacts of UOGD on communities. They can be broadly grouped into health impacts (headaches, respiratory issues, and stress), economic impacts (income and job creation, increased business activity, and tax revenue), social impacts (changing populations and increase in migrants), environmental impacts (degradation of water and air quality and large-scale landscape change), infrastructure and cost of living impacts (lack of housing, increased traffic, and road damage), and psychosocial impacts (feelings of stress and guilt due to dependency on UOGD income, feelings of powerlessness and frustration due to lack of access to information to inform decision-making) (Brasier et al. 2011; George 2019; Perry 2012, 2013; Malin and DeMaster 2016; Weinberger et al. 2017).

As in Colorado, a publicly available screening tool, PennEnviroScreen, is accessible that can help inform prioritization of impacts. PennEnviroScreen combines data on several metrics related to environmental exposures, as well as socioeconomic and demographic information (PA DEP 2023b). Other metrics related to some economic and infrastructure impacts can be obtained from publicly available datasets provided by the US Census Bureau (e.g., the American Community Survey). Nonetheless, as is the case in Colorado, information on other priority impacts might need to be collected through additional community-based surveys, focus groups, data-sharing partnerships with industry, or other resources.

In addition, several groups in Pennsylvania convene yearly in a Shale and Public Health Conference.[16] This forum provides another opportunity for multisector discussion of potential impacts associated with UOGD and might inform prioritization of impacts for a CI assessment.

Permian Region of New Mexico

Few surveys of communities in the Permian region exist related to the potential impacts of UOGD on individual and community health and well-being. One study that surveyed community residents in the Permian region (of Texas, not New Mexico) (Elser et al. 2020) highlighted air quality, traffic-related pollution, noise, vibration, and a general concern for environmental degradation as important impacts to consider in the region. Although no state-level screening tool that combines data on environmental and social metrics is available in New Mexico, the New Mexico Environment Department (NMED) provides information on several data resources related to air quality, water quality, and greenhouse gas emissions that can be useful in prioritizing impacts in those communities (NMED 2025b). It also provides a publicly available data catalog and interactive map with information on water, soil, and industrial and point source facilities locations (NMED 2018, 2025a). In addition, the New Mexico Department of Health offers a publicly available data tool, the New Mexico Indicator-Based Information System, that provides a range of information on health, demographic, and community health metrics across the state (NM Health 2022). As described in Colorado and Pennsylvania, industry-provided data and community-based data collection efforts provide other ways to gather information on potential impacts for a CI assessment process.

POTENTIAL METHODS

- Literature reviews
- Community-based participatory research methods, including community group discussion, forum, town hall, and other meetings
- Multisector forums and meetings

iv. Identify Other Related Factors

The scoping phase of a CI assessment generally includes consideration of other related factors that can influence what impacts are chosen for the assessment, such as terrain, weather, climatic, and atmospheric conditions, other sources of environmental emissions, other sources of local government revenue, and other sources of job creation. UOGD activities are often sited in communities near other sources that contribute to the same types of impacts associated with UOGD, such as changes to air quality and water quality, changes to local infrastructure, or changes to the local economy. In addition, communities with a long history of oil and gas development (OGD) or early UOGD are often located near active UOGD activities and abandoned oil and gas wells.

GUIDING QUESTIONS

- What other industries are located near the community?
  - Are there other industrial activities included in the geographic and temporal boundaries set for the CI assessment?
- Are there adverse and beneficial impacts associated with nearby industries and other sources or activities that might affect, or are the same as, one or more impacts included in the CI assessment?
- How might other identified impacts interact with the impacts selected for the assessment?
- What impacts related to terrain, weather, climatic, and atmospheric conditions might affect the prioritized impacts in the CI assessment?
- Have CI assessments been performed for the other nearby sources during permitting processes or in the literature?

POTENTIAL METHODS

- Literature reviews
- Ethnographic research methods, including surveys, focus groups, in-depth interviews, and archival analyses
- Community-based participatory research methods, including community group discussions, forums, town halls, and other meetings
- Local, state, and federal publicly available data
- Local, community, and industry data sources or data collection
- Multisector forums and meetings

Geographic and Temporal Boundaries in the Denver-Julesburg Region of Colorado, the Marcellus Region of Pennsylvania, and the Permian Region in New Mexico

The Denver-Julesburg region spans more than 70,000 square miles. The majority of the basin is in Colorado, but it also extends into Wyoming, South Dakota, Kansas, and Nebraska (WSGS 2024). The counties of Weld, Arapahoe, Cheyenne, and Lincoln experience the highest levels of UOGD, although the basin encompasses 23 counties (ECMC 2024a). Meanwhile, the Marcellus region of Pennsylvania spans about 95,000 square miles (US EIA 2017), with UOGD activity spanning the entirety of the southwest to northeast corners of the state, spanning 34 counties. Most UOGD activity is concentrated in Bradford, Susquehanna, Lycoming, Butler, Armstrong, Washington, and Green counties (PA DEP 2024). The Permian region consists of several shale plays spanning over 75,000 square miles, predominantly across New Mexico and Texas (US EIA 2020). The Permian Basin consists of 66 counties, and Lea and Eddy counties are responsible for 29% of UOGD activities in the region (US EIA 2023). In setting geographic boundaries to assess cumulative impacts in these regions, considerations include whether the CI assessment will cover all areas experiencing any level of activity in the regions or whether the assessment will focus on communities that experience the highest levels of activity. Another consideration is whether to include neighboring and adjacent counties where no UOGD activity is occurring, but that could experience spillover effects. In all three regions, UOGD activity experienced boomtime activity beginning in the 2000s–2010s (Jacquet 2018; Raimi 2017). Similar to setting geographic boundaries, setting temporal boundaries involves considering whether it is feasible for the assessment to span from the initial phases of development in the region (i.e., when the first unconventional well is drilled) through the boomtime phase of activities, or whether the focus will be on some other specific time frame.

Other Related Factors in the Denver-Julesburg Region of Colorado, the Marcellus Region of Pennsylvania, and the Permian Region in New Mexico

Other related factors that could affect one or more impacts selected for a CI assessment in the study regions referenced in this roadmap primarily consist of (1) other active industries or activities in the region that might contribute to, for example, emissions of air pollutants, employment rates, and sources of income; and (2) other climatic factors that could affect impacts selected for a CI assessment.

In addition to UOGD, conventional oil and gas extraction occurs in all regions referenced in this roadmap (Fishman 2005; Raimi 2017). In both the Denver-Julesburg and Marcellus regions, substantial agricultural activity contributes other sources of emissions and economic benefits to these regions (Haggerty et al. 2019; Hoy et al. 2018; Pétron et al. 2014; Riddick et al. 2022). Other industries present in the Marcellus region include coal mining and petrochemical production (US EIA 2024). For example, a large ethane cracker plant is located in Beaver County, PA, which is also a dense locus of UOGD activity (Shell n.d.). In the Permian region, other active industry includes crude oil refining (US EIA 2024).

Other climatic factors present in the Denver-Julesburg and Permian regions include aridity and susceptibility to wildfires that might also affect prioritized impacts in the region (Metro Denver EDC 2025; New Mexico State University 2025). In the Denver-Julesburg region, temperature inversions also occur, given the region's topography, which affects air quality (City and County of Denver 2025). The Marcellus region of Pennsylvania features a continental climate with variable temperatures and more precipitation compared with the rest of the state (NCDC n.d.).

v. Summary of Scoping

A completed scoping phase in a CI assessment often includes a mutually agreed-upon list of prioritized impacts to assess, a set of associated metrics to measure impacts, and data sources that will be used to evaluate the prioritized impacts for the assessment. A completed scoping phase also identifies the geographic and temporal boundaries for the assessment, along with other related factors that might influence the impacts, metrics, or data sources that will be used.

C. PHASE 3 — ANALYSIS

The analysis phase of a CI assessment builds on the results of the scoping phase and often continues the work of evaluating relationships and interactions among impacts begun in the scoping phase. The analysis phase generally includes the following actions: a baseline assessment of population health, a baseline assessment of the prioritized impacts, an analysis of trends and the cumulative impacts of the prioritized impacts, and a determination of the significance of the cumulative impacts. As described in the scoping phase, impacts (and their associated exposures or factors) can interact or relate to one another in multiple ways. For this reason, cumulative impacts can be considered additive, incrementally interactive, or synergistic (see Blakely 2021 for a detailed description of types of cumulative impacts). Multiple methods can also be applied in the analysis phase for assessment of cumulative impacts; these include index-based methods, matrix-based methods, statistical models, and spatial analysis (see Rish et al. 2024, and Verweil and Rish 2025 for a comprehensive review of methods related to assessing cumulative impacts). Analysis methods can be quantitative or qualitative, or some combination of the two. Importantly, methods for analyzing and assessing cumulative impacts — including methods for combining and evaluating different types of qualitative and quantitative data, determining relationships among impacts, and assessing and weighing tradeoffs between adverse and beneficial impacts — remain an active area of study across sectors. As such, the considerations outlined in the following sections were formulated to inform the process of analysis, rather than provide detailed guidance for specific methods.

i. Assess Baseline

The analysis phase of a CI assessment generally begins with a baseline assessment that provides a point of reference with which to analyze changes and trends in the community and in the prioritized impacts. Collecting information on baseline community health can provide information on intrinsic (e.g., age, demographics) and extrinsic (e.g., access to healthcare) characteristics at the individual and community level that might modify identified impacts.

A lack of baseline data for evaluating trends in populations affected by UOGD has historically been cited as a challenge in assessing impacts of concern for these communities (Adgate et al. 2014). However, a lack of definitive baseline data does not prevent one from conducting a CI assessment. If information or data are not available, surveys or interviews can help establish baseline information for the impacts being assessed, or baseline conditions can be approximated using statistical models. Community knowledge and data (e.g., ethnographic interviews and surveys, community-sourced local science data, and oral histories) are also valuable to establish baseline information. Each approach should consider the precision and accuracy required to meet the overall assessment objectives characterized during the scoping phase.

GUIDING QUESTIONS

- What time frame will be used to collect baseline information about the community (e.g., will the baseline assessment reflect conditions before UOGD)?
- What is the community's baseline health status?
  - Information related to baseline health status might include demographic, socioeconomic, quality of life, and health-related characteristics, such as unemployment rates, social cohesion, access to healthcare, healthcare utilization, rates of smoking, rates of asthma, and rates of chronic disease.
  - Information related to baseline health status might also include information on susceptible populations within the community (e.g., UOGD workers and their households, low-income households, children, or older individuals, as well as federally recognized American Indian tribes and Alaskan Native entities).
- What is the baseline status of the identified impacts that will be assessed?
- What information or data needed to establish the baseline assessment is missing?
  - Can the information gaps be filled using surveys or community sources of knowledge?

POTENTIAL METHODS

- Local, state, and federal publicly available data
- Statistical models
- Government, nonprofit, or research institution reports or white papers
- Data collection, including environmental sampling, surveys, and remote sensing
- Local, community, and industry data sources or data collection
  - Concept mapping
  - Participatory research methods, such as participatory GIS, photovoice, community, or crowd-sourced local science data
  - Oral histories, local news archives, and local history archives
  - Ethnographic interviews and observations
- Community health surveys
- Prior community, government, industry, or other assessments

ii. Assess Cumulative Impacts

After baseline information for the CI assessment is established, the assessment includes analysis of trends in the prioritized impacts over time and analysis of cumulative impacts. There is no standardized approach for how cumulative impacts should be analyzed. In practice, analysis of cumulative impacts is often determined by the prevailing decision context. For example, consideration of cumulative impacts as part of permitting processes within some states requires the use of prescribed guidance and a method (e.g., the use of a specific screening tool to comply with Massachusetts and New Jersey processes) (N.J.A.C. 7:1C; 310 C.M.R 7.02(14)). Analysis of cumulative impacts may also include the use of screening tools to visualize and map metrics for the prioritized impacts. Such tools generally include either the use of an index-based approach — such as a single scoring approach that combines values for metrics into a single score to represent overall cumulative impact — or a matrix approach that keeps categories of metrics separate and distinct to be evaluated using thresholds or criteria (as discussed in the following section, *Significance of Cumulative Impacts*). Index-based approaches typically include weighting among the prioritized impacts or groups of impacts (e.g., natural environment, socioeconomic, psychosocial, and spiritual). Other approaches include exposure modeling, statistical modeling, qualitative methods, or the use of mixed methods. Analysis of cumulative impacts can include a comparison of impacts using reference cases (e.g., comparison of prioritized impacts to those in a non-UOGD community or comparison of prioritized impacts at baseline with changes over time in a UOGD community). A survey of various analytical methods can be found in Rish and colleagues (2024) and US EPA (2016; 2023; 2024). Although we are not aware of examples of the use of artificial intelligence (AI) in the assessment of cumulative impacts, AI has the potential to facilitate analysis of exposures and impacts.

Depending on the approach chosen, the analysis phase often builds on the initial consideration of identified relationships between and among impacts that was begun in the scoping phase and often includes consideration of additive, multiplicative, synergistic, or antagonistic relationships among the prioritized impacts, including potential interactions within media (e.g., multiple chemicals in the air) and across media (e.g., air, water, and soil). Other considerations include how to assess the relationship among adverse and beneficial impacts, as well as how other intrinsic or extrinsic characteristics at the individual or community level might modify these relationships or interactions. Other elements for the analysis phase often include evaluating future changes to the prioritized impacts (within the temporal boundaries identified in the scoping phase) or assessing uncertainty associated with the analysis of cumulative impacts (e.g., uncertainty associated with future scenarios, uncertainty associated with modeling exposure, and uncertainty associated with different baseline assumptions).

GUIDING QUESTIONS

- Does the decision context for the CI assessment prescribe analytical methods for assessing cumulative impacts?

Baseline Assessment in the Denver-Julesburg Region of Colorado, the Marcellus Region of Pennsylvania, and the Permian Region of New Mexico

Denver-Julesburg Region of Colorado

Specific to the UOGD context, the Colorado Energy and Carbon Management Commission (ECMC) produced both an initial and updated report with what was termed baseline information to support ongoing evaluation and assessment of potential cumulative impacts as required under Rule 904 (ECMC 2024b; COGC 2023). The reports evaluated data for oil and gas development plans and associated oil and gas locations that had been approved in 2022, including information on water quality, land use, wildlife, air quality, and trends in greenhouse gas emissions and ozone concentrations (Colorado Oil and Gas Conservation Commission 2023; ECMC 2024b). Those data, as well as other data available from Colorado EnviroScreen and any community- or industry-provided information, might be too recent for appropriately informing the baseline assessment. However, depending on the time frame selected to reflect baseline conditions, the data sources might potentially be queried for the years of interest to help inform the baseline assessment (CDPHE 2024).

Marcellus Region of Pennsylvania

Although no baseline assessments specific to the UOGD context are available for the Marcellus region, the US Geological Survey (USGS) has conducted baseline assessments of groundwater quality across several UOGD counties in Pennsylvania (USGS 2020) that could be useful in assessing baseline conditions for a CI assessment. The USGS assessments seek to evaluate the constituents in groundwater and establish data that can be used to analyze the impacts of UOGD in a county (e.g., Senior and Cravota III 2017). As in Colorado, PennEnviroScreen provides another publicly available tool for which data inputs could be helpful to find appropriate data to inform baseline assessment (PA DEP 2023b). Multisectoral data-sharing partnerships are another option to assemble data to inform the baseline assessment.

Permian Region of New Mexico

Additionally, no baseline assessments specific to the UOGD context are available for the Permian region in New Mexico. However, the NMED provides a data catalog that includes information to understand water quality, the location of industrial sites, and existing permitting across the state, which can be used to inform baseline assessments (NMED 2018). In addition, NMED's OpenEnviroMap allows users to visualize the distribution of industrial sites, environmental resources, and information on water quality at different geographic scales and yearly intervals (NMED 2025). Data assembled through collaboration across sectors and assessment participants, as described for Colorado and Pennsylvania, are likely to provide the most comprehensive information to inform baseline assessments.

- What approach is most appropriate for analyzing cumulative impacts in the community, given the decision context (i.e., a single quantitative measure of cumulative impact, some quantitative measure of exposure, a spatial mapping of metrics, or a comparison of impacts across communities)?
  - What resources (e.g., information, data, time, expertise, labor, and money) are available for conducting the analysis?
  - Is there interest in determining cumulative impacts relative to a point of temporal or geographic point of reference that is not experiencing UOGD activity? (If so, baseline information should also be collected for this point of reference.)
  - Is there interest in including an assessment of future changes in the prioritized impacts?
- How might metrics associated with the prioritized impacts interact with one another?
- What methods are available and appropriate to assess interactions between and among impacts? What methods are available and appropriate to assess tradeoffs between adverse and beneficial impacts?
- How might baseline community characteristics modify the prioritized impacts and the relationships among impacts?
- Is it appropriate to include an evaluation of uncertainty in the CI assessment? (This question might be determined by the decision context and approach chosen.)
- What analytical approach would lend itself to identifying and successfully implementing management strategies for cumulative impacts in the assessment?

POTENTIAL METHODS[15]

- Spatial analysis and mapping
- Index-based methods
- Matrix-based methods
- Exposure modeling
- Statistical models
- Comparative analysis
- Cost-benefit and other economic analyses
- Simulation modeling
- Meta-analysis

- Research triangulation
- Scenario analysis
- Network analysis
- Qualitative modeling

iii. Significance of Cumulative Impacts

The analysis phase of a CI assessment also includes some determination of the significance of the cumulative impacts analyzed. Again, the significance of cumulative impacts in the CI assessment is often determined by the prevailing decision context. The significance of cumulative impacts can be determined using limits or thresholds, it can be based on subjective factors, or it can be some combination of these approaches. Generally, this step has been cited as one of the most challenging phases in CI assessment because, regardless of the approach chosen, significance determinations are often decided using a value judgment, and what constitutes significant, unreasonable, or cumulative is a normative question subject to debate (Baptista et al. 2022). Index-based approaches typically use thresholds that are based on relative measures, such as percentiles, to determine the significance of cumulative impacts. For example, California's CalEnviroScreen tool designates census tracts with cumulative scores ≥75th percentile (which is calculated using a relative ranking) as tracts that experience high economic, health, and environmental burdens (i.e., cumulative impacts) and thus are eligible for certain funding. Another method might include assigning thresholds based on multiple percentiles for groups of metrics (Zeise and Blumenfeld 2021). In addition, thresholds might be assigned using relative rankings of metrics between geographic locations (e.g., comparing cumulative impacts for UOGD versus a non-UOGD community).

To help inform a CI assessment decision, a threshold based on a relative ranking alone might be useful in determining certain permitting decisions or might need to be considered alongside limits and thresholds for categories of impacts. However, it is important to note that screening tools have limitations that might preclude their use in certain regulatory or permitting

Analysis of Cumulative Impacts in the Denver-Julesburg Region, Colorado; the Marcellus Region, Pennsylvania; and the Permian Region, New Mexico

Although multiple research articles and other publications have documented a range of potential environmental, social, economic, and community impacts of UOGD across the study locations in this roadmap (see Appendix A, Table A-1), there are only a few instances in which cumulative impacts are analyzed. These examples largely consist of environmental assessments or environmental impact statements as required under NEPA related to oil and gas activities in these regions more broadly (i.e., not specifically focused on the oil and gas basins noted above). A recent environmental impact statement (EIS) published by the Bureau of Land Management (BLM) for the Big Game Habitat Conservation for Oil and Gas Management in Colorado plan includes a generalized analysis of cumulative impacts that broadly relied on a comparison of baseline characteristics in the environment with expected impacts of alternatives or other actions in the same geographic area (where other actions include oil and gas development) (US BLM 2024b). Analysis of cumulative impacts was provided for each resource category (physical environment, biological resources, and social and economic systems) that generally relied on qualitative comparative and scenario analysis using historical and projected data on trends of resources within each resource category, although it appeared that screening tools were also used. Similarly, a recent environmental assessment published by BLM for the review of the permit applications to drill in Eddy County, New Mexico, also employed comparative and scenario analysis (primarily qualitative) that used historical and projected data on trends of specific impacts on air quality, water quality, greenhouse gas emissions, and community characteristics (US BLM 2024a). In this analysis, cumulative impacts were considered for each impact individually.

Other studies examine multiple, rather than cumulative, impacts in UOGD contexts across broader regions encompassing our study locations. One example describes an analytical approach to evaluating the intersection of UOGD activity with food and water systems in Colorado (Malin 2025). Another example is a study by Mayfield and colleagues (2019), which evaluates the impacts of the shale gas boom in the Appalachian Basin (including the Marcellus region) on air quality, greenhouse gas emissions, and employment. That analysis used several modeling methods, including statistical regression-based models, air quality models, and emissions models. Impacts were estimated for each impact category separately, and tradeoffs between impacts were assessed using a traditional cost-benefit analysis. Another study that focused on large emitting facilities in New Mexico (including oil and gas activities in the Permian region) analyzes the effect of these facilities on air quality, greenhouse gas emissions, and the characteristics of communities living near those facilities (Pacyniak et al. 2023). That analysis largely used spatial analysis alongside index-based methods to visualize multiple impacts across New Mexico and in specific counties (CDC n.d.).

Beyond UOGD, there are other examples of analytical methods used to assess cumulative impacts to inform a decision. In Minnesota, the Minnesota Pollution Control Agency has required consideration of cumulative impacts in what is termed "cumulative levels and effects" analyses for air permitting processes in certain parts of southern Minneapolis (Minn. Stat. 116.07 subd.4a). This method combines the use of criteria air pollutant and air toxics dispersion modeling with identification of human health outcomes related to air pollutants and air toxics and collection and quantitative and qualitative description of environmental health data in the community along with comparisons to other communities (MPCA 2013).

processes. For example, the metrics used in many screening tools are based on area-level proxies rather than direct measures. Data sources and temporal scales used for metrics in screening tools are often inconsistent. Existing guidance on CI assessment, as summarized in Ehrlich and Ross (2015), describes determinations of significance of cumulative impacts that are based on a comparison of impacts with some limit or threshold of acceptable change.

GUIDING QUESTIONS

- Does the decision context for the CI assessment prescribe analytical methods for assessing the significance of cumulative impacts?
- Does the analytical approach chosen in the CI assessment lend itself to quantitative or qualitative determinations of thresholds or significance of cumulative impacts?
- Does current literature describe thresholds that are relevant for the community?

POTENTIAL METHODS

- Literature review
- Inter- and multidisciplinary conferences or symposia
- Professional judgment among assessment participants
- Expert opinion, including consensus methods and Delphi surveys

iv. Summary of Analysis

A completed analysis phase in a CI assessment includes a baseline assessment of population health and the prioritized impacts, a mutually agreed-on analytical method for assessing cumulative impacts and trends in the prioritized impacts, and some discussion and determination of the significance of the cumulative impacts in the assessment. The results of the analysis phase will depend on the decision context for the CI assessment and the method chosen to assess cumulative impacts.

D. PHASE 4 — MANAGEMENT

The management phase of a CI assessment includes identifying and implementing potential strategies for preventing, minimizing, or monitoring cumulative impacts identified to maximize beneficial impacts while minimizing adverse ones. Management of cumulative impacts generally follows the impact mitigation hierarchy approach (IAIA 2013), which consists of a series of steps aimed at minimizing adverse impacts. The management phase is informed by the results of the analysis phase, particularly the identified significance of cumulative impacts. For example, in the context of setback distances, a strategy to minimize cumulative impacts can take the form of changing the setback distance between residential neighborhoods and UOGD. Management of cumulative impacts can

Significance of Cumulative Impacts in the Denver-Julesburg Region, Colorado; the Marcellus Region, Pennsylvania; and the Permian Region, New Mexico

Although determining the significance of cumulative impacts is largely subjective and ultimately based on determinations of acceptable change, both Colorado and Pennsylvania have state-specific screening tools that can provide useful examples for identifying potential thresholds to assess the significance of cumulative impacts. Both tools identify thresholds based on relative rankings. Colorado's EnviroScreen tool provides a measure of cumulative environmental, health, and socioeconomic burden and can be used to identify communities meeting the cumulative impacts criteria of a disproportionately impacted community as defined under Colorado law (C.R.S. § 24-4-109(2)(b)(II)). This criterion defines a threshold for experiencing cumulative impacts as a Colorado EnviroScreen score >80th percentile (CDPHE 2024). Colorado's recently adopted Cumulative Impacts and Enhanced Systems and Practices Rulemaking (2 C.C.R. § 404-1) does not similarly designate a threshold for cumulative impacts but does require that a cumulative impacts analysis include a copy of the most recent Colorado EnviroScreen data for the oil and gas location. Pennsylvania's PennEnviroScreen tool also provides a measure of cumulative burden or "undue environmental burden" on certain communities and can be used to identify vulnerable groups as defined under the state regulations, defined as communities with a PennEnviroScreen score ≥80th percentile (PA DEP 2023a; PA DEP 2023b).

New Mexico does not currently have any similar index-based tools to quantify cumulative burdens in a community. However, in New Mexico, the Albuquerque Bernalillo County Air Quality Control Board adopted a regulation in 2023 requiring stronger air quality analysis and control technologies for sources of criteria and ambient air pollutants located in or near an overburdened community. In this regulation, overburdened communities are the 20% of census block groups in the county that experience the highest cumulative environmental and public health burden as identified using the New Mexico Department of Health's New Mexico Indicator-Based Information System (20.11.72 N.M.A.C; NM Health 2022).

include strategies to address cumulative impacts even if the significance determination of impacts is not entirely conclusive.

As described in other sections of this roadmap, the management phase of a CI assessment might or might not be applicable depending on the decision context for the assessment, and it can be iterative with the analysis phase. For example, adaptive management is one approach that can be used to address cumulative impacts, which involves an iterative learning process, including planning, implementing, monitoring, evaluating, and adjusting management strategies.

GUIDING QUESTIONS

- Does the decision context for the CI assessment prescribe inclusion of management strategies for cumulative impacts?
- What is the outcome of the CI analysis phase (i.e., have significant cumulative impacts been identified)? What strategies might maximize beneficial impacts while minimizing adverse impacts identified in the scoping and analysis phases that contribute to overall cumulative impacts?
- What strategies are available to prevent, minimize, or monitor cumulative impacts identified in the analysis phase?
- How will management strategies themselves be monitored and evaluated?

POTENTIAL MANAGEMENT APPROACHES

- Use of mitigation hierarchy
- Adaptive management approaches
- Planning approaches such as multicriteria decision analysis
- Community-based management approaches
- Co-management agreements
- Planning approaches such as multicriteria decision analysis
- Long-term moderation and monitoring
- Integrated approaches such as interorganizational or interagency collaboration

POTENTIAL MANAGEMENT STRATEGIES

- Prevention measures
- Minimization measures
- Monitoring measures
- Restoration measures
- Offsetting measures

Management of Cumulative Impacts in the Denver-Julesburg Region, Colorado; the Marcellus Region, Pennsylvania; and the Permian Region, New Mexico

The 2024 Colorado Cumulative Impacts and Enhanced Systems and Practices Rulemaking provides for the Colorado Department of Public Health & Environment to recommend monitoring requirements or best management practices to address cumulative impacts as part of permit renewals or approvals (2 C.C.R. § 404-1). In addition, the rulemaking requires that permit applicants include a description of planned measures to mitigate adverse impacts in both the preproduction and production phases of operations. The cumulative impact analysis section of this rule also requires measures that the operator plans to take to “avoid, minimize, or mitigate adverse cumulative impacts.” It also requires descriptions for impacts to resources, including best management practices or enhanced systems and practices.

Draft legislation introduced in 2023 in the Pennsylvania Senate related to permitting in certain areas proposes that the Pennsylvania Department of Environmental Protection can require additional conditions or mitigation measures in approving permits based on cumulative environmental impacts (S.B. 888). The type of monitoring, mitigation, or management strategy that can be required or recommended in the examples of either CO or PA is not described in the related documentation.

In Albuquerque-Bernalillo County, New Mexico, permitting requirements established in 2023 related to sources of air pollution that are located, or proposed to be located, near areas defined by the state as experiencing the highest cumulative environmental and public health burden are required to apply Best Available Control Technology (BACT) to manage and mitigate impacts (20.11.72 N.M.A.C). Another regulation related to permitting solid waste facilities in areas defined as vulnerable (by the regulation) includes provisions for a community impact assessment, wherein applicants should describe mitigation measures to manage the facility’s expected impacts on multiple resources, including historical and cultural resources, visual and scenic resources, air quality, socioeconomics, noise, transportation, and public and occupational health (20.9.3 N.M.A.C.).

ENDNOTES

1. See Section I.G. Key Concepts and Terminology; we define CI assessment as a process of evaluating both quantitative and qualitative data representing cumulative impacts to inform a decision, including strategies to prevent, minimize, or modify cumulative impacts to the extent possible.

2. UOGD refers to the development and production of oil and natural gas as practiced starting around the beginning of the 21st century through multistage hydraulic fracturing in horizontal wells. UOGD processes occur on and off the well pad and include the following:

> *Field development*: exploration, site preparation, vertical and horizontal drilling, well completion (casing and cementing, perforating, acidizing, hydraulic fracturing, flowback, and well testing) in preparation for production and management of wastes.
>
> *Production operations*: extraction, gathering, processing, and field compression of gas; condensates; management of produced water and wastes; and construction and operation of field production facilities.
>
> *Postproduction*: well closure and land reclamation.

3. See Box 2: Defining Cumulative Impacts, Cumulative Risk, and Cumulative Effects in *https://www.heienergy.org/publication/cumulative-impact-assessment-unconventional-oil-and-gas-development-communities*.

4. *https://www.heienergy.org/publication/cumulative-impact-assessment-unconventional-oil-and-gas-development-communities*

5. Between 2014 and 2018, HEI Energy hosted research planning workshops in Colorado, Pennsylvania, Texas, and West Virginia during which recommendations were solicited for research about community exposures and health effects associated with UOGD. HEI Energy heard a need to (1) capture differences in potential exposures across UOGD operations, regions, and populations; (2) distinguish potential UOGD exposures from other sources; (3) provide information that is actionable and involves partnerships from multiple sectors; and (4) understand how close is too close for people to live, work, and go to school near development. HEI Energy is now funding research related to air emissions, noise, and water quality changes that can help to inform those decisions related to such questions, but that research encompasses only part of the experience for people in communities located near UOGD.

6. *https://www.heienergy.org/events*

7. The list of potential methods and resources included in each section is not intended to represent a comprehensive examination of all methods that can and have been used in CI assessment.

8. We acknowledge that there are many definitions of community; we selected this definition to encompass the combination of place, culture, identity, and action.

9. *https://www.ipieca.org/resources/meaningful-engagement-practitioner-guidance*

10. *https://groundworkusa.org/wp-content/uploads/2018/03/GWUSA_Best-Practices-for-Meaningful-Community-Engagement-Tip-Sheet.pdf*

11. *https://www.urban.org/sites/default/files/publication/104935/fostering-partnerships-for-community-engagement_0.pdf*

12. *https://www.api.org/-/media/files/policy/exploration/100-3_e1.pdf*

13. Although we acknowledge the importance of ecological health as a component of or contributing to health and well-being, this roadmap is primarily focused on human health. Ecological impacts are included as they relate to impacts that affect human health and the well-being of individuals in an affected population.

14. *https://www.heienergy.org/literature-hub*.

15. See Rish and colleagues (2024) and US EPA (2016, 2023, 2024) for an overview of analytical methods for use in CI assessment.

16. *https://www.shalepalwv.org/*

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APPENDIX A

Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada

Table A-1. Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada[a]

	Study Locations			
Impacts	**Denver-Julesburg Region, Colorado**	**Marcellus Region, Pennsylvania**	**Permian Region, New Mexico and Texas**	**Other Locations in the United States and Canada**
Natural Environment				
Air	ATSDR 2010; Allshouse et al. 2019; Bahreini et al. 2018; Benedict et al. 2018, 2019; Cheptonui et al. 2023; Collett in press; Collett et al. 2016; CDPHE 2012, 2016, 2017c, 2017b, 2017a, 2018a, 2018c, 2018b; COGC 2023; Cushing et al. 2021; Dix et al. 2023; Eisele et al. 2016; Esswein et al. 2013, 2014; Evans and Helmig 2017; Flocke et al. 2020; Franco et al. 2016; Franklin in press; Frazier 2009; Frischmon and Hannigan 2024; Gilman et al. 2013; Halliday et al. 2016; Heimerl et al. 2023; Helmig et al. 2015, 2021; Holder et al. 2019; Ilonze et al. 2024; Koss et al. 2017; Ku et al. 2024; Li et al. 2020; Lindaas et al. 2019; Lyu et al. 2020; Macey et al. 2014; Majid et al. 2017; McDuffie et al. 2016; McKenzie et al. 2012, 2018; McMullin et al. 2018; Nsanzineza et al. 2019; Oltmans et al. 2019, 2021; Ortega et al. 2021; Peischl et al. 2018; Pétron et al. 2012; Pfister et al. 2017; Pollack et al. 2021; Rodriguez et al. 2009; Rossabi et al. 2021; Silberstein et al. 2024; Swarthout et al. 2013; Thompson et al. 2014; Vigil 2015; Warner et al. 2013; Zaragoza et al. 2017	ATSDR 2016b; Baek in review; Banan and Gernand 2018; Barth-Naftilan et al. 2018; Bonetti et al. 2023; Campa et al. 2022; Chang et al. 2016; Chen et al. 2017; Cushing et al. 2021; Dennis et al. 2022; DiGuilio et al. 2023; Fann et al. 2018; Gernand in review; Goetz et al. 2017; Gradient Corporation 2019; Hill and Ma 2017; Lewellyn et al. 2015; Li et al. 2020; Long et al. 2021; Macey et al. 2014; Maskrey et al. 2016; Mol et al. 2020; Ouyang et al. 2019; Orak and Pekney 2020; Pekney et al. 2018; PA DEP 2010, 2018; Pennsylvania DOH 2018; Reilly et al. 2015; Riddick et al. 2024; Roohani et al. 2017; Rossabi and Helmig 2018; Rowan et al. 2012; Saint-Vincent et al. 2021; Skalak et al. 2014; Steinzor et al. 2013; Swarthout et al. 2015; Van Sice et al. 2018; Warner et al. 2013; Wendt Hess et al. 2019; Yan et al. 2017; Yang et al. 2024	Dix et al. 2020; Dix et al. 2023; Eisenlord et al. 2018; Franklin; Heimerl et al. 2023; Koss et al. 2017; Majid et al. 2016; Marsavin et al. 2024; Pan et al. 2023; Plant et al. 2024; Pollack et al. 2023; Radhakrishnan et al. 2023; Serrano et al. 2023	Baek in review; Beausoleil et al. 2022; Black et al. 2021; Buse et al. 2019; COGC 2023; Dubé et al. 2022; Franklin in press; Gernand in review; HEI Energy 2025[b]; HEI Energy Research Committee 2020; Hildebrandt Ruiz in press; Klasic et al. 2022; Mayer 2017; Mayfield et al. 2019; NASEM 2003

continued

Table A-1. Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada[a]

	Study Locations			
Impacts	**Denver-Julesburg Region, Colorado**	**Marcellus Region, Pennsylvania**	**Permian Region, New Mexico and Texas**	**Other Locations in the United States and Canada**
Water	Aakhus and Lewinski 2017; Bonetti et al. 2023; Chambers et al. 2024; Chen et al. 2023; COGC, 2023; ECMC 2024; Gross et al. 2013; Hladik et al. 2014; Jubb et al. 2024; Kanno and McCray 2021; Lackey et al. 2022; Li and Carlson 2014; McDevitt et al. 2022; Nelson et al. 2015; Ryan in press; Sherwood et al. 2016; Shores et al. 2017; Wen et al. 2021	Alawattegama et al. 2015; Agarwal et al. 2020; ATSDR 2016a; Bain et al. 2021; Baka in press; Bamberger et al. 2019; Banan and Gernand 2021; Blondes et al. 2020; Boyer et al. 2012; Brown et al. 2019; Bugher et al. 2024; Cantlay et al. 2019; Casey et al. 2015; Casey et al. 2022; Chen et al. 2024; Clark et al. 2022; Cravotta et al. 2022; Darrah et al. 2014; Drollette et al. 2015; Epuna et al. 2022; Esswein et al. 2013; Ferrar et al. 2013; Frazier 2009; Grieve et al. 2018; Haines et al. 2024; Hayes 2009; Hildenbrand et al. 2020; Hladik et al. 2014; Jackson et al. 2013; Johnson et al. 2015; Kingsbury et al. 2023; Knee and Masker 2019; Landis et al. 2016; Lewis et al. 2016; Li et al. 2021, 2023; Low et al. 2016; Majid et al. 2017; Marza et al. 2022; McDevitt et al. 2022, 2024; McMahon et al. 2019; Molofsky et al. 2016; Ma et al. 2019, 2022, 2023; Niu et al. 2018; Osborn et al. 2011; Rathnayaka et al. 2024; Rish and Pfau 2018; Shaheen et al. 2022, 2024; Olmstead 2013; Perry, 2013; Saiers in review; Soriano et al. 2020, 2022, 2023; States et al. 2013; Theodori and Podeschi 2020; Torres et al. 2017; US EPA 2015; Warner et al. 2013; Wen et al. 2018, 2019, 2021; Wickline and Hopkinson 2020; Wilson et al. 2012; Wilson et al. 2014; Woda et al. 2018; Xiong et al. 2022; Zhang et al. 2015; Ziemkiewicz et al. 2013	Bean et al. 2018; Chen et al. 2023a; Eisenlord et al. 2018; Gardiner et al. 2020; Hildenbrand et al. 2016; Jiang et al. 2021; Jiang et al. 2022; Kashani et al. 2024; Liden et al. 2022; Marza et al. 2022; MDevitt et al. 2022; Nelson and Heo 2020; Nicot et al. 2023; Rodriguez et al. 2020; Scanlon et al. 2022; Stemple et al. 2024; Tarazona et al. 2024; Thakur et al. 2022; Townsend et al. 2021; Wang 2021	Beausoleil et al. 2022; Black et al. 2021; Buse et al. 2019; COGC 2023; Dubé et al. 2022; Hajat et al. 2020; HEI Energy 2025[b]; HEI Energy Research Committee 2020; Klasic et al. 2022; Krupnick et al. 2017; Lawe et al. 2005; Mayer 2017; NASEM 2003; Ryan in press; Saiers in review; Yap 2016

continued

Table A-1. Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada[a]

	Study Locations			
Impacts	**Denver-Julesburg Region, Colorado**	**Marcellus Region, Pennsylvania**	**Permian Region, New Mexico and Texas**	**Other Locations in the United States and Canada**
Greenhouse gases	Benedict et al. 2019; Cheadle et al. 2017; COGC 2023; ECMC 2024; Evans and Helmig 2017; Flocke et al. 2020; Heimerl et al. 2023; Ilonze et al. 2024; Lackey et al. 2022; Larson et al. 2018; Lindaas et al. 2019; Lyu et al. 2020; McDuffie et al. 2016; Nsanzineza et al. 2019; Oltmans et al. 2019; Ortega et al. 2021; Rodriguez et al. 2009; Schade in review; Silberstein et al. 2024; Zaragoza et al. 2017	Chang et al. 2016; Dennis et al. 2022; DiGuilio et al. 2023; Fann et al. 2018; Orak and Pekney 2020; Pekney et al. 2018; Riddick et al. 2024; Saint-Vincent et al. 2021; Wendt Hess et al. 2019; Yang et al. 2024	Cardoso-Saldaña et al. 2023; Chen et al. 2022; Chen et al. 2023b; Cusworth et al. 2021; Daniels et al. 2023; Heimerl et al. 2023; Kunkel et al. 2023; Opara et al. 2024; Townsend et al. 2021; Schade in review; Stokes et al. 2022; Varon et al. 2023; Veefkind et al. 2023; Yu et al. 2022	Black et al. 2021; COGC 2023; HEI Energy 2025[b]; Klasic et al. 2022; Mayfield et al. 2019; Schade in review
Noise	Malin 2020; Collett in press	Theodori and Podeschi 2020 Richburg and Slagley 2018	Not documented in the reviewed literature	Adgate et al. 2014; Black et al. 2021; Buse et al. 2019; HEI Energy 2025[b]; HEI Energy Research Committee 2020; Hemmerling et al. 2021; Klasic et al. 2022
Environmental degradation	Malin 2020	Brasier et al. 2011	Elser 2020; Kashani et al. 2024	Adgate et al. 2014; Beausoleil et al. 2022; Black et al. 2021; Dubé et al. 2022; HEI Energy 2025[b]; Hemmerling et al. 2021; Klasic et al. 2022; Krupnick et al. 2017; Mayer 2017; NASEM 2003
Accidents, spills, leaks	Shores et al. 2017; Kanno and McCray 2021	Theodori and Podeschi 2020		Adgate et al. 2014; HEI 2015; HEI Energy 2025[b]; Hemmerling et al. 2021; NASEM 2003
Built Environment				
Transportation and infrastructure	Haggerty et al. 2018	Brasier et al. 2011; Perry et al. 2012; Perry, 2013; Theodori and Podeschi 2020		Adgate et al. 2014; Buse et al. 2019; Klasic et al. 2022; Krupnick et al. 2017; Mayer 2017; NASEM 2003
Socioeconomic				
Employment	Haggerty et al. 2018; Malin 2020; Weber 2012	Perry, 2013; Theodori and Podeschi 2020	Elser 2020; Figgins et al. 2021; Ross et al. 2024; Wang 2020	Black et al. 2021; Buse et al. 2019; Klasic et al. 2022; Krupnick et al. 2017; Mayfield et al. 2019

continued

Table A-1. Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada[a]

	Study Locations			
Impacts	**Denver-Julesburg Region, Colorado**	**Marcellus Region, Pennsylvania**	**Permian Region, New Mexico and Texas**	**Other Locations in the United States and Canada**
Income	Haggerty et al. 2018; Malin 2020; Malin et al. 2023a	Brasier et al. 2011; Perry et al. 2012; Perry, 2013; Theodori and Podeschi 2020	Ross et al. 2024; Wang 2020	Black et al. 2021; Buse et al. 2019; Haggerty et al. 2018; Klasic et al. 2022; Krupnick et al. 2017; NASEM 2003
Cost of living	Haggerty et al. 2018	Brasier et al. 2011; Perry, 2013; Theodori and Podeschi 2020	Figgins et al. 2021	Black et al. 2021; Buse et al. 2019; Haggerty et al. 2018; Klasic et al. 2022; Krupnick et al. 2017
Public revenue and local government services	Newell and Raimi 2018	Brasier et al. 2011; Perry, 2013	Prest et al. 2025; Wang 2018	Klasic et al. 2022
Health Outcomes				
General self-rated health, quality of life outcomes	Mayer et al. 2020	Perry 2012; Perry 2013; Steinzor et al. 2013		Adgate et al. 2014; Aker et al. 2024; Black et al. 2021; Boslett et al. 2021; HEI Energy 2025[b]; HEI Energy Research Committee 2019; Klasic et al. 2022; Krupnick et al. 2017; Mayer 2017; Willis et al. 2024
Morbidity and mortality outcomes	CDPHE 2012, 2016, 2017c, 2017b, 2017a, 2018a, 2018c, 2018b; Holder et al. 2019; McKenzie et al. 2012; McKenzie et al. 2018; McMullin et al. 2018	ATSDR 2016a, 2016b; Brown et al. 2019; Gradient Corporation 2019; Long et al. 2021; PA DOH 2018; Rish et al. 2018		Aker et al. 2022; Aker et al. 2024; Black et al. 2021; Casey et al. 2019; Deziel et al. 2020; HEI Energy 2025[b]; HEI Energy Research Committee 2019; Klasic et al. 2022; Krupnick et al. 2017; Li et al. 2022; Mayer 2017; Scheule et al. 2022
Psychosocial and Spiritual				
Psychosocial outcomes	Malin 2020; Malin and Kallman 2024	Perry et al. 2012; Perry 2013; Theodori and Podeschi 2020	Elser 2020	Adgate et al. 2014; Buse et al. 2019; Casey et al. 2019; Klasic et al. 2022; Willis et al. 2024
Powerlessness	Marlin-Tackie et al. 2020; Mckenzie et al. 2016; Malin et al. 2019; Malin 2020	George 2019; Jalbert et al. 2019; Malin et al. 2019; Malin and Demaster 2016; Perry et al. 2012		Mayer 2017
Identity and values	Haggerty et al. 2018	Brasier et al. 2011; Perry et al. 2012; Perry, 2013; Theodori and Podeschi 2020	Ross et al. 2024	Adgate et al. 2014; Buse et al. 2019; Haggerty et al. 2018; Klasic et al. 2022; Mayer 2017
Spiritual				Buse et al. 2019

continued

Table A-1. Peer-Reviewed and Gray Literature About Potential Impacts on Populations Affected by UOGD in the United States and Canada[a]

	Study Locations			
Impacts	Denver-Julesburg Region, Colorado	Marcellus Region, Pennsylvania	Permian Region, New Mexico and Texas	Other Locations in the United States and Canada
Community				
Quality of life	Haggerty et al. 2018	Brasier et al. 2011; Perry et al. 2012; Theodori and Podeschi 2020	Ross et al. 2024	Adgate et al. 2014; Buse et al. 2019; Haggerty et al. 2018; Klasic et al. 2022; Mayer 2017; NASEM 2003

[a]All literature reviewed and the HEI spatial bibliography were current as of January 2025.
[b] See HEI Energy's Spatial Bibliography, *https://www.heienergy.org/literature-hub*, for nationwide references.

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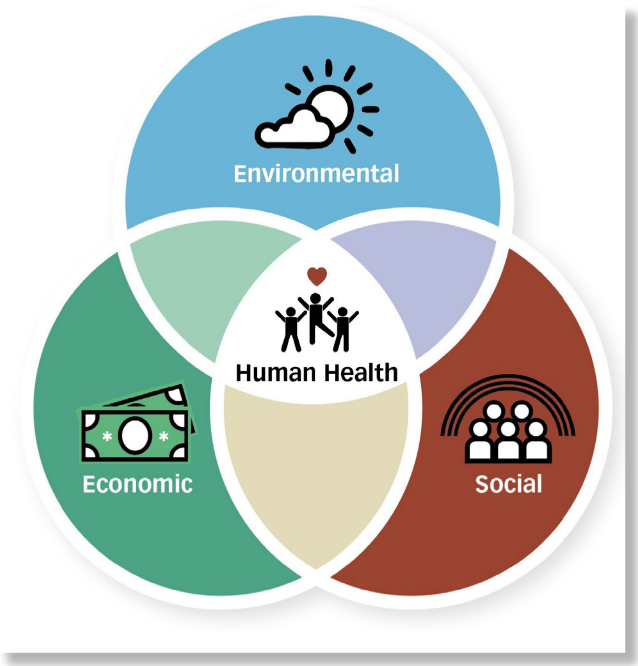
APPENDIX B

✔ Checklist for Cumulative Impact Assessment



The health of people living in any community can be affected by an array of environmental, social, and economic factors. Numerous studies throughout the scientific literature document how exposures associated with one or even a few factors might affect human health. The same is not true for understanding how integrated (or cumulative) exposure to all factors can affect health. This checklist forms part of a larger roadmap that contributes to ongoing efforts to advance the practice of assessing cumulative exposures and their impacts in the United States using a tool referred to as cumulative impact assessment (CI assessment). It provides considerations that can inform a CI assessment process (illustrated on the next page), alongside example contexts for how these considerations might be applied in real-world communities. CI assessments can help to reframe scientific and policy discussions so that they encompass the full spectrum of factors that can affect human health and, in so doing, position decision-makers to capitalize on beneficial impacts while avoiding adverse impacts. Because CI assessment processes are highly context-specific, this checklist and the roadmap are not intended to provide prescriptive guidance on the implementation of a CI assessment.

The format of this checklist reflects a four-phase, generic process for CI assessment described in the roadmap (**Figure 1**).

We ask anyone who elects to use the roadmap and checklist to share your experience and any ideas for improving these resources by emailing us at *energy@healtheffects.org*.

Decision Context for CI Assessment

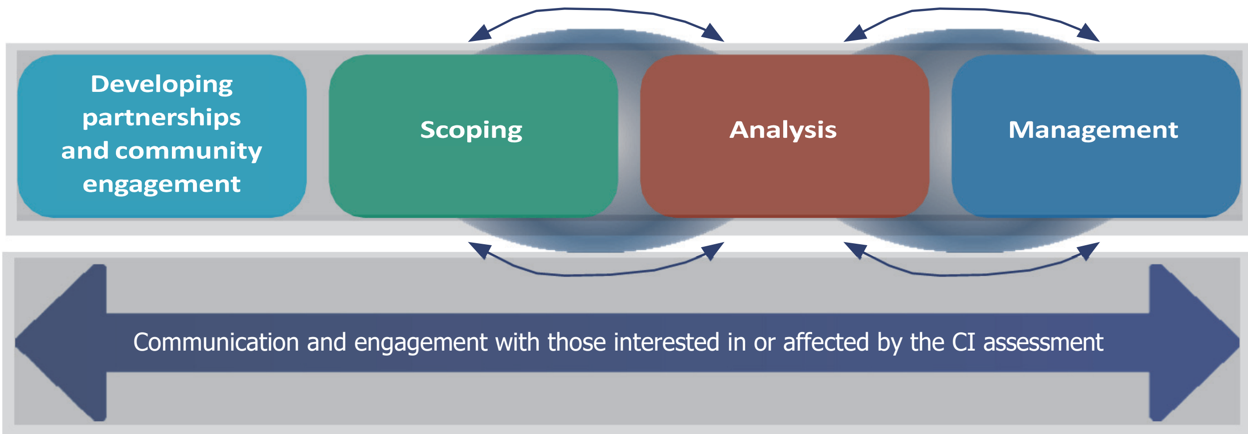


Figure 1. Overview of the four-phase, generic process for CI assessment described in this roadmap, including communication and engagement throughout the CI assessment process (large arrow) and the potential for iteration between phases (shown using thin arrows).

DECISION CONTEXT: WHAT QUESTION OR ISSUE IS BEING ADDRESSED?

The analytical approach and methods used in a CI assessment are shaped by the context in which it is being applied. CI assessment can inform regulatory decisions, and it can also be used for nonregulatory, research, or educational purposes.

1. What is the decision context for the CI assessment?

- ❍ Federal, state, or local regulation
- ❍ Nonregulatory, research, or educational project
- ❍ Other

PHASE 1. DEVELOPING PARTNERSHIPS AND COMMUNITY ENGAGEMENT: WHO SHOULD BE INVOLVED?

A key component of the CI assessment process is building partnerships and engaging with people in communities across sectors who are interested in or somehow affected by the decision or activity that has initiated the assessment process. Continued communication and engagement throughout and after the CI assessment process are critical aspects of this phase.

2. Who will lead and who will be involved in the assessment process?

- If the decision context is regulatory, recruit key partners that the regulation requires for participation in the CI assessment process; these might include government officials, industry representatives, research or academic partners, and community members.
- Identify individuals with the following expertise and experience for the project team: policy, industry, research and analysis, environmental health, and community voices.
- Identify other individuals who want to participate in the assessment process, who have been involved in prior research or assessment efforts, and who have not been involved in prior efforts.

3. How will participants be involved in the assessment process?

- Define roles and responsibilities for all assessment participants, which might include project management, data collection, research and analysis, advisory, oversight, and communication.
- Define roles and responsibilities based on interest, expertise, and potential impact on the project implementation and outcomes.
- Define how participants will be compensated, how their information will be protected, and how the assessment process will be facilitated.

4. How will information be communicated throughout and after the assessment process?

- Define how all aspects of the assessment process will be communicated among assessment participants.

5. How will broader engagement occur?

- Define the general public and identify how the public will be involved in the assessment process.
- Define how all aspects of the assessment process, including results, will be communicated to the public.

PHASE 2. SCOPING: WHAT IS THE FULL SCOPE OF EXPOSURES AND FACTORS AND WHAT IS MOST IMPORTANT TO INCLUDE IN THE ASSESSMENT?

The scoping phase of a CI assessment is intended to both explore and set parameters and boundaries for the breadth of the assessment. It consists of identifying and prioritizing which impacts to evaluate in the assessment, determining geographic and temporal boundaries for the assessment, and identifying other related factors that might interact with or affect the impacts being assessed.

6. Identify potential impacts

- If the decision context is regulatory, determine and identify what categories of impacts are required to be assessed (e.g., natural environment, built environment, socioeconomic, health, psychosocial, spiritual, and community-level).
- Define how potential impacts will be identified. Methods can include a literature review, surveys, focus groups, group discussions, multisector forums, or some other mechanism.
- Identify and list potential impacts for an array of factors that might affect human health and well-being of individuals in an affected population; these might include natural environment, built environment, socioeconomic, health, psychosocial, spiritual, and community-level impacts.
- Identify and list what exposures and factors are associated with the identified impacts.
- Ensure that all assessment participants have been consulted on what potential impacts to consider.
- If appropriate, ensure that the general public has had an opportunity to identify potential impacts for consideration in the assessment.

7. Prioritize potential impacts

- Identify potential impacts that are of value to the community; consult community member assessment participants for the best way to survey or speak with other community members.
- Identify potential relationships or potential interactions among and between impacts; consult all assessment participants.
- Identify what data or information is available on identified impacts; consult government partners, industry partners, and research or academic partners for resources.
- Identify the temporal scale and spatial scale of available data and information.
- Determine whether any critical information gaps exist.
- Based on available information, impacts of highest concern, time, labor, and resources, select a final set of impacts and what metrics will be used to assess those impacts in the assessment; endeavor for consensus among all assessment participants.

8. Determine geographic and temporal boundaries

- Determine whether the decision context specifies the geographic and temporal scope of the assessment.
- Determine the spatial extent of activities being assessed and whether prioritized impacts extend beyond these boundaries; consult government partners, industry partners, community members, and research or academic partners.
- Determine spatial scale of assessment (e.g., counties, census tracts, census blocks), which will partly depend on data and information identified in 7.
- Determine what time frame should constitute the baseline for the assessment and what time frame should constitute the assessment of impacts into the future; consult all assessment participants. This decision will likely depend on data and information identified in 7.

9. Identify other related factors

- Identify other industries, sources, or activities that are located within the geographic scope of the assessment that might affect, or are the same as, one or more prioritized impacts (such as emissions of air pollutants or greenhouse gases). Consult all assessment participants.
- Determine whether other assessments have been performed for other nearby sources of concern; consult government partners and research or academic partners, and consider conducting a literature review.
- Identify terrain, weather, climatic, or atmospheric conditions within the geographic scope of the assessment that might affect prioritized impacts; consult all assessment participants.

PHASE 3. ANALYSIS: WHAT ANALYTICAL METHODS ARE AVAILABLE AND MOST APPROPRIATE?

The analysis phase of a CI assessment builds and expands on the results of the scoping phase. It includes additional consideration of relationships and interactions among and between impacts and their associated exposures and factors begun in the scoping phase. The analysis phase includes an assessment of baseline conditions of the population in which the CI assessment is being conducted, an assessment of cumulative impacts, and a determination of the significance of cumulative impacts.

10. Assess baseline

- Based on the temporal boundaries identified in item 8, identify time period for the collection of baseline information.
- Collect baseline information on prioritized impacts within the geographies determined in item 8, which might include data on water quality, air quality, health outcomes, and employment rates.
- If additional information is identified as missing in item 6, collect data on missing information. Collection methods might include environmental sampling, remote sensing, surveys, focus groups, or ethnographic research methods.
- Collect data on baseline health status of the community, which might include rates of chronic disease, asthma, quality of life metrics, and healthcare utilization. Data collection is likely to be conducted by government partners or other research and academic partners.

11. Assess cumulative impacts

- If the decision context is regulatory, identify whether certain analytical or other methods are prescribed to assess cumulative impacts.
- Consult all assessment participants to determine appropriate methods for analysis; these might include spatial analysis, statistical modeling, exposure assessment, or scenario modeling.

Considerations for determining appropriate analytical methods (Subsection #11)**:**

- Identify resources available for conducting analysis and modify analytical methodology as needed.
- Determine how the assessment of future changes in prioritized impacts will be conducted.
- Determine how interaction among prioritized impacts will be assessed.
- Determine how tradeoffs between beneficial and adverse impacts will be assessed.
- Determine the appropriateness of including an evaluation of uncertainty for the assessment of cumulative impacts.
- Identify whether certain analytical methods are more relevant to identifying and successfully implementing management strategies for cumulative impacts.
- Determine whether assessment of cumulative impacts will be evaluated among groups of prioritized impacts, or whether a single determination of cumulative impact is more appropriate.
- Analyze cumulative impacts. Analysis likely to be conducted by government, industry, research, or academic partners.

12. Determine the significance of cumulative impacts

- If the decision context is regulatory, identify whether thresholds or methods to determine the significance of cumulative impacts are prescribed in the regulation.
- Determine if there are appropriate thresholds that would constitute significant cumulative impacts. Determination is likely to be a normative and subjective process conducted in consultation with all assessment participants and might include a literature review, review of other impact assessments in the region, consultation among assessment participants and experts outside of assessment participants.
- Evaluate whether cumulative impacts assessed in item 11 surpass the identified thresholds for the assessment.

PHASE 4. MANAGEMENT: WHAT ARE THE OPTIONS FOR ADDRESSING THE OUTCOME OF THE ASSESSMENT?

The management phase of a CI assessment includes the identification and implementation of potential strategies for preventing, minimizing, and monitoring cumulative impacts. The management phase might include iteration with the analysis phase of a CI assessment. This phase might or might not be applicable depending on the decision context for the assessment.

13. Avoid, minimize, and monitor cumulative impacts

- If the decision context is regulatory, determine what management strategies are required to address cumulative impacts; consult all assessment participants. Implementation is likely to be conducted by industry partners alongside government, research, or academic partners.
- Identify the outcome of the assessment and whether significant cumulative impacts have been identified.
- Identify strategies to prevent or minimize cumulative impacts and thresholds identified in the analysis phase. Strategies might include the implementation of technological solutions, modifications of the activities being assessed, or modifications of governance processes. Consult all assessment participants; implementation likely to be conducted by industry partners alongside government, research, or academic partners.
- Determine any strategies to maximize beneficial impacts while minimizing adverse impacts identified in the analysis phase.
- Identify strategies to monitor cumulative impacts identified in the analysis phase. Strategies might include implementing additional data collection and analysis efforts or establishing working groups. Consult all assessment participants; implementation likely to be conducted by industry partners alongside government partners, community members, and research or academic partners.
- Determine how management strategies will be monitored and evaluated. Strategies might include the establishment of working groups and multisector collaboration. Consult all assessment participants; implementation likely to be conducted by industry partners alongside government partners, community members, and research or academic partners.

APPENDIX C

Special Panel Biographies

Chair, Julia Haggerty, Department of Earth Sciences at Montana State University (MSU)

Dr. Haggerty is an Associate Professor of Geography in the Department of Earth Sciences at MSU, where she holds a joint appointment in the Montana Institute on Ecosystems. She received her bachelor's degree from Colorado College in liberal arts and her doctorate from the University of Colorado in history. An award-winning teacher, Dr. Haggerty teaches courses in human, economic, and energy resource geography at MSU. She also leads the Resources and Communities Research Group in studying the ways rural communities respond to shifting economic and policy trajectories, especially as they involve natural resources. Dr. Haggerty has expertise in diverse rural geographies, including those shaped by energy development, extractive industries, ranching and agriculture, and amenity development and conservation. Partnerships and collaboration with diverse stakeholders are central to her approach.

Before joining MSU, Dr. Haggerty was a postdoctoral fellow at the University of Otago in New Zealand (2005–2007) and a policy analyst with Headwaters Economics in Bozeman, Montana (2008–2013). She speaks frequently to public audiences about her research and has served on a number of boards and advisory committees operating at local, state, national, and international scales.

Nicole Deziel, Department of Environmental Health Sciences at Yale School of Public Health

Dr. Deziel is an Associate Professor of Epidemiology in the Department of Environmental Health Sciences at the Yale School of Public Health and Co-Director of the Yale Center for Perinatal, Pediatric, and Environmental Epidemiology. She obtained a master's degree in industrial hygiene and a doctorate in environmental health from the Johns Hopkins Bloomberg School of Public Health. Her research focuses on applying statistical models, biomonitoring techniques, and environmental measurements to provide comprehensive and quantitative assessments of exposure to traditional and emerging environmental contaminants in population-based studies. Her research uses a combination of large, administrative datasets and detailed community-focused studies to advance understanding of environmental exposures to chemicals, particularly carcinogens and endocrine disruptors. This research also serves to illuminate exposure mechanisms underlying associations between environmental chemicals and disease, thereby informing more effective policies to reduce exposures and protect public health. Dr. Deziel's contributions have been concentrated in two main areas: (1) exposure and human health impacts of unconventional oil and gas development ("hydraulic fracturing") and (2) residential exposure to chemicals in common consumer products (e.g., pesticides, flame retardants) and cancer risk (particularly thyroid cancer). In addition, she considers disproportionate burdens of exposures ("environmental justice") and the combination of environmental and social stressors in the context of her work.

Stephanie Malin, Department of Sociology at Colorado State University (CSU)

Dr. Malin is an environmental sociologist specializing in the impacts of extraction and energy production on communities. Her main interests include environmental justice, environmental health, social movements, and the social and ecological effects of capitalist economies. She also examines communities building more distributive and regenerative systems. Stephanie serves as a professor in the Department of Sociology at CSU, and she is an adjunct professor with the Colorado School of Public Health. Stephanie cofounded and codirects the Center for Environmental Justice at CSU. She is an award-winning teacher of courses on environmental justice, water and society, and environmental sociology.

Dr. Malin is the author of two books, B*uilding Something Better: Environmental Crises and the Promise of Community Change* (2022) with Meghan Elizabeth Kallman and *The Price of Nuclear Power: Uranium Communities and Environmental Justice* (2015). She conducts public sociology and engaged scholarship, and her work can additionally be found in news outlets like *The Conversation* and *High Country News*. Dr. Malin's work has been supported by grants from the US Department of Energy, US Environmental Protection Agency, National Science Foundation, National Institutes of Environmental Health Sciences, the American Sociological Association, the Colorado Department of Public Health & Environment, the Rural Sociological Society's Early Career Award, and the Colorado Water Center. Dr. Malin has also enjoyed serving in elected leadership positions for the American Sociological Association's section on Environmental Sociology and the International Association for Society and Natural Resources. She completed a Mellon Foundation Postdoctoral Fellowship at Brown University after earning her doctorate in sociology from Utah State University.

Daniel Rossi-Keen, RiverWise

Dr. Rossi-Keen is the executive director of RiverWise. RiverWise exists to organize community power and voice so that residents can assert agency over the future of Beaver County, Pennsylvania. He has served on the boards of more than 30 nonprofit and civic organizations, teaches regularly at colleges and universities around the region, and writes a biweekly column entitled "Community Matters" for the *Beaver County Times*. Dr. Rossi-Keen holds a doctorate in rhetoric and philosophy of communication from Ohio University, a master's degree in rhetoric and culture from Ohio University, a master's degree in philosophy from Ohio University, a graduate certificate in women's studies from Ohio University, a master's degree in theological studies from Reformed Theological Seminary, and a bachelor's degree in interdisciplinary studies from Grove City College. Dr. Rossi-Keen lives in Aliquippa with his wife and four children, who daily motivate him to work toward more vibrant communities throughout Beaver County.

ABBREVIATIONS AND OTHER TERMS

ATSDR	Agency for Toxic Substances and Disease Registry
BACT	Best Available Control Technology
BLM	US Bureau of Land Management
BTEX	benzene, toluene, ethylbenzene, and xylenes
CDPHE	Colorado Department of Public Health and Environment
CDC	US Centers for Disease Control and Prevention
CEQ	Council on Environmental Quality
CI	cumulative impacts
COGC	Colorado Oil and Gas Conservation Commission
CSU	Colorado State University
ECMC	Energy and Carbon Management Commission
EIA	Energy Information Administration
EJC	Environmental Justice Clinic
EPA	US Environmental Protection Agency
HAP	hazardous air pollutants
HFTS	hydraulic fracture test site
IAIA	International Association for Impact Assessment
MPCA	Minnesota Pollution Control Agency
MSU	Montana State University
NEPA	National Environmental Policy Act
NMED	New Mexico Environment Department
OGD	oil and gas development
PM	particulate matter
PMF	positive matrix factorization
TRACER	Tracking Community Exposures and Releases (Collaboration)
UOG	unconventional oil and gas
UOGD	unconventional oil and gas development
USGS	US Geological Survey
VOC	volatile organic compounds
WHO	World Health Organization
WSGS	Wyoming State Geological Survey

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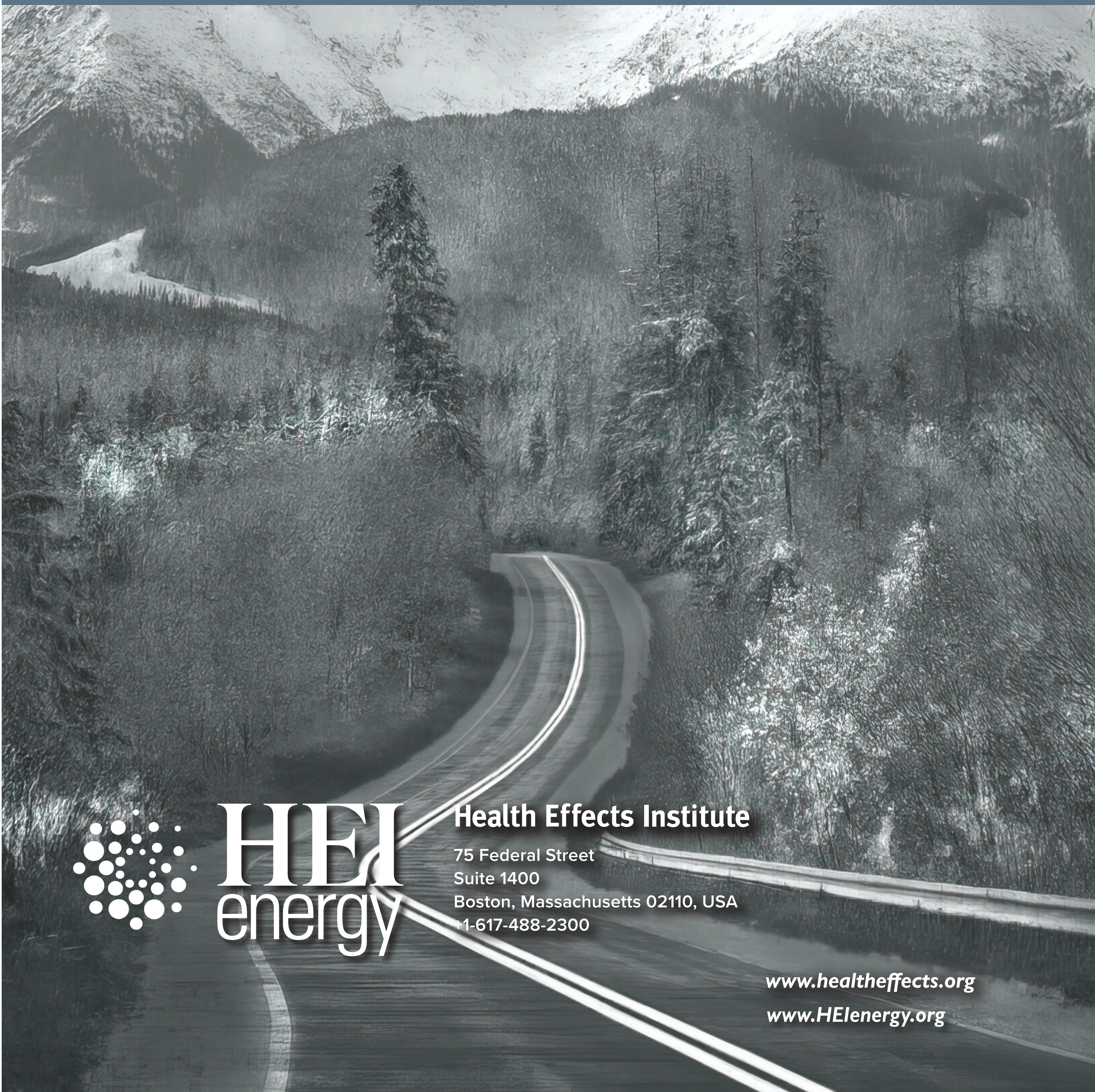

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