










PRACTICE BRIDGE

Means, motive, and opportunity: A method for understanding stakeholder agency within food–energy–water systems

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Wicked problems are inherent in food–energy–water systems (FEWS) due to the complexity and interconnectedness of these systems, and addressing these challenges necessitates the involvement of the diverse stakeholders in FEWS. However, successful stakeholder engagement requires a strong understanding of the relationships between stakeholders and the specific wicked problem. To better account for these relationships, we adapted a means, motive, and opportunity (MMO) framework to develop a method of stakeholder analysis that evaluates the agency of stakeholders related to a wicked problem in FEWS. This method involves two key components: (1) identification of a challenge at the FEWS nexus and (2) evaluation of stakeholder agency related to the challenge using the dimensions of MMO. This approach provides a method for understanding the characteristics of stakeholders in FEWS and provides information that could be used to inform stakeholder engagement in efforts to address wicked problems at the FEWS nexus. In this article, we present the stakeholder analysis method and describe an example application of the MMO method by examining stakeholder agency related to the adoption of improved swine waste management technology in North Carolina, USA.

Keywords: Stakeholder analysis, FEWS, Environmental sustainability, Transdisciplinary research, Stakeholder engagement, Livestock production

Introduction

Developing sustainable food–energy–water systems (FEWS) will necessitate addressing a variety of “wicked problems,” which are complex challenges that lack clear solutions and require novel approaches to research and management (Rittel and Webber, 1973; Rodríguez et al., 2019; Wade et al., 2020). FEWS epitomize wicked problems due to their interconnectedness and interdependence, wherein competing resource demands affect resource availability and reinforce the interdependence of each component (Levin et al.,

2012; D’Odorico et al., 2018; Dargin et al., 2019). Due to the complexity and interrelatedness of wicked problems, tackling these challenges in FEWS requires the involvement of diverse groups of stakeholders (Kliskey et al., 2021), that is, the “people and organizations who are involved in or affected by an action or policy and can be directly or indirectly included in the decision making process” (Vogler et al., 2017, p. 6).

Stakeholder engagement in research and management at the FEWS nexus is critical for understanding the

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complex challenges common in these systems and developing innovative solutions to address these challenges (Armitage et al., 2008; Eaton et al., 2021; Kliskey et al., 2021). However, stakeholder engagement requires knowledge of the various stakeholders in these systems. For example, successful stakeholder engagement is characterized by the inclusion of diverse stakeholders (Reed et al., 2009; Muro and Jeffrey, 2012; Eaton et al., 2021). Thus, identifying whom to approach requires a solid understanding of both the wicked problem and the relationships between the stakeholders in the system, in order to ensure that the relevant stakeholders, including marginalized stakeholders, can be effectively engaged. However, developing an understanding of wicked problems and the relevant stakeholders at the FEWS nexus can create a barrier due to the complexity of these systems and the need for transdisciplinary collaboration given that such systems inherently transcend conventional fields of study (Brown et al., 2010; Rodríguez et al., 2019; Wade et al., 2020).

Stakeholder categorization approaches are used to identify the characteristics of stakeholders in a given system, including their relationship to a phenomenon (Reed et al., 2009). In some approaches such as stakeholder analysis matrices, those performing the analysis categorize stakeholders (Reed et al., 2009) based on attributes such as interest and influence (e.g., Nedelciu et al., 2019; Smrekar et al., 2020), power and influence (e.g., Olander and Landin, 2005), or enablers and influencers (e.g., Kennon et al., 2009). Bendtsen et al. (2021) found that the attributes of interest and influence were documented in over 71% of published stakeholder analyses. Other approaches to categorization are driven by stakeholders (Reed et al., 2009), including stakeholder-led categorization (e.g., Hare and Pahl-Wostl, 2002), in which stakeholders develop categories and assign stakeholders to those categories, and social network analysis, in which stakeholders identify the relationships between the stakeholders in a system (e.g., Paletto et al., 2015).

However, the application of these existing methods for stakeholder categorization presents challenges due to a lack of definition of key terms, transparency, and reproducibility (Bendtsen et al., 2021). These challenges may intensify when transdisciplinary teams with diverse expertise and varying levels of knowledge of the system and problem apply these methods. Some methods are also time- and resource-intensive, presenting a challenge for researchers and managers who are short of both (Reed et al., 2009). Furthermore, approaches to stakeholder categorization can lack an action orientation, that is, these methods do not explicitly assess stakeholders' agency to address a given challenge and instead focus solely on stakeholder interests (Bendtsen et al., 2021). The agency of a stakeholder describes "the capacity of the individual to plan and initiate action" (Onyx and Bullen, 2000). Understanding the capacity of stakeholders to take action related to a challenge at the FEWS nexus can provide insight as to why change is, or is not, occurring in a specific system. Additionally, assessing stakeholder agency is particularly relevant to the research and management of

wicked problems in FEWS, given the importance of involving stakeholders in addressing these problems (Kliskey et al., 2021). An improved understanding of stakeholder agency could ultimately facilitate successful stakeholder engagement in FEWS research and management by informing which and how stakeholders should be involved (Reed et al., 2009).

We developed a stakeholder analysis method for assessing the agency of stakeholders associated with a wicked problem by adapting a "means, motive, and opportunity" (MMO) approach for stakeholder categorization. This method is particularly well-suited for tackling wicked problems in FEWS because it:

- focuses on stakeholder agency,
- includes individual and collective levels of analysis,
- requires minimal time and resources, and
- uses common language accessible to researchers and resource managers with different levels of system and stakeholder understanding, as well as to the transdisciplinary teams that are common in these systems.

In this practice bridge, we:

1. present and describe the MMO framework adapted as a method for stakeholder categorization in FEWS;
2. provide an example of how the MMO method can be applied to a wicked problem at the FEWS nexus, namely swine waste management in North Carolina; and
3. discuss the strengths, challenges, and future applications of the MMO stakeholder analysis method.

MMO method for stakeholder analysis

The MMO framework has been previously used to understand behavior or action in several disciplines including business (Pendse, 2012), psychology (Neuman and Keashly, 2010; O'Reilly and Pfeffer, 2021), and cybersecurity (Van Ruitenbeek et al., 2010). This approach uses three dimensions (MMO) to examine the likelihood of a given action or to identify the necessary conditions for effective action. These applications of the MMO approach assert that the convergence of MMO for an individual indicates that they are more likely to act or be effective in their action than an individual who lacks in one or more of the dimensions (Van Ruitenbeek et al., 2010; Pendse, 2012; O'Reilly and Pfeffer, 2021).

We adapted the MMO framework to categorize stakeholders in terms of their agency related to wicked problems in FEWS. Stakeholders may be individuals, informal actor groups (e.g., farmers), formal organizations (e.g., a farming association), or institutions (e.g., the U.S. Department of Agriculture). The dimensions of MMO describe the multiple factors contributing to a stakeholder's agency related to a given challenge at the FEWS nexus (**Table 1**). The convergence of MMO suggests that

Table 1. Means, motive, and opportunity dimensions of stakeholder agency. DOI: <https://doi.org/10.1525/elementa.2021.00066.t1>

Dimension	Definition
Means	What types(s) and level(s) of capital (e.g., social, political, financial) does the stakeholder possess related to the problem of focus (Emery and Flora, 2006)?
Motive	What reason(s) does the stakeholder have to act in terms of the problem of focus? The source of motive may be external (e.g., governmental regulations, direct health impacts), or internal (e.g., value-driven), or both.
Opportunity	What is the proximity (i.e., degree of involvement) of the stakeholder to the problem of focus? Does the stakeholder experience opportunities for, or barriers to, taking action?

Table 2. Qualitative rating scale for stakeholder means, motive, and opportunity. DOI: <https://doi.org/10.1525/elementa.2021.00066.t2>

Rating	Interpretation
0	None
1	Low
2	Medium
3	High

a given stakeholder has a greater degree of agency related to the challenge, whereas a lack of MMO implies a lower degree of agency.

Because FEWS problems typically involve many stakeholders, we specified a qualitative rating system that can require minimal time and data to estimate the MMO dimensions of agency for each stakeholder with regard to a given challenge (**Table 2**). This scale can incorporate both quantitative and qualitative data when assigning ratings. Sources of information such as research publications, popular press articles, stakeholder interviews or conversations, and existing researcher knowledge can all inform stakeholder ratings and should be utilized based on the team's research or management context, information needs, and available resources. In other words, a team can assign MMO ratings rapidly using easily accessible resources and with minimal time and information requirements, or it could perform a highly detailed assignment of ratings using a variety of sources of information, depending on the level of depth and accuracy needed to meet their objectives.

We also propose a method to weight the agency of stakeholders in the given system, in addition to the MMO dimensions of agency. Weights can be assigned using the same qualitative rating scale (**Table 2**). This weighting component provides an opportunity to incorporate additional knowledge about the system in the assessment of stakeholder agency, given that some stakeholders may

have greater agency than others due to factors outside of the MMO dimensions. For example, the internal alignment of stakeholder groups (e.g., farmers) might be a possible weighting metric. In this example, strong alignment due to cohesive messaging or organized activism would suggest that the stakeholder possesses greater agency related to the focal challenge. The use of weights should be considered depending on the research or management context and the goals of those implementing the MMO method of stakeholder categorization. The unweighted or weighted ratings for all stakeholders in a given system can also be summed to evaluate the collective level of stakeholder agency in the system and provide information on the collective degree of stakeholder agency related to the focal problem (Equations 1–3).

$$1. \text{Means}_{\text{system}} = \sum_i \text{means}_i \times \text{weight}_i,$$

where i is the i th stakeholder.

$$2. \text{Motive}_{\text{system}} = \sum_i \text{motive}_i \times \text{weight}_i,$$

where i is the i th stakeholder.

$$3. \text{Opportunity}_{\text{system}} = \sum_i \text{opportunity}_i \times \text{weight}_i,$$

where i is the i th stakeholder.

We recommend that stakeholder ratings be assigned as a team in order to incorporate the diverse knowledge and perspectives present within a transdisciplinary team. Additionally, team-driven rating evaluates the collective knowledge of the system of interest and incorporates each team member's understanding of that system, which can promote learning for all individuals involved. These discussions of stakeholder ratings also facilitate the emergence of a systems lens.

The process of assigning ratings can be iterative, wherein the team may reevaluate the assigned ratings as new information or perspectives are introduced. The collaborative, iterative nature of this method also presents an opportunity for users to identify gaps in knowledge and new directions for research and stakeholder analysis and involvement. New questions about the current state of the FEWS, stakeholder agency, or potential future changes to the system may emerge through the process of team discussion and assigning ratings. These questions provide a foundation for further exploration of the relationships between stakeholders and the problem of focus. This process can foster a more robust understanding of the system and supply information that may ultimately be used to inform decision making related to stakeholder engagement. In this way, the MMO method provides both a process for team engagement around a common language (MMO) and a product that presents and compares information on stakeholder agency (**Figure 1**).

Case study: Swine waste management in North Carolina

Background

The NSF-funded INFEWS-ER Virtual Resource Center for Transdisciplinary Graduate Student Training at the Nexus of Food, Energy, and Water published a call for graduate

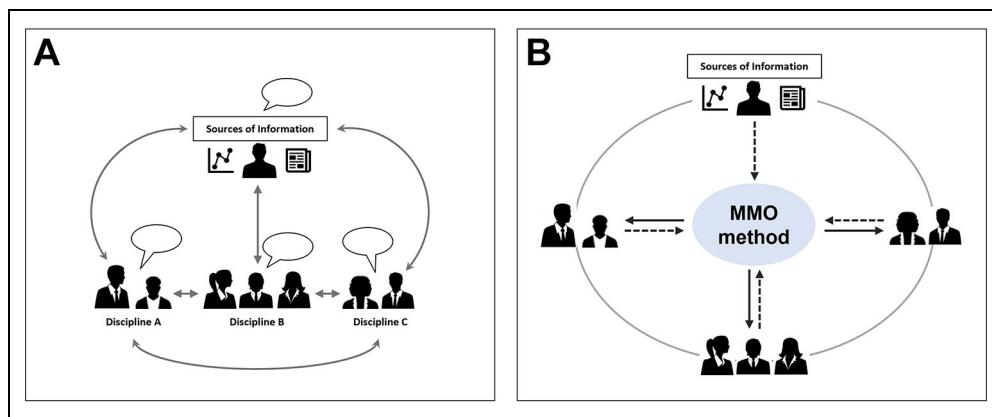


Figure 1. Depiction of means, motive, and opportunity (MMO) method compared to other stakeholder analysis processes. (A) Research team lacks the common language to discuss stakeholder information. Each team member's unique perspective is not being leveraged to improve understanding of the wicked problem. New knowledge gained from information sources is interpreted independently by each team member. (B) The MMO method is an iterative process for developing a shared system understanding and categorizing stakeholders through the common language, incorporating both the team's existing knowledge and new knowledge as it is acquired. Adapted from figure 3 illustrating project organizational models in Smith et al. (2014). DOI: <https://doi.org/10.1525/elementa.2021.00066.f1>

students interested in participating in a cohort challenge focused on exploring the relationships between livestock production, local resources, and stakeholders to identify future opportunities for stability and resilience within these systems (Rodríguez et al., 2019; Innovations at the Nexus of Food, Energy, and Water Systems Educational Resources, 2021). The team that was formed ultimately included 10 graduate students, three peer mentors, and four faculty advisors representing disciplines including agronomy, agricultural education and communication, animal science, biological and agricultural engineering, educational leadership, environmental science, law, and natural resources. The faculty advisors assigned the team the topic of livestock production in North Carolina, and the student members narrowed the group's focus to swine production in North Carolina. Through weekly virtual meetings, the team collaborated for 8 months between October 2020 and May 2021. During the first 6 months of the collaboration, the team focused on learning more about the swine production system in North Carolina with the guidance of the faculty advisors. During the final 2 months of the collaboration, the student participants led the adaptation of the MMO method for use in stakeholder analysis and the case study application of the method to the North Carolina swine production system.

The challenge of swine waste management in the state of North Carolina in the southeastern United States presents an example of a wicked problem at the FEWS nexus that will require the involvement of diverse stakeholders in order to ensure the health and safety of local communities, reduce pollution, and protect the livelihoods of swine producers. Swine production in North Carolina has experienced dramatic changes over the past 4 decades due to shifts in both markets and regulations. Between 1987 and 2007, the statewide inventory of hogs more than quadrupled to 10.1 million hogs, and in late 2020, the

hog population was estimated to be 8.8 million hogs (USDA National Agricultural Statistics Service, 2021). In North Carolina, hogs are primarily raised in large confined facilities that use the lagoon–sprayfield manure management system, in which liquid manure is anaerobically treated and stored in open-air storage ponds known as lagoons before application to nearby cropland (Zering and Wohlgenant, 2005). These lagoons are major sources of air pollutants and greenhouse gas emissions (Battye et al., 2019; Glibert, 2020). Additionally, odors can affect the quality of life of the predominately Black and low-income communities located near the lagoons and may have negative health impacts for those communities (Wing et al., 2000; Kilburn, 2012; Nicole, 2013), as well as for on-farm workers (Akdeniz et al., 2013). Accidental discharge from lagoons can also impair nearby waterways during extreme rain events, hurricanes, or structural failures (Roberson et al., 2019; North Carolina Department of Environmental Quality, 2020). Although the lagoon–sprayfield system is an important method for recycling nutrients in animal waste for crop production, the application of nutrients can compromise water quality in surrounding watersheds because nutrients are easily leached from sprayfields (Maurer et al., 2017; Guidry et al., 2018; Kravchenko et al., 2018).

In response to growing concerns about the aforementioned issues, in 1997, the state of North Carolina enacted a moratorium on new or expanded swine operations that did not implement improved waste management technologies intended to reduce environmental impacts (House Bill 515, State Law 1997-458, 1997; Ladd and Edwards, 2002). These limitations have caused the North Carolina hog inventory to remain stable or decrease since the early 2000s (USDA National Agricultural Statistics Service, 2021). The moratorium also prompted investment in research on environmentally superior technologies,

Table 3. List of stakeholders in the North Carolina swine production system with means, motive, opportunity, and alignment ratings. DOI: <https://doi.org/10.1525/elementa.2021.00066.t3>

Stakeholder	Means ^a	Motive ^a	Opportunity ^a	Alignment ^a
Swine farm employees	1	1	1	1
Swine producers	1	2	3	1
Integrators	3	1	3	3
Wholesale buyers/retailers	3	1	2	0
Pro-industry groups	3	1	2	3
State legislators	3	1	3	1
Agricultural/swine industry lobbyists	2	1	2	3
Environmental lobbyists	2	3	2	3
State government agencies (e.g., Department of Environmental Quality)	2	2	3	3
Consumers	1	1	1	0
Residents of communities in the primary swine-producing counties of North Carolina	1	2	1	1
Environmental/social justice groups	1	3	1	2
Researchers	2	2	1	0
Electric utility companies	2	1	2	1
Natural resources	1	3	1	3
Collective weighted sum (Equations 1–3)	49	46	51	
Normalized sum^b	0.36	0.34	0.38	

Summed ratings are indicated by bold font.

^aScale for means, motive, opportunity, and alignment: 0 = none, 1 = low, 2 = medium, 3 = high.

^bCollective weighted sum is divided by the maximum possible weighted sum for the number of stakeholders in the analysis.

including investment through a 2000 agreement between the North Carolina Attorney General and Smithfield Foods (Smithfield Agreement, 2000; Williams, 2009). However, the majority of swine operations have not adopted improved manure management technologies and instead continue to primarily utilize the lagoon–sprayfield system, consequently generating ongoing environmental, health, and social concerns (Deviney et al., 2021). As the team learned more about the swine production system in North Carolina, we recognized the lack of widespread adoption of improved waste management technologies and wanted to better understand the agency of stakeholders related to this challenge. As such, we applied the MMO method to answer the following question:

What is the agency of stakeholders to drive the adoption of improved swine waste management technologies in North Carolina?

Stakeholder identification

Stakeholder identification is a common challenge in stakeholder analysis, and multiple methods for stakeholder identification exist (Bryson, 2004; Schlange, 2006; Reed et al., 2009). When applying the MMO method, the approach used to initially identify stakeholders will influence the results of the stakeholder categorization because it will determine which stakeholders are included in the

assessment of agency. In this case study, given our time and resource constraints, we identified stakeholders using (1) informal conversations with experts, such as academic researchers, and individuals involved in the swine production system, such as swine producers and activists; (2) recent popular press articles covering swine production in North Carolina; (3) scholarly journal articles focused on topics such as swine waste management, environmental justice, and pollution; and (4) the existing knowledge of our geographically and disciplinarily diverse team (**Table 3**). The approach used to identify stakeholders will depend on the particular FEWS problem and the resources and expertise of the team applying the MMO method.

We defined stakeholders as either individuals comprising an informal group united by a characteristic relevant to the analysis (e.g., swine producers) or formal organizations or institutions (e.g., pro-industry groups). As such, a given individual may be represented by more than one stakeholder group. We refined, added, and combined stakeholders in our list as we further developed our understanding of the system. In future applications of the MMO method, formal stakeholder identification methods could be used to improve the comparability and consistency of the process, and any informal methods used should be described in detail for transparency and clarity (Bendtsen et al., 2021).

Alignment as weighting

We utilized stakeholder alignment to weight the agency of stakeholders in the North Carolina swine production system. Alignment reflected the cohesiveness of each stakeholder group's perspective concerning the given FEWS challenge. In this example, some stakeholder groups may be more internally aligned in their perspective on adopting improved waste management technologies than others. For instance, swine producers in North Carolina may be independent producers, contract producers, or be a company-owned farm, and they may use different production systems and maintain different herd sizes (USDA National Agricultural Statistics Service, 2021). As a result, we presume that although swine producers represent a single stakeholder in this stakeholder analysis, they may have different production objectives, capacities, and practices that influence their willingness and ability to adopt different swine waste management technologies. Accordingly, we chose to incorporate this additional information by using alignment to weight all three dimensions of stakeholder agency. However, it should be noted that stakeholder MMO could be weighted separately using different factors, depending on the research or management context.

Estimating means, motive, opportunity, and alignment

We utilized information from the previously listed sources, in addition to the U.S. census, Census of Agriculture, and publicly available financial information, to inform our ratings for MMO and alignment (**Table 2**). In our case, the faculty advisors on the team, including two involved in the North Carolina swine production system, were critical in identifying appropriate sources of information, including potential informants. Drawing on these sources and through team discussions, we assigned ratings to each stakeholder that reflected our collaborative assessments of stakeholder MMO and alignment (**Table 3**).

For instance, in evaluating the means of integrators, or the companies that provide hogs to independent growers under a production contract (Harper, 2009), we examined factors such as their annual revenue, which can be well over \$100 million (Dun and Bradstreet, 2021). Additionally, integrators employ lobbyists in North Carolina (North Carolina Department of the Secretary of State, 2021). We determined that this stakeholder group demonstrates substantial means to favorably or negatively affect the adoption of improved swine waste management technology, largely due to their extensive financial and political capital. In assessing the means of the residents of communities in the primary swine-producing counties of North Carolina, we considered factors such as the relatively low median household income of approximately \$40,000 in these counties, as well as recent successful nuisance lawsuits brought by the members of these communities against the swine industry (U.S. Census Bureau, 2019; Robertson, 2020). However, we determined that the success of these lawsuits did not meaningfully increase the means (e.g., financial, political) of this stakeholder group related to our specific focal problem. As such, we ultimately

assigned the stakeholder group consisting of the residents of these communities a low means. For the stakeholder group of environmental/social justice organizations, we considered different organizations' public statements and activism to conclude that this stakeholder group demonstrates high motive related to the focal challenge. But, we noted their reliance on public contributions and relatively low revenue as an indication of lower means related to the adoption of improved swine waste management technology (North Carolina Conservation Network, 2019; ProPublica, 2021). Given that the MMO method is designed to be iterative, these stakeholder ratings could be reassessed by the team at any time in response to the introduction of new information or to a substantial change in the system.

Key results and emergent questions

By applying the MMO method of stakeholder categorization, we increased our understanding of the challenge of the adoption of improved swine waste management technology in North Carolina and the characteristics of stakeholders related to this wicked problem at the FEWS nexus. Collectively, we identified relatively low levels of MMO related to the adoption of improved waste management technology among the stakeholders in our analysis (**Table 3**). The existence of relatively low stakeholder MMO ratings indicates that there is room for stakeholder agency to increase related to our focal problem and suggests that it may be valuable to broadly explore and understand potential factors limiting stakeholder agency in this system.

Furthermore, we found unequal levels of MMO among the stakeholders, indicating differences in agency across the stakeholders in this system (**Table 3**). **Figure 2** demonstrates how these results can be visualized. Several stakeholders, such as consumers and swine farm employees, were assigned low ratings in all dimensions of agency. In other words, we identified that these groups currently possess little agency to favorably affect the adoption of improved waste management technology. In turn, these stakeholder groups may need to build additional agency in order for meaningful progress to be made in the adoption of improved swine waste management technology. In contrast, we found that other stakeholders possessed high means and low motive or opportunity (e.g., integrators and wholesale buyers/retailers), or the opposite (e.g., swine producers). These stakeholders currently have greater agency related to the adoption of improved swine waste management technology, but given the lack of widespread adoption of these technologies, our results suggest that they are using that agency to prevent or postpone the adoption of these technologies.

Through our discussion and stakeholder rating process, we also identified several questions about how changes to the FEWS could impact stakeholders' agency related to the focal problem. These questions could help better discern the relationships among stakeholders and the focal problem and potentially identify additional stakeholders that could be included in stakeholder categorization. Furthermore, these questions may encourage additional review of the stakeholder MMO and alignment ratings and

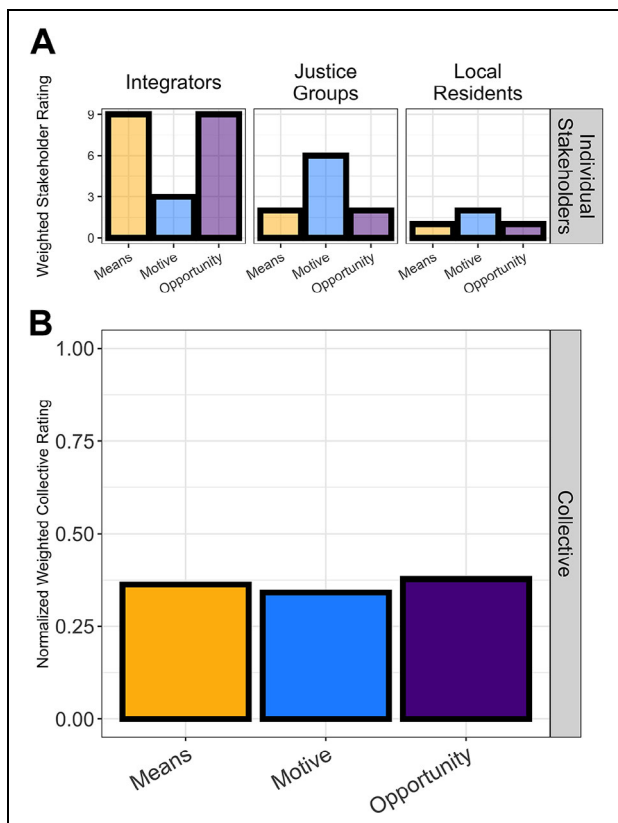


Figure 2. Visualization of weighted stakeholder means, motive, and opportunity (MMO) ratings. (A) Weighted MMO ratings (Table 3) for three of the stakeholders included in the analysis: integrators, environmental/social justice groups, and residents of communities in the primary swine-producing counties of North Carolina. (B) Normalized weighted ratings (Table 3) of MMO for all stakeholders collectively in the system. DOI: <https://doi.org/10.1525/elementa.2021.00066.f2>

consideration of potential interactions among stakeholders such as how stakeholder MMO and alignment may change in response to an action by another stakeholder, or how stakeholder agency would need to increase or be redistributed in order for the changes described below to occur.

These questions include the following:

1. How would stakeholder agency change if North Carolina passed a state law requiring all current swine production facilities to update manure management systems to meet the Smithfield Agreement requirements for environmentally superior technologies (Smithfield Agreement, 2000)?
2. How would stakeholder agency change if a major purchaser and distributor of North Carolina pork products required all pork sold in its stores to be produced in systems with manure management technologies that demonstrably reduce impacts on environmental quality compared to the lagoon-sprayfield system?

3. How would stakeholder agency change if members of the communities located in the primary swine-producing counties of North Carolina increased their existing activism and united around the idea of swine producers adopting superior waste management technologies?

Our team, brought together through a voluntary graduate student cohort challenge, primarily applied the MMO analysis as a method to further our understanding of the North Carolina swine production system and the obstacles to the adoption of improved swine waste management technology. However, the results of the MMO analysis can be interpreted in diverse ways depending on the FEWS context and the objectives of the team. In the context of swine production in North Carolina, a team focused on facilitating the adoption of improved swine waste management technology might use the results of the MMO analysis to identify practical interventions that could facilitate this change. For instance, our results suggest that providing environmental and social justice organizations, which already possess high motive, with additional financial or other capital could facilitate the adoption of these technologies. Increasing the agency of some stakeholders may disrupt the existing unequal distribution of agency that has until now delayed the adoption of improved waste management technology. Alternatively, for a team using the MMO method to categorize stakeholders prior to stakeholder engagement, the identification of stakeholders with low levels of agency, especially means, may indicate that additional effort or resources will be necessary to successfully engage some stakeholders. As these examples illustrate, the MMO method lends itself to application both as a method to increase understanding of a FEWS system and the stakeholders therein, as well as a method to inform action, intervention, or engagement, depending on a team's context and objectives.

Conclusion

The MMO method for stakeholder categorization provides both a process and a product for stakeholder analysis that is well-suited for application to wicked problems at the FEWS nexus. The team-driven process for assigning ratings encourages all team members to learn from each other and about the problem, and a systems lens indirectly emerges from these discussions. The results of the MMO stakeholder analysis can provide researchers or resource managers insight into the relationship between the various stakeholders in a FEWS and a wicked challenge of interest. This method categorizes stakeholders based on their agency related to the given FEWS challenge, information which could be used to better understand which and how stakeholders should be engaged in research and management surrounding the given challenge. For example, extra effort may be necessary to successfully engage and include stakeholders that have been identified through the analysis to have low means related to the focal problem.

Furthermore, the MMO method presents several features that are well-suited for use by the transdisciplinary

research and management teams that are common in FEWS (Reed et al., 2009; Bendtsen et al., 2021). The use of commonly used terminology, instead of technical or discipline-specific terms, lends it to use in transdisciplinary teams, wherein members may have variable skills, knowledge, and familiarity with stakeholder analysis. Depending on the FEWS context and the objectives and resources of the team, this method can also be applied with varying levels of depth and accuracy. A newly formed team such as ours could use the MMO method as a rapid approach to share knowledge and learn more about a specific system and problem, or a team of experienced practitioners could perform a highly detailed application of the method in order to inform specific actions or interventions with stakeholders. Similarly, the MMO method can be used with or without the participation of stakeholders themselves in the categorization process (e.g., stakeholders can provide information through interviews). This method presents a highly adaptable and versatile approach to learning more about a wicked problem at the FEWS nexus and categorizing stakeholders related to this problem, focusing on stakeholder agency and tailored for use by transdisciplinary teams. For instance, the flexibility of this method with regard to depth, as well as its use of common terminology, led to its use as an undergraduate class exercise introducing sustainability students to complex issues such as food waste and crop insurance (VA Nichols, personal communication, 24 January, 2022).

This introduction and application of the MMO method for stakeholder analysis at the FEWS nexus provides the foundation for further development, refinement, validation, and use of this approach. For example, a valuable next step in developing this approach could be to use formal, in-depth interviews with additional individuals in the swine production system through a highly detailed and more resource-intensive application of this method to validate the stakeholder MMO ratings assigned during our relatively rapid application. Furthermore, applying this method to different FEWS and challenges will be important in understanding the utility of this approach across a range of different research contexts and identifying potential obstacles to its implementation. The MMO method has the potential to enhance research in FEWS by providing an approach for assessing the agency of stakeholders in these systems, ultimately facilitating more informed research and the sustainable management of natural resources.

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Competing interests

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Author contributions

Contributed to conception and design: KB, VN, EG, MN, CE, KKP, AD, JC, JK, EC.

Contributed to acquisition of data: KB, VN, EG, MN, CE, KKP, AD.

Contributed to analysis and interpretation of data: KB, VN.

Drafted and/or revised the article: KB, VN, EG, MN, CE, KKP, AD, JW, MA, FD, JC, JK, EC.

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