What Drives the Use of Non-Traditional Water Sources in the Chemical Sector?

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RESEARCH PROBLEM AND PURPOSE

Incentives have been expanding for industrial companies worldwide to explore opportunities for alternative water use and internal water reuse. For example, climate change has caused water scarcity issues and source water quality changes, limiting the use of existing water sources. In other cases, companies are experiencing increased costs due to water rate increases, and external pressures to become more sustainable (e.g., emergence of the blue economy; Choudhary et al. 2021). Such challenges emphasize the importance of exploring the use of non-traditional water sources as a sustainable solution (Cath et al., 2021; Voulvoulis, 2018). These sources may include using brackish groundwater, re-used industrial wastewater, power and cooling wastewater, and produced water.

Although researchers have been developing innovative water treatment technologies, adoption has been slow in many industrial sectors. We posit that this is due to complex decision-making processes and tradeoffs that cannot be captured by looking at the technical system alone. For example, a new technology may meet specifications determined by techno-economic analyses (TEA), but if it is not aligned with an organization's priorities, human capacity, and capital infrastructure investment plans, it will not be adopted. Here, we capture such factors using a systems-of-systems (SoS) approach to understand what drives the use of alternative water sources or internal water reuse in the chemical sector. The chemical sector is a significant user of water and is 25% of the gross domestic product in the US, so it is imperative to study opportunities for the use of non-traditional water sources in this sector (Dieter et al. 2018, CISA 2019). Based on ongoing interviews and discussions with subject-matter experts (SMEs), we created a hybrid causal/cognitive map that brings together technical, financial, organizational, and regulatory factors that impact decisions to use non-traditional water sources. A SoS conceptualization allows us to identify leverage points (e.g., technology adaptation, policies) that can result in increased use of alternative water sources or internal water reuse in the chemical sector.

METHODS

When making decisions about water use, chemical sector stakeholders must consider multiple tradeoffs and make decisions within existing organizational constraints. In order to capture this complex decision-making environment, we use a SoS approach which allows us to view the system broadly and understand the essence of the problem at hand (DeLaurentis & Callaway, 2004). A SoS is comprised of multiple, autonomous systems that work together to create a more complex system (Maier, 1998; Baldwin and Sauser, 2009). Here, our two systems are the technical system and the organizational system in which the chemical sector operates. Based on this SoS conceptualization we created a hybrid causal-loop diagram and cognitive map representing the SoS structure. This map represents relationships between various factors that influence decisions to use alternative water sources.

As a first step to create our systems map, we used the National Alliance for Water Innovation's industrial "pipe parity" metrics (e.g., cost, human health, energy efficiency). These metrics were developed to understand what solutions can make alternative water sources viable in the industrial sector (Cath et al., 2021). Building from such existing literature, we created a draft of a cognitive map of the SoS (referred to as a systems map henceforth; see Figure 1), which was reviewed and conceptually validated by more than 10 water-sector subject matter experts. Currently, we are using this map as part of semi-structured interviews with stakeholders (e.g., operational staff, engineers, supervisors) at two chemical plants (one in the US and one in Belgium). As part of the interview, participants are asked to review the systems map and provide feedback and suggested changes. We will perform inductive qualitative analysis on interview data to understand interdependencies and respondents' perceptions, informing our systems map (Spearing et al., 2022; Spearing & Faust, 2020). This data and analysis collection is underway, with over 10 interviews conducted to date.

KEY FINDINGS AND IMPLICATIONS

Figure 1 shows the initial systems map that explores the factors that influence the use of alternative water sources in the chemical sector. Each arrow shows a causal relationship in which one factor impacts another. For example, as automation increases, the amount of labor needed decreases, showing a negative relationship (in red). On the other hand, as automation increases, the system complexity would also increase (positive relationship, shown in blue).

Unsurprisingly, we found that multiple factors impact decisions to use alternative water sources, including current and future water availability, cost, environmental regulations and incentives, and labor. We see that organizational and external constraints are embedded in technical characteristics of existing systems and potential technologies/innovations. For instance, the quality of effluents directly impacts public health, which cascades to alter public opinions toward the company. Here, we see that the technical system directly impacts society through environmental impacts. Further, we can see how characteristics of a new technology (e.g., automation, resiliency) are intertwined with labor (Figure 2). If a new technology is automated, there will be a reduction in the amount of labor needed, but there will also be an increase in system complexity, which then creates a need for additional workforce training, increasing the overall labor demand. This is an example of how indirect, cascading relationships can cause the system to behave unexpectedly—automation doesn't necessarily mean there will be reduced labor needs. Further, workers may become reliant on automation, creating a need for additional and consistent training so the workforce knows how to respond when there are issues. Additionally, the system complexity added due to automation can reduce the process resiliency, which may already be constrained by supply chains.

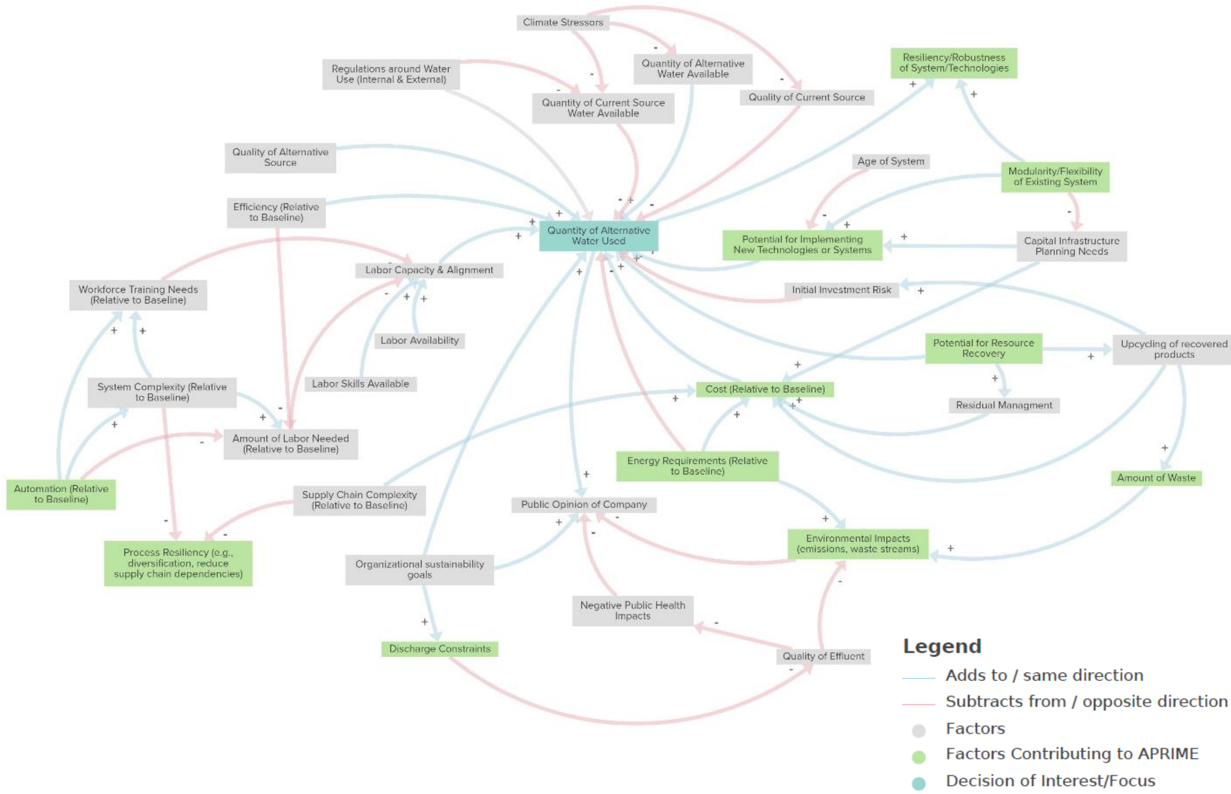

Figure 1: Factors influencing the use of alternative water sources in the chemical sector.

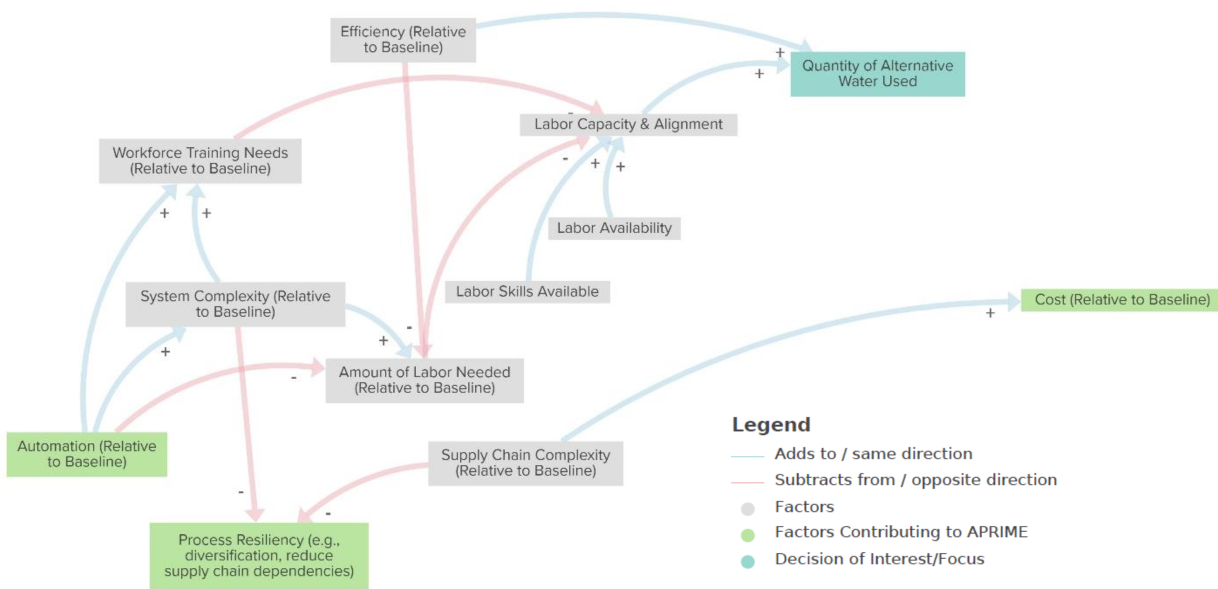

Figure 2: Labor capacity and supply chain as it relates to technical considerations. Note that this is the same map as Figure 1, just focused on one aspect.

Initial results show that drivers vary based on geographic location due to differing situational contexts. For instance, at our case study site in Belgium, there are increased regulatory and external pressures to operate sustainably. Interestingly, stakeholders do not reflect on these constraints negatively, they believe that they are important to protect the environment, despite the costs associated with such regulations. Additionally, initial interviews at the Belgium site revealed that a culture of innovation—employees who are willing to advocate for a sustainable change—has led them to be early adopters of new water treatment technologies. This shows that aspects of some organizations can be drivers for sustainable change. Another regional difference is the price of municipal water. Interviews with US-based stakeholders showed that there is less thought about using alternative water sources because their current source, often municipal water, is inexpensive, limiting companies' willingness to consider alternative water sources.

FUTURE WORK

Our research team will continue to conduct and analyze semi-structured interviews with stakeholders at our chemical case study sites. Based on these results, we will continue to revise and expand the systems map, creating both a general and site-specific map. The interconnectivity of the identified factors (Figure 1) emphasized the importance of creating tools to aid in decision-making (e.g., balance trade-offs, decide between technology alternatives). In turn, we will create a semi-quantitative model for each chemical site that includes the physical processes, as well as the organizational and external constraints identified in Figure 1. This allows us to integrate technical and organization considerations and identify innovations that may be suitable for each site (i.e., considering technical specifications, institutional knowledge, capital plans, etc.). These results can be used to develop strategies to overcome barriers to internal water reuse and alternative water source usage and to inform technology development, building from the TEA commonly used to also include the organizational operating environment.

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