# ENHANCING POSITIVE PUBLIC PERCEPTION OF DECENTRALIZED WASTEWATER SERVICE THROUGH PUBLIC OUTREACH: AGENT-BASED SIMULATION IN BANDUNG CITY



**THESIS**

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# ABSTRACT

## Enhancing Positive Public Perception Of Decentralized Wastewater Service Through Public Outreach: Agent-Based Simulation In Bandung City

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Clean water and sanitation are critical for maintaining public health and well-being, preventing infectious diseases, stunted growth in children, and preserving water quality. In Indonesia, safe disposal of wastewater remains a significant issue, impacting both urban and rural areas. This research aims to address this challenge by proposing an agent-based model to understand the dynamic evolution of public belief in Bandung City. The study utilizes surveys to gather current public beliefs and perceptions about municipal wastewater management and Decentralized Wastewater Treatment Systems (DEWATS). These beliefs are then analyzed using Partial Least Squares Path Modeling (PLS-PM), fuzzy clustering, and Agent-Based Modeling (ABM) methodologies to create social groups and simulate their evolution through various scenarios using the SOARS computational software. Key findings underscore the significance of well-defined constructs in PLS-PM for model validity, with high reliability noted in the constructs of Benefit and Concern. The study highlights the necessity of effective communication strategies that emphasize the advantages of DEWATS while addressing technical and social concerns to enhance public acceptance. The identified cluster profiles—The Enthusiasts, The Ambivalent, and The Conflicted—indicate the need for tailored engagement strategies to cater to the unique perceptions and concerns of each group. The ABM simulations provide insights into interaction patterns and belief dynamics, illustrating how different variables affect public acceptance and adoption rates. This research introduces a novel application of Agent-Based Modeling in Indonesia's wastewater planning, integrating primary data collection and diverse public outreach strategies. By simulating the dynamic evolution of public beliefs in an agent-based approach, the study offers valuable insights for policymakers and enhances community engagement in wastewater management.

Keywords: Wastewater management, Public perception, Agent-Based Modeling, DEWATS, Community engagement, Bandung,

# ABSTRAK

## *MENINGKATKAN PERSEPSI POSITIF PUBLIK TERHADAP LAYANAN AIR LIMBAH TERDESENTRALISASI MELALUI PENJANGKAUAN PUBLIK: SIMULASI BERBASIS AGEN DI KOTA BANDUNG*

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*Air bersih dan sanitasi sangat penting untuk kesehatan masyarakat, mencegah penyakit menular, mempromosikan perkembangan anak yang sehat, dan menjaga kualitas air. Di Indonesia, pembuangan air limbah yang aman masih menjadi tantangan besar, yang mempengaruhi baik daerah perkotaan maupun pedesaan. Penelitian ini berfokus pada Kota Bandung, dengan mengusulkan model berbasis agen untuk mengeksplorasi evolusi dinamis keyakinan publik terkait pengelolaan air limbah. Studi ini menggunakan survei untuk menangkap persepsi publik saat ini tentang pengelolaan air limbah kota dan Sistem Pengolahan Air Limbah Terdesentralisasi (DEWATS). Persepsi ini dianalisis menggunakan Pemodelan Jalur Least Squares Partial (PLS-PM), pengelompokan fuzzy, dan Pemodelan Berbasis Agen (ABM) untuk mengkategorikan kelompok sosial dan mensimulasikan evolusi keyakinan mereka melalui berbagai skenario menggunakan perangkat lunak komputasi SOARS. Temuan utama menekankan pentingnya konstruksi yang terdefinisi dengan baik dalam PLS-PM untuk validitas model, dengan keandalan tinggi yang dicatat dalam konstruk Manfaat dan Kekhawatiran. Studi ini menyoroti perlunya strategi komunikasi yang efektif yang menekankan keuntungan DEWATS sambil menangani kekhawatiran teknis dan sosial untuk meningkatkan penerimaan publik. Profil kelompok yang diidentifikasi—The Enthusiasts, The Ambivalent, dan The Conflicted—menunjukkan perlunya strategi keterlibatan yang disesuaikan untuk memenuhi persepsi dan kekhawatiran unik dari setiap kelompok. Simulasi ABM memberikan wawasan tentang pola interaksi dan dinamika keyakinan, menggambarkan bagaimana variabel yang berbeda mempengaruhi penerimaan dan tingkat adopsi publik. Penelitian ini memperkenalkan aplikasi baru Pemodelan Berbasis Agen dalam perencanaan air limbah di Indonesia, mengintegrasikan pengumpulan data primer dan strategi penyuluhan publik yang beragam. Dengan mensimulasikan evolusi dinamis keyakinan publik, studi ini menawarkan wawasan berharga bagi pembuat kebijakan dan meningkatkan keterlibatan masyarakat dalam pengelolaan air limbah.*

*Kata Kunci: Air limbah, Keyakinan, Modelling Berbasis Agen, Publik Outreach, SOARS, Bandung*

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# Chapter I Introduction

## I.1 Background

Safe water supply and sanitation are crucial for public health and well-being, preventing the spread of infectious diseases (Cairncross et al., 2010), stunted growth in children (Torlesse et al., 2016), and waterborne illnesses (Lin et al., 2018), and reducing the burden on healthcare systems (Ferreira et al., 2021). Comprehensive WASH (Water, Sanitation, and Hygiene) practices encompass access to clean water, eradication of open defecation (Odagiri et al., 2020), and safe disposal of wastewater (Singh et al., 2004). Proper sanitation involves the management of excreta from facilities used by individuals, through emptying, transport, treatment, and eventual discharge or reuse. The difference between "basic sanitation" and "safe sanitation" lies in the complete treatment of wastewater before it is discharged into the environment. Safe disposal is crucial for environmental and public health yet remains a significant challenge in Indonesia (Nastiti et al., 2012).

Safe water access and sanitation are stated in the sixth indicator of the UN's SDGs (Sustainable Development Goals) which is also used by Indonesia's Ministry of National Development Planning/National Development Planning Agency (BAPPENAS) as a benchmark for the country's sustainable development. In the SDGs —more specifically sub-goal 6.3— the ministry targets safe disposal of wastewater should be increased by half in 2030 (BAPPENAS, 2023). Indonesia's government also established a target of 15% safe sanitation and 90% sanitation for their National Medium-Term Development Plan (RPJMN). This can be achieved by either on-site and decentralized sanitation systems or off-site centralized sanitation systems. However, achieving the targets has proven to be somewhat a struggle. By 2022, only 10,61% of Indonesia households' wastewater management are safely disposed (BPS, 2023) and it is found that 70% water resources are polluted by *E. Coli* Bacteria (NAWASIS, 2023). The data presented shows dire need to increase the public access to safe wastewater disposal to achieve said development goals.

The rate of improvement in safe municipal wastewater disposal is considerably slow as can be seen in Figure I.1. From 2020 to 2021 there is a 0.39% decrease in coverage, but that can be attributed to the shock of COVID-19 pandemic. 2021 to 2022 shows recovery and considerable increase (2.91%) though not as high as needed to achieve the set development goals. When compared to basic sanitation, there is a stark gap between the numbers. This indicates that providing safe municipal wastewater disposal access is strenuous for the Indonesian government and the problem requires additional attention and possibly more creative problem solving. This also supports the possibility that components of the system are still uncovered and requires further looking into.

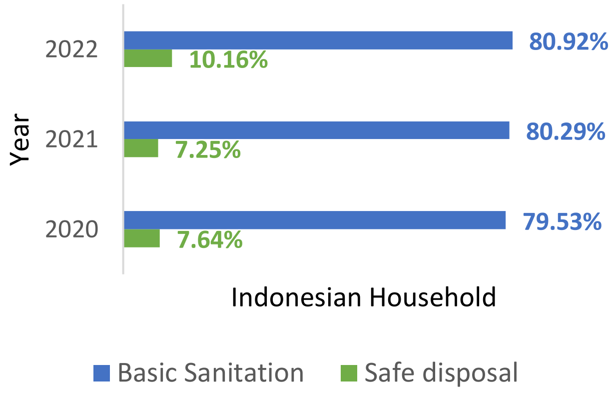


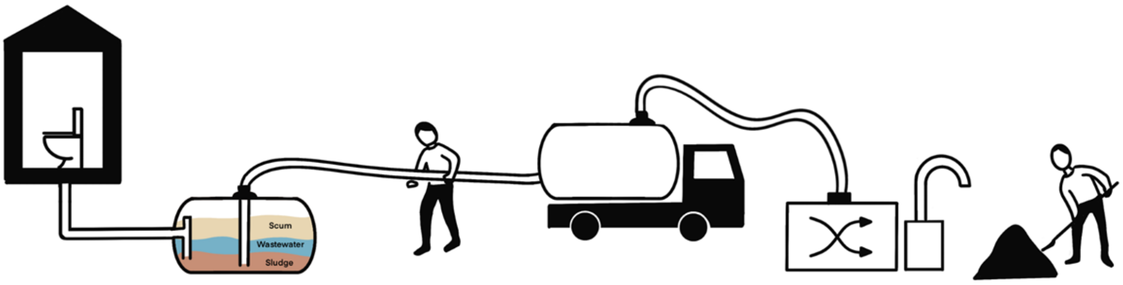

*Figure I.1 Percentage of safely disposed household wastewater in Indonesia (BPS, 2023)*

The Indonesian government views decentralized wastewater treatment systems (DEWATS) as a promising solution to its sanitation challenges. This is evident by the initiatives from the central government to assist local authorities in planning and implementing DEWATS (PUPR 2016). Yet, adversity in garnering public acceptance and adoption persists because of existing social stigma. In one case, the locals of Bantul Regency, Yogyakarta rejected a 40 billion Indonesian Rupiah's worth plan to build an FSTP in the area. The main protests of the locals were concerning environmental damage from the plant such as unpleasant smells and clean water pollution. Social-economic issues were also brought up, as the public was concerned whether the plant would recruit workers from the local population (Jetis & Trimulyo, 2024).

Rejection has also happened when plans are already implemented which happened in 2023 where local citizens rejected the operation of an FSTP in Tulungagung Regency, Central Java. The installation was only able to operate for 5 years then forced to cease its services. The local citizens expressed similar concerns as the Bantul residents. This resulted in considerable financial losses as the locals continued to reject any plans for renovation or attempt to revive the operation. However, reportedly, there are still sludge transportation trucks operating in the area with no formal data of their disposal site location, generating additional threat of water pollution due to untreated sewerage disposal (Tribunx, 2024).

Despite its history of rejection, DEWATS are still planned to be implemented in other cities. One location being Bandung City. Bandung's local government developed a Wastewater Management Masterplan (PUPR, 2020), showing wastewater management expansion plans in the years 2011 to 2032. The east districts of Bandung City are mentioned as areas for DEWATS to be implemented. This area has been previously dependent on the transportation of sludge to an existing off-site wastewater treatment plant in the south area of Bandung. However, this has resulted in an overload for the existing plant thus creating urgency for additional treatment facilities. A new Fecal Sludge Treatment Plant (FSTP) is planned to operate in the area to address this problem (Setiyawan et al., 2021; PUPR, 2020). Beside technicalities, it is crucial that this plan is accepted as a whole, and the service adopted by the public for it to serve its purpose and avert socio-environmental risks (Capps et al., 2020).

The success of the Bandung DEWATS plan is dependent by residents' adoption of policies (Xu et al., 2023). Other than support for treatment facilities, the public hold other essential roles in the sanitation value chain (Figure I.2) of sustainable DEWATS (Cecilia et al., 2023), from septage containment through utilizing septic tanks, to on-site facility maintenance, to scheduled septic tank desludging (Capps et al., 2020; Gómez-Román et al., 2020). Therefore, it is crucial that residents in the targeted area maintain a positive perception of the system and their roles, which will influence their adoption decisions. According to a previous study by Gómez-Román et al. (2020), factors influencing acceptance and adoption by the public include: (1) awareness of water issues, (2) acceptance of the infrastructure plans, (3) familiarity with wastewater treatment systems, and (4) perception of DEWATS benefits and costs. Conversely, social stigma will lead to low acceptance and adoption (Bruch & Atwell, 2015a; Ligtenberg & Bregt, 2014).




| CAPTURE AND CONTAIN | EMPTYING | TRANSPORTATION | TREATMENT, DISPOSAL, AND REUSE |
|---|---|---|---|
| • Adopt proper and safe sanitation installations in their own home<br>• Ensure the installment of standardized septage tanks in homes for containment | • Ensure the periodical emptying of the septic tank (de-sludging)<br>• Monitor the scheduling of de-sludging | • Seek assistance from trusted sludge transportation service providers (municipal authority or third party providers)<br>• Participate in any local scheduled septic tank emptying programs | • Accept and support infrastructure plans, mainly fecal sludge treatment plant (FSTP), in the local area<br>• Participate in monitoring the safe disposal of treatment residue |

*Figure I.2 Sanitation chain of DEWATS*

Previous studies have highlighted the significance of public perception in waste infrastructure planning and policy implementation. Previous study by Garnett & Cooper (2014) gave empirical evidence suggesting urgency of positive public perception in waste management decision-making through effective dialogue. However, their methods could not provide methods to measure the extent public perception and its implication of policy adoption. On the other hand, Msaki (2022) conducted empirical quantitative research to measure existing knowledge, attitude, and perceptions (KAPs) on wastewater treatment but ultimately concluded that extensive outreach efforts are still needed prior to implementing wastewater policy to foster acceptability and anticipate failure. Gómez-Román et al. (2020) research yielded findings that show lack of awareness of water problems critical for DEWATS acceptance and suggested that outreach through public discussions will allow citizens to take part in policy implementation and support its success. The studies mentioned emphasized the importance of outreach efforts, but none addressed how specific methods foster adoption nor a comparison result of varying methods.

To better understand and address these dynamics, Social Influence and Diffusion of Innovation Theory (Rogers, 2003) offers valuable insights. This theory explains how public perception and behavior towards new technologies, such as DEWATS, are shaped by social networks and the behaviors of early adopters and opinion leaders within a community. According to this theory, individuals' decisions to adopt or reject an innovation are heavily influenced by the observed behaviors and endorsements of others. In the context of DEWATS, this means that the perception of its benefits, costs, and risks can spread through the community, with targeted outreach strategies playing a crucial role in accelerating the diffusion process. By leveraging social influence and focusing on early adopters, government agencies can foster a positive perception of DEWATS and increase its adoption.

However, even with effective outreach strategies, challenges in public perception and resistance may arise, as seen in Bantul and Tulungagung. Cognitive Dissonance Theory (Festinger, 1957) provides a framework for understanding such resistance. This theory suggests that when individuals experience a conflict between their existing beliefs and new information—such as the benefits of DEWATS—they may reject the new information to maintain cognitive consistency. In these cases, it is essential to address community concerns directly and provide consistent, reinforcing messages through public socialization and exhibitions. Moreover, as highlighted by Hinojosa et al. (2017)cognitive dissonance not only motivates individuals to reduce discomfort but can also lead to significant attitude and behavior changes if effectively managed. This implies that outreach strategies should focus on creating environments that reduce dissonance by aligning new information with the community's existing values and beliefs. Incorporating self-affirmation and selective information processing approaches can further enhance the effectiveness of these strategies by helping individuals integrate new information in a way that is congruent with their self-concept and reducing resistance to change.

In addition to these theories, the implementation of DEWATS can be further understood through the lens of Complex Adaptive Systems (CAS) theory (Holland, 1992) and Emergence Theory. These theories provide a framework for analyzing how individual behaviors and interactions within a community can led to emergent patterns at the macro level, such as widespread adoption or rejection of DEWATS. CAS theory posits that in a complex system like a community, individual decisions—shaped by personal beliefs, social networks, and government outreach efforts—collectively influence overall public perception and adoption rates.

The non-linear nature of the relationships within a complex system are difficult to explore with traditional statistic techniques (Harrison et al., 2007). These dynamic changes in beliefs and their influencing factors cannot be predicted through static analysis. This research will build on previous studies (Kandiah et al., 2017; Kandiah et al., 2019; Mallory et al., 2019; Schwarz & Ernst, 2009) to propose an agent-based model for examining the dynamic evolution of public belief toward off-site wastewater services. Linear methods fall short in predicting outcomes or capturing emerging patterns in such complex systems. Therefore, Agent-Based Modeling (ABM) is particularly well-suited for studying these emergent behaviors, as it allows for the simulation of various scenarios and the identification of effective strategies for promoting DEWATS adoption.

The interaction processes can be computationally represented in a model representative of real-life behaviors (Davis et al., 2007) . Emerging patterns of the processes could be further analyzed by running through a simulation by testing of various scenarios and strategies in a virtual environment (Gershenson, 2002; Harrison et al., 2007). Modeling and simulation have also been instrumental in evaluating strategies and policy scenarios (Gershenson, 2002; Nouri et al., 2019). Agent-based modeling (ABM) and simulation exists among other methods for modelling complex systems. However, the distinguishing feature ABMs is their consideration of agent autonomy, agent heterogeneity, and adaptive decision-making (Heckbert et al., 2010; Macy & Flache, 2002) which sets them apart from other methods like System Dynamics. System Dynamics is more suitable for modeling macro-level processes that do not require accounting for individual adaptiveness (Davis et al., 2007).

ABM has been used for several studies regarding water research, a specific topic reviewed in an article by Xu et al (2023) that highlighted ABM as a promising tool for interdisciplinary water research. Previous studies have notably used ABM to simulate water technology adoption using empirical data of public perception. Schwarz & Ernst (2009) studied diffusion of environmental innovations which results show regulation as having high impact on diffusion. However, they did not incorporate how a public outreach process contributed to the diffusion and only considered regulation in its scenarios. Kandiah et al. (2019) also used ABM and simulation to explore water reuse technology adoption with inter-agent communication mechanisms. Through their simulation, they generated different adoption rate scenarios via spatial analysis, yet also without incorporating government outreach initiatives. This gap indicates that the agent-based simulation of public outreach program outcomes for water management, specifically DEWATS, remains underexplored, presenting an opportunity for further investigation.

To complement these theories, the Belief-Desire-Intention (BDI) model developed by Georgeff et al. (1999) provides a computational framework for understanding the decision-making processes underlying public adoption of new technologies. In the context of DEWATS, belief represents the public's knowledge and perceptions of the system, desire represents the community's goals or desired outcomes, and intention reflects their commitment to adopting and supporting the system. The BDI model is particularly relevant for dynamic and uncertain environments, making it an ideal tool for simulating how public beliefs and intentions evolve in response to outreach efforts and environmental changes. The study by Mancha & Yoder (2015) further supports the relevance of the BDI model, showing how subjective norms, attitudes, and perceived behavioral control positively influence behavioral intentions, which are critical for the successful adoption of DEWATS.

This model aims to help understand how public belief can dynamically change through socialization interventions and other influence mechanisms. Differences in public belief will create social groups or clusters, providing insights into best practices for enhancing public participation (Kandiah et al., 2019). The emergent patterns of belief change can reveal how the public shifts clusters based on updated perceptions of wastewater management services. The proposed research seeks to develop an innovative agent-based model focusing on the dynamic evolution of public belief regarding wastewater management services in Bandung City. The primary objective is to conduct surveys to gather current data on public beliefs, create clusters representing these beliefs, and simulate their evolution through various scenarios.

## I.2 Problem statement

The disparity between basic and safe sanitation coverage in Indonesia indicates the existence of overlooked components that demand specific attention. The sluggish progress in enhancing public access to safe wastewater disposal presents a significant challenge to conventional top-down policy approaches. Although Decentralized Wastewater Treatment Systems (DEWATS) is proposed as a potential solution to accelerate proper wastewater disposal treatment in Indonesia, historical instances of public rejection threaten the success of similar future sanitation plans.

This research seeks to redefine the problem by emphasizing the potentially neglected role of public perception in DEWATS planning. It proposes that fostering positive public perception can serve as a catalyst for increased public adoption and support of DEWATS policies, thereby mitigating the risk of rejection during implementation. The study introduces an alternative and intricate approach by incorporating public perception through agent-based modeling, exploring the dynamic changes that occur with the application of publicly preferred socialization methods and the effects of inter-person communication.

This contextual approach aims to provide a more comprehensive understanding of one of the challenges in wastewater management and policy implementation. By focusing on the dynamic evolution of public perception and its impact on the public perception of DEWATS, the study aims to offer valuable insights for designing more effective and socially accepted wastewater policies and the needed social outreach efforts to achieve it.

## I.3 Research objective

This research aims to investigate the role of public perception in the planning and implementation of Decentralized Wastewater Treatment Systems (DEWATS) in Indonesia. It seeks to explore how public opinion on DEWATS evolves and identify key factors influencing these perceptions. The study will assess the effectiveness of different socialization methods and interpersonal communication strategies in shaping public attitudes towards DEWATS. By using agent-based modeling, it will simulate public perception dynamics and predict the impact of various communication strategies on the adoption and support of DEWATS policies. The research intends to provide insights and recommendations for designing more effective and socially accepted wastewater policies. It aims to identify strategies to mitigate public rejection and enhance the success of DEWATS initiatives through improved public engagement and communication efforts.

## I.4 Research questions

Based on the determined problem statement and research objective, this research will try to answer the following questions:

1. What are the current public beliefs and perceptions about municipal wastewater management and Decentralized Wastewater Treatment Systems (DEWATS) in East Bandung City?

2. How do different socialization methods and interpersonal communication influence and drive changes in public perception and belief about DEWATS?
3. What scenarios and communication strategies can effectively enhance public engagement and support for DEWATS policies?
4. What insights can agent-based modeling provide about the interaction patterns and belief dynamics within the community regarding DEWATS?

### I.5 Research approach and methods

This research will utilize quantitative analytical methods agent-based modelling simulation (ABMS) and other to answer the research questions. In contrast to conventional technical models, Agent-Based Modeling and Simulation stands out as a prevalent bottom-up methodology, enabling this research to delineate distinct attributes and behavioral decision rules for individual agents or actors within the model, thereby capturing agent heterogeneity (Bruch & Atwell, 2015a).

By constructing the model from the ground up, this approach will illuminate possible assumptions about individual traits and behavior, the dynamics of interpersonal interactions, and the context in which these interactions unfold. Agent-based models possess the capacity to discern potentially self-reinforcing behaviors or feedback loops, offering insights into more effective policy designs through the identification of significant shortcomings inherent in current policies (Bruch & Atwell, 2015a; Sterman, 2006).

This method allows for a detailed examination of interactions among agents and the emerging consequences of such interactions. It is particularly relevant for understanding the dynamic evolution of public perception regarding DEWATS and the impact of various communication strategies on public adoption and support. By simulating real-world complexities, agent-based modeling provides a nuanced understanding of how public perception can be influenced and how effective engagement strategies can be developed.

### I.6 Research Contribution

The research makes contributions to both theoretical understanding and practical applications in the field of sustainable urban development, particularly concerning the adoption of Decentralized Wastewater Treatment Systems (DEWATS). The theoretical contributions are highlighted with empirical data collection methods and advanced analytical techniques such as path analysis and clustering. These methods provide insights into the complex interplay of factors influencing public attitudes towards DEWATS. The integration of agent-based modeling represents a significant methodological innovation, extending theoretical boundaries by simulating the dynamic evolution of public belief systems over time.

On a practical level, the research offers actionable insights for policymakers, urban planners, and practitioners, especially for DEWATS plans in East Bandung Area. By identifying key drivers and barriers to DEWATS adoption and simulating potential trajectories of adoption, the study provides valuable information for designing effective communication and engagement strategies. This research bridges theory and practice, facilitating evidence-based decision-making and supporting the implementation of sustainable urban sanitation development strategies. The findings aim to foster resilient and environmentally sustainable cities by enhancing public acceptance and support for DEWATS policies.

### I.7 Key assumptions and research limitations

Two principal key assumptions frame this research. First, it is assumed that public participation is a fundamental element in enhancing the sustainability of wastewater services. Recognizing the importance of community engagement, the study proposes that by enhancing the public in decision-making processes and awareness campaigns can lead to more effective and sustainable DEWATS adoption and anticipate public rejection. Second, the research adopts the logic of the Belief-Desire-Intent (BDI) framework (Georgeff et al., 1999), proposing that the strength of an individual's belief influences their desire, and, subsequently, their proximity to the intent of acting which in this case is adoption of DEWATS. This psychological framework is adopted to understand and model the cognitive processes influencing individuals' engagement and perception with DEWATS practices.

However, it is important to note certain limitations in the scope of this study. The research adopts a hard systems approach, focusing on structural and tangible aspects with an emphasis on explicit and quantitative data. While this approach provides clear, measurable insights, it may overlook underlying social, cultural, and behavioral intricacies that a soft systems approach would better capture. These subtler aspects can contribute for a comprehensive understanding of public perception and behavior but are not easily quantifiable.

Furthermore, the study acknowledges that a more comprehensive analysis would involve implementing the proposed model and empirically comparing its outcomes to real-world policies. This comparative approach would potentially provide a more robust assessment of the bottom-up modeling approach and its alignment with practical policy implications.

## I.8 Novelty and originality

This study brings a novel approach by using primary data collection through surveys to establish the current public beliefs and social groups related to wastewater management in Bandung City. It stands out by employing an agent-based model to simulate the intricate dynamics of information exchange among agents, leading to the evolution of public beliefs within distinct social groups. Including different public outreach efforts in the simulation aims to capture and understand how varying engagement strategies influence public beliefs about wastewater management. This innovative method seeks to contribute valuable insights into the dynamics of public belief, with potential implications for policy and community engagement strategies.

The study introduces several novelties to the field. Firstly, it contributes to academic research on public beliefs regarding decentralized, on-site wastewater management and services, providing a foundation for future decision-making in sanitation by highlighting emerging problems and challenges. Secondly, it applies Agent-Based Simulation to Indonesia's wastewater management planning, specifically in Bandung City, moving beyond merely predicting variable values to uncovering observable emergent properties that showcase the dynamics of public belief and interactions. Emerging patterns offer insights into potential best practices for public outreach and key focus areas for public communication.

From a theoretical standpoint, the study advances understanding of public perception formation and adoption processes within the context of DEWATS. By employing empirical data collection methods and sophisticated analytical techniques such as path analysis and clustering, the research elucidates the intricate interplay of factors influencing public attitudes and behaviors towards DEWATS. This deeper understanding enriches theoretical frameworks surrounding policy adoption, social influence, and decision-making processes, thereby contributing to scholarly discourse in environmental sustainability and urban planning.

The integration of agent-based modeling represents a methodological innovation by simulating the dynamic evolution of public belief systems over time, facilitating the exploration of complex feedback loops and nonlinear dynamics. This approach offers insights into emergent phenomena and system-level behavior, expanding the toolkit available to researchers studying socio-environmental systems, fostering interdisciplinary dialogue, and advancing theoretical frameworks for modeling human-environment interactions.

Practically, the findings have tangible implications for policymakers, urban planners, and practitioners promoting sustainable urban development. By identifying key drivers and barriers to DEWATS adoption and simulating potential trajectories, the study offers actionable insights for designing targeted interventions and outreach strategies. Policymakers can use insights from path analysis to prioritize resources and tailor communication efforts, while urban planners can leverage agent-based modeling to explore the effectiveness of different policy interventions and infrastructure investments in fostering widespread DEWATS adoption in urban contexts like Bandung City.

## I.9 Writing structure

Structured into distinct chapters, this thesis begins with Chapter 1 offering an introduction to the topic, accompanied by brief background data. This chapter also includes an explanation of the research approach, outlining research objectives, posing research questions, and acknowledging the study's limitations. Chapter 2 provides an in-depth exploration of previous agent-based modeling research, elucidating its relevance to the research objectives and questions. In Chapter 3, the methodology process is presented, detailing the steps involved in the construction of the agent-based model. Chapter 4 shows analysis of the modeling and simulation results, conducting a comprehensive examination and interpretation of the emerging data. Finally, Chapter 5 serves the conclusion, summarizing key findings and presenting conclusive remarks and proposing potential future research thus providing a coherent and insightful end to the thesis.

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# Chapter II Literature Review

## II.1 Introduction

Safe water supply and sanitation are fundamental for sustaining human life, playing a crucial role in preserving public health and well-being. Proper disposal of human wastewater prevents the spread of infectious diseases, avoids stunted growth in children, maintains water quality, and protects communities from waterborne illnesses. The absence of proper sanitation infrastructure places a significant burden on healthcare systems, which could otherwise focus on other critical health issues. Given these essential benefits, promoting sustainable and hygienic living environments through effective wastewater management is imperative.

This literature review aims to provide a comprehensive overview of the current state of Decentralized Wastewater Treatment Systems (DEWATS), particularly in the context of Bandung City, Indonesia. It will explore technical solutions, policy frameworks, health impacts, and the role of public perception in the adoption of DEWATS. By identifying existing research gaps, this review sets the stage for the proposed research, which seeks to enhance our understanding of public engagement strategies and the dynamic evolution of public beliefs regarding DEWATS. This introduction outlines the chapter structure and underscores the importance of addressing these critical issues to foster sustainable urban development.

## II.2 General Current State of DEWATS

### II.2.1 Technicality of DEWATS

Decentralized wastewater treatment systems (DEWATS) utilize various technologies designed to treat wastewater close to its source. Key technologies include biogas reactors, constructed wetlands, anaerobic baffled reactors, and anaerobic filters. These systems are often modular and can be tailored to local conditions and community needs (Massoud et al., 2009; Suriyachan et al., 2012). They operate on principles of anaerobic and aerobic digestion, leveraging natural processes to break down and treat waste. The design and functionality of DEWATS are marked by their simplicity, low energy requirements, and minimal operational complexity, making them suitable for rural and peri-urban areas where centralized systems are impractical (Bernal et al., 2021a; Wilderer & Schreff, 2000).

The environmental benefits of DEWATS include reduced pollution of water bodies, conservation of water through reuse, and minimal ecological disruption due to smaller infrastructure footprints. These systems align with sustainable development goals by promoting the reuse of treated wastewater for irrigation, reducing the demand on freshwater resources, and lowering greenhouse gas emissions from wastewater treatment processes (Bernal et al., 2021a; Wilderer & Schreff, 2000).

Compared to centralized systems, DEWATS offer several benefits. Decentralized systems generally have lower capital and operational costs because they eliminate the need for extensive sewer networks. This makes DEWATS an economical option, especially for communities with limited financial resources (Bernal et al., 2021a). DEWATS can be easily scaled up or down according to the specific needs of a community. This modularity allows for irrigation phased implementation, making it easier to manage and expand the system over time (Wilderer & Schreff, 2000).

Additionally, DEWATS can promote local treatment and reuse of wastewater, reducing the ecological footprint associated with transporting wastewater over long distances. The reuse of treated wastewater for irrigation and other non-potable uses helps conserve freshwater resources (Isern et al., 2012; Msaki et al., 2022; Tamburino et al., 2020). Decentralized systems are also less vulnerable to systemic failures compared to centralized systems. In the event of a malfunction, only a small section of the network is affected, allowing the rest of the system to function normally (Wilderer & Scherf, 2000).

Several regions have successfully implemented DEWATS, demonstrating their effectiveness and benefits. In Lobitos, Peru, the implementation of decentralized wastewater treatment systems, such as biodigesters and septic tanks, has provided rural communities with opportunities to be self-reliant and avoid infrastructural connections to faraway urban areas. The success of these systems was heavily tied to understanding the local geographical, social, cultural, political, and economic contexts, as well as the ease of their operation and maintenance in the long term (Smyrilli et al., 2018). Similarly, in Palestine, the implementation of a portable containerized wastewater treatment system for rural areas demonstrated significant cost savings and efficiency, with an estimated cost-saving of approximately 40 million dollars compared to a centralized wastewater treatment plant in (Sallam et al., 2024). Another example is in Gujarat State, India, where a low-maintenance communal sewage system funded through a government-regulated corporate social responsibility program enabled a rural village to be cited as the first open defecation-free village in the state (Dumencu & Clearford, 2016).

Despite these successes, several challenges have been encountered in the implementation of DEWATS across different regions. In many areas, public acceptance remains a significant barrier. In India, affordability for future users has been a concern, especially in slums of rural towns. Ensuring economic sustainability through stakeholder participation and socio-economic analysis has been crucial to identifying low-cost, easy-to-maintain technologies (Brunner et al., 2018). In Brazil, the implementation of constructed wetlands for decentralized wastewater treatment has faced challenges due to large capital investments and high operation and maintenance costs. Although these systems can be cost-effective in the long run, the initial financial burden can be prohibitive for many communities (Machado et al., 2017). These challenges highlight the need for comprehensive planning, community engagement, and financial strategies to support the successful implementation and sustainability of DEWATS programs.

### II.2.2 DEWATS in Indonesia

Under the Indonesian Accelerated Sanitation Development for Human Settlements Program, thousands of new DEWATS may be realized in the coming years. Evaluations in Java have shown that DEWATS comply with current regulations and demonstrate varied levels of performance based on their design. For example, the system involving activated sludge showed the best overall performance in effluent quality. However, challenges such as financial sustainability and community involvement remain. Surveys have indicated that while users are generally satisfied with DEWATS, there is a need for better management of operational costs and more frequent desludging. Furthermore, the involvement of women in the planning and maintenance phases is crucial for the long-term success of these systems (Kerstens et al., 2012).

However, more recent reports also show that the current state of DEWATS faces significant challenges in gaining public acceptance and adoption due to existing social stigmas. For example, in Bantul Regency, Yogyakarta, a plan worth 40 billion Indonesian Rupiah to build a fecal sludge treatment plant (FSTP) was rejected by the locals (Jetis & Trimulyo, 2024). Their main concerns were related to potential environmental damage from the plant, including unpleasant smells and pollution of clean water. Additionally, socio-economic issues were raised, as the public was worried about whether the plant would hire workers from the local population.

A similar rejection occurred in 2023 in Tulungagung Regency, Central Java, where local citizens opposed the operation of an FSTP that had been in service for five years (Tribunx, 2024). The plant was forced to cease operations due to the same concerns expressed by Bantul residents. This led to substantial financial losses, as the locals continued to reject any plans for renovation or attempts to revive the operation. Despite the closure, there are reports of sludge transportation trucks still operating in the area without formal records of their disposal sites, posing an additional threat of water pollution due to untreated sewage disposal.

### II.2.3 Policy and Regulatory Frameworks

Policies governing DEWATS vary widely across regions. National policies in countries like India promote decentralized systems through frameworks that support resource recovery and environmental sustainability. Internationally, organizations like the United Nations and WHO emphasize the need for improved sanitation and endorse DEWATS as a viable solution for developing countries (Bernal et al., 2021a). These policies influence decision-making by providing guidelines on the quality standards for treated wastewater, incentives for adoption, and integration into urban planning strategies (Zaharia, 2017). Regulatory challenges include inadequate institutional frameworks, lack of technical expertise, and financial constraints. Policies need to address these challenges by promoting capacity building, ensuring financial mechanisms to support infrastructure development, and fostering public-private partnerships (Brunner et al., 2018; Zaharia, 2017). Effective policy frameworks can significantly enhance the adoption and management of DEWATS (Kerstens et al., 2012).

In Indonesia, government documents like Bandung Raya Wastewater Masterplan outlines specific policies and regulatory frameworks to support the adoption of DEWATS (PUPR, 2020). The master plan emphasizes the need for decentralized systems to address the unique geographical and socio-economic challenges in the Bandung metropolitan area. It includes guidelines for integrating DEWATS into existing urban infrastructure and highlights the importance of community involvement and local capacity building to ensure the sustainability of these systems.

### II.2.4 Overall Management Implications of DEWATS

One of the primary managerial challenges is ensuring the financial sustainability of DEWATS. The cost-effectiveness of these systems is largely dependent on the number of users per site. Systems serving a higher number of households tend to have lower per capita costs. For instance, median usage below the planned levels significantly raises capital costs per capita, as seen in community sanitation centers where the median cost per capita can be considerably higher than for systems with house connections and simplified sewers (Singh et al., 2015). To address this, it is essential to optimize site selection and ensure higher utilization rates. Moreover, user communities often cover only daily operational costs, neglecting expenses for desludging, major repairs, and capital replacement. Thus, introducing financial mechanisms that reflect the 'polluter pays' principle and regularly adjusting fees to account for inflation and system aging are recommended (Singh et al., 2019; WSP, 2013).

Another significant managerial implication of DEWATS is community. Systems with greater community participation in planning and implementation phases tend to show higher levels of satisfaction and sustainability. For example, the SANIMAS (Sanitasi Oleh Masyarakat) approach, which emphasizes community engagement and empowerment, has proven effective in Indonesia. Communities involved in SANIMAS like projects report higher satisfaction and better maintenance of the systems (Kerstens et al., 2012; Smyrilli et al., 2018; WSP, 2013). However, ensuring sustained community involvement requires ongoing support and training, particularly in areas such as operation and maintenance (O&M). Women's involvement in these processes is also crucial, as they are often more involved in daily system operation and can provide valuable insights and support (Gómez-Román et al., 2021; Kerstens et al., 2012; WSP, 2013).

Policies should also specifically address the needs of communities disproportionately affected by failing septic systems. This includes prioritizing these areas for financial assistance, education, and outreach efforts (Capps et al., 2020). Environmental justice considerations should be integrated into all aspects of OWTS management, from planning and decision-making to implementation and enforcement. These factors can greatly shape public perception before the implementation of infrastructure system, allowing for a steadier ground for future public engagement mechanisms, Integrating DEWATS into broader city sanitation strategies is essential for their long-term viability. Most DEWATS developments in Indonesia have been discrete and scattered, implemented outside of larger strategic plans. This lack of integration can lead to underutilization and inefficiencies. Effective management of DEWATS requires developing citywide sanitation plans that map out the roles of decentralized systems alongside centralized networks. This approach ensures that DEWATS are implemented in areas where they are most needed and can be effectively managed and monitored (Zaharia, 2017). This strategy is what Bandung is attempting in its Wastewater Masterplan (PUPR, 2020).

These managerial implications of DEWATS in Indonesia highlight the need for financial sustainability, active community involvement, and integrated planning. Addressing these aspects through effective policies, financial mechanisms, and community engagement strategies will enhance the adoption and management of DEWATS, ensuring their success in improving urban sanitation (Brunner et al., 2018; Libralato et al., 2012).

## II.3 Status quo: Public Perception of DEWATS

### II.3.1 Importance of Public Perception in Adoption

Despite the potential advantages of DEWATS, social acceptance is crucial to successful implementation. Public perception and willingness to adopt DEWATS can be influenced by factors such as awareness of environmental issues, perceived benefits, and involvement in the decision-making process. Effective community engagement and educational campaigns are essential to fostering acceptance and ensuring long-term sustainability of DEWATS.

Community engagement is crucial for acceptance and long-term sustainability. Educational campaigns and participatory planning processes help build local capacity and ensure that systems are well-maintained and effectively managed. For example, in Lobitos, Peru, understanding the overall context and addressing factors like community engagement were essential for the success of decentralized wastewater treatment systems. This approach fostered better maintenance and sustainability of the systems, ensuring their long-term success and reliability (Smyrilli et al., 2018). Moreover, in Indonesia, community-managed DEWATS developments have shown that involving local communities in the planning and management phases significantly enhances the process of acceptance and management of the applied technologies (Gómez-Román et al., 2021; Kerstens et al., 2012; Msaki et al., 2022).

There is currently insufficient data on the extent of community involvement in wastewater management for cases Indonesia. In the Bandung masterplan, the participation of members of the public is predominantly to utilizers or end-users. The public is observed in the form of utilizing wastewater systems and septic tanks. Despite residents' awareness of refraining from discharging domestic waste into rivers, challenges arise in establishing communal septic tanks in densely populated regions due to land constraints. Furthermore, community knowledge limitations, particularly concerning advancements in domestic waste treatment technology, contribute to the complexities of the situation. Some issues in the aspect of community participation include (PUPR, 2020):

1. Community complaints regarding pollution in the surrounding environment have been frequent; community involvement exists, especially for addressing environmental pollution issues.
2. The lack of awareness among business entities to operate their wastewater treatment plants effectively, leading to river pollution.
3. Ineffectiveness of socialization efforts as they fail to reach all businesses generating liquid waste.
4. Ineffective implementation of socialization activities that have not brought about behavioral changes in the community.
5. The absence of involvement from business entities in contributing to wastewater management, particularly in controlling river pollution.

### II.3.2 Factors Influencing Public Perception

Public perception of DEWATS is influenced by various factors, including awareness of water issues, environmental concerns, and perceived benefits of the technology. A study by (Gómez-Román et al., 2021) found that a lack of awareness about water issues significantly affects the acceptance of DEWATS in regions where water problems are not apparent. This suggests that raising awareness about water scarcity and environmental sustainability can improve public acceptance of these systems. Furthermore, priming environmental concerns before presenting information about DEWATS has been shown to enhance positive attitudes towards the technology. Participants who were made aware of environmental issues before learning about the benefits of DEWATS were more likely to have favorable perceptions and behavioral intentions towards adopting these systems, even when potential disadvantages were presented (Gómez-Román et al., 2021).

Another critical factor is the role of community engagement and involvement in the decision-making process. Successful implementation of DEWATS requires the active participation of local communities, as well as the provision of educational campaigns to build understanding and trust. For instance, (Bernal et al., 2021b) emphasized the importance of community involvement in minimizing environmental impacts and facilitating resource recovery. They highlighted that engaging communities in planning and maintenance processes can ensure the long-term sustainability of decentralized wastewater systems. Additionally, educational efforts that emphasize the economic and health benefits of DEWATS can help overcome resistance and encourage adoption. For example, (Mesquita et al., 2021) demonstrated that decentralized systems using septic tanks and anaerobic filters can meet environmental standards in developing countries, provided that there is proper maintenance and community engagement.

Variability in public acceptance and compliance with regulations could also affect success of DEWATS implementation. In Bengaluru, India, Kuttuva et al. (2018) found that economic incentives and the cost of alternative water sources significantly influenced the level of compliance with decentralized wastewater treatment and reuse mandates. Large apartment complexes that relied on expensive tanker water supplies were more likely to comply with reuse requirements, while smaller complexes with lower water costs and less stringent enforcement often struggled to meet standards. This highlights the need for tailored policy approaches that consider local economic conditions and provide support for compliance. Additionally, challenges related to social stigma and environmental concerns can also impact public acceptance, as seen in regions like Indonesia, where decentralized wastewater plans faced resistance due to fears of pollution and unpleasant odors

### II.3.3 Need for further studies in public perception

Public perception is a crucial factor influencing the adoption and success of DEWATS, but significant evidence gaps exist regarding its full impact. Awareness and community engagement are essential for acceptance, as demonstrated by (Gómez-Román et al., 2021), who found that lack of awareness about water issues significantly affects acceptance in regions where water problems are not apparent. Priming environmental concerns can also enhance positive attitudes towards DEWATS (Gómez-Román et al., 2021).

However, comprehensive studies that examine varying degrees of public perception across different regions and socio-economic contexts are lacking. While Bernal et al., (2021b) highlighted the importance of community involvement in minimizing environmental impacts, the variability in public acceptance and compliance with regulations underscores the need for localized studies. For instance, in Bengaluru, India, economic incentives and the cost of alternative water sources significantly influenced compliance levels with decentralized wastewater treatment and reuse mandates Kuttuva et al. (2018). These instances highlight the need for more detailed research to bridge the evidence gap in understanding the full impact of public perception on DEWATS adoption.

The need for comprehensive studies on DEWATS is underscored by the contradictions and variability observed in different regions. Despite demonstrating significant environmental and economic benefits, the challenges in implementation and public acceptance reveal the complexities involved. In Indonesia, public resistance due to fears of pollution and unpleasant odors has led to the rejection of projects like the fecal sludge treatment plants in Bantul Regency and Tulungagung Regency (Jetis & Trimulyo, 2024; Tribunx, 2024).

Moreover, the effectiveness of community engagement and educational campaigns needs rigorous evaluation. While Bernal et al. (2021b) and Mesquita et al. (2021) highlight the importance of community involvement and proper maintenance for sustainability, empirical data supporting these assertions across diverse settings are needed. The success of decentralized systems in regions like Lobitos, Peru, and Palestine contrasts with the challenges faced in India and Indonesia, pointing to the necessity for a framework that can be adapted to various contexts. Studies in this trajectory would provide a robust foundation for developing tailored strategies to address unique challenges and leverage specific advantages of DEWATS in different regions.

## II.4 Communication and Socialization Methods

Public socialization and discussion play pivotal roles in the planning of a sustainable sanitation infrastructure. Engaging the community in these processes fosters awareness, understanding, and a sense of ownership among the public (Mallory et al., 2019). It provides a platform for sharing valuable insights, local knowledge, and concerns related to sanitation needs and practices (Garnett & Cooper, 2014). Through open discussions, planners can gain a deeper understanding of the specific challenges and preferences of the community, enabling the development of infrastructure that aligns with their needs (Garnett & Cooper, 2014; Msaki et al., 2022). Moreover, public involvement ensures that diverse perspectives are considered, promoting inclusivity, and addressing potential issues that may arise during implementation. The collective input from socialization and discussions creates a more robust and sustainable sanitation plan, reflecting the shared values and priorities of the community it serves.



### II.4.1 Socialization and public campaign

Fostering comprehensibility among the public can effectively achieve socially sustainable sanitation infrastructure. Kaminsky & Javernick-Will (2014) demonstrated that if the public understood the outcomes and connecting them to processes, significantly reduces the abandonment of sanitation systems, explaining 85% of abandonment cases in rural Guatemala. Similarly, urban planning with early participation, improved communication, and suitable locations, partners, and mature technology can facilitate the adoption of sustainable waste management and sanitation systems, as noted by (Särkilahti et al., 2017).

Therefore, effective socialization and public campaigns are crucial in the planning phase of sanitation projects. These campaigns ensure that communities are well-informed about the benefits and proper use of sanitation systems, fostering community ownership and long-term sustainability. Engaging the community early and continuously through public discussions and social marketing helps address local concerns, build trust, and encourage active participation, leading to better health outcomes and proper maintenance of infrastructure (Garnett & Cooper, 2014).

There are several successful examples of fostering public campaigns in sanitation projects. In rural Orissa, India, a sanitation campaign that combined emotional motivators, such as shaming, with subsidies significantly increased latrine ownership among households, demonstrating the power of targeted public campaigns (Orgill-Meyer et al., 2019; Pattanayak et al., 2009). Additionally, socialization programs in a coastal region in Indonesia, increased participants' understanding of the importance of improving environmental sanitation through effective outreach and education (Azzahra et al., 2022). The Clean City Program in Puebla, Mexico, which adopted social marketing techniques, effectively engaged community members and improved public sanitation (Fernandez-Haddad & Ingram, 2015).

In one of Indonesia's technical guides to conduct wastewater infrastructure planning, lies guidelines for conducting socialization and public campaigns. It is explained that the goal of public socialization are as follows:

1. Raising public awareness about the wastewater treatment system
2. Consensus of stakeholders
3. Gaining more public participants: giving information on the responsibility, the process of joining the service, process of registration, process of retribution collection, existing possible government incentives
4. Informing the responsibilities of the public.

Furthermore, the methods of socialization that can be adopted:

1. Public consultant meetings
2. Group discussion
3. Questionnaires and door-to-door socialization
4. Study tour
5. Exhibitions
6. Material distributions
7. Printed and Online Media

Despite the successes, there are notable challenges in implementing these campaigns. Factors such as illiteracy, lack of awareness, and socioeconomic barriers can hinder participation and effectiveness. For instance, the Total Sanitation Campaign in India faced poor implementation and low political priority, leading to unsatisfactory outcomes (Hueso & Bell, 2013). In a coastal village in Indonesia, the absence of proper sanitation facilities highlighted the need for increased public knowledge and engagement (Azzahra et al., 2022). These challenges underscore the need for further study to identify best practices and develop more inclusive and effective strategies for sanitation campaigns. Future research should focus on maintaining and rehabilitating sanitation infrastructure and sustaining long-term behavior change to ensure the effectiveness of these interventions (Orgill-Meyer et al., 2019).

### II.4.2 Interpersonal Communication through Word-of-Mouth

Word of mouth (WOM) communication is a powerful tool in shaping public perception, with its impact significantly influenced by various factors related to the nature of the sender-receiver relationship and the characteristics of the message. Effective WOM depends on the richness and strength of the message as well as personal and situational factors. This influence is well documented in the context of professional services, where credence qualities play a critical role in consumer choices (Sweeney et al., 2008).

Communication habits play a significant role in the generation and consumption of WOM. Consumers perceive WOM generation and consumption as complementary activities, although their relationship with product experience and media exposure can vary. For instance, consumer product experience and media exposure are positively correlated with the propensity to generate WOM, though their effect on WOM consumption is mixed (Yang et al., 2012). The psychological drivers behind WOM, such as the need for self-enhancement and social bonding, play a crucial role in determining the content and impact of WOM communications. Positive WOM is often driven by self-enhancement motives, while negative WOM is motivated by self-affirmation, social comparison, and the desire to help others (Alexandrov et al., 2013). Understanding these underlying motivations can help marketers design more effective WOM campaigns that leverage these psychological drivers to achieve desired outcomes.

Furthermore, it was found that personality similarity between individuals significantly enhances the effectiveness of WOM. Research has shown that a high level of personality similarity between the sender and receiver increases the likelihood of a subsequent purchase by 47.58% (Adamopoulos et al., 2018). This finding gives insight that the psychological drivers behind WOM can be used to effectively leverage it in marketing strategies.

WOM also influences perceived usefulness of innovations by affecting consumer perceptions of information credibility, the size of the adopter population, and the availability of complementary products. These factors play a crucial role in the case of shaping consumer purchase intentions (Kawakami & Parry, 2013) which could also be insightful for infrastructure adoption. In online communities, WOM systematically alters marketing messages and meanings, demonstrating that communal WOM does not simply amplify marketing messages but also modifies them in significant ways (Kozinets et al., 2009).

In developing countries like Indonesia, research by Mason (2008) emphasizes that WOM advertising is particularly effective in turbulent markets. In developing countries, where market conditions can be unpredictable, successful companies often use WOM proactively to create strong, positive brand images. This approach can be highly beneficial for promoting DEWATS, as personal endorsements and shared experiences can build trust and encourage community acceptance of decentralized wastewater solutions. Direct WOM also plays a crucial role in driving consumer actions. Akil (2020) found that direct WOM significantly increases attention levels, with 84.6% of respondents reporting heightened interest in restaurant visits due to personal recommendations. Applying similar strategies to DEWATS promotion could effectively increase awareness and adoption by leveraging the influence of direct personal communication.

In today's digital era, electronic word-of-mouth (eWOM) has become increasingly influential, particularly in Indonesia’s dynamic social commerce landscape. According to Ong & Ito (2018), influencer marketing effectively changes consumer perceptions, especially regarding destination images, leading to increased travel intentions and WOM referrals. Adapting this approach to DEWATS promotion by partnering with local influencers can help communicate the benefits and importance of decentralized wastewater treatment systems to a wider audience.

### II.4.3 Word-of-Mouth relevance in Indonesian culture

In Indonesia, the cultural relevance of Word-of-Mouth (WOM) marketing is deeply rooted in the country's collectivist values. Collectivist cultures, like Indonesia's, prioritize group harmony, familial ties, and community over individualism (Lam et al., 2009). This means that personal recommendations and shared experiences within close-knit social groups hold significant influence. In such societies, trust is often placed more heavily on personal endorsements rather than on impersonal advertising, making WOM an exceptionally powerful tool for spreading information and influencing consumer behavior (Lam et al., 2009).

Moreover, the collectivist nature of Indonesian culture means that positive or negative experiences shared within one's community can significantly influence broader consumer perceptions. This social structure supports the idea that WOM can accelerate new product adoption and brand acceptance while reducing promotional costs for businesses. In environments with high advertising clutter, WOM stands out as a credible and effective communication channel, leveraging the trust inherent in personal recommendations. Furthermore, the preference for WOM in Indonesia is also influenced by the country's high-context communication style, where indirect and non-verbal cues play a significant role in communication (Lam et al., 2009). In such an environment, the nuanced and personal nature of WOM is more effective than direct marketing strategies, as it allows for a more personalized and contextually appropriate sharing of information.

## II.5 Overview of Study Area

Bandung City is part of the Bandung metropolitan area (BMA), which consists of Bandung, Cimahi City, Bandung and West Bandung Regency with an area of 3392 $km^2$ in 2005 and a total population of 8.2 million in 2014. Together with its surrounding regions that are included in the Bandung Metropolitan Area, Bandung City demonstrates high population growth, reaching 3,5% per year (Tarigan et al., 2016). It is also a National Activity Centre (Pusat Kegiatan Nasional—PKN) of Indonesia and have reported positive economic growth.

Although there are positive economic activity reports, the increase in population has brought about considerable challenges in ensuring sustainable urban development and maintaining a satisfactory living standard for residents. The constraints faced by the public sector in meeting community needs and developing infrastructure to sustain the area's growing activities have been acknowledged by the Secretary of the Bandung City's Development Planning Board (Sayuti, 2009). Moreover, based on the most recent survey gauging the satisfaction of Bandung citizens with the city's services and development, there are certain issues that, as per the majority, are inadequately addressed by the local authorities (PSPK&eLSID, 2015). These concerns include transportation, clean water management, solid waste collection, and flood protection. Additionally, we bring attention to other matters such as the management of slum areas, the provision of clean water, and conflicts between local governments, all of which pose significant challenges for Bandung City in its pursuit of a sustainable urban environment.

### II.5.1 Water Management in Bandung City

The city's clean water supplier is a municipality-owned company called Perusahaan Umum Daerah (PERUMDA) Tirtawening Bandung, which is responsible for clean water distribution to households and industries. In 2012, PDAM Bandung distributed to around 1.6 million people of Bandung, which means that almost half of the population still does not have access or at least a piped connection to clean water (Andani, 2014). Furthermore, households with an existing piped connection to clean water often experience frequent interruptions in the continuity of the water supply. In certain areas, the stability of clean water pressure is inconsistent, occasionally leading to a complete halt in the flow. The combination of a constrained clean water supply and a high rate of water loss, coupled with the rising water consumption, creates a significant disparity between supply and demand. This issue is of considerable importance not only in Bandung City mirroring various other regions across Indonesia (Komarulzaman, 2013).

Perusahaan Umum Daerah (PERUMDA) Tirtawening is also responsible for the utility and operation of the municipal wastewater service. The main installation used for wastewater treatment is the use of Wastewater Treatment Plant (WWTP) Bojongsoang located in the south of Bandung. Its low altitude location was deemed strategic for a piped-based distribution system. However, as the population grows and the city's activities heightened.



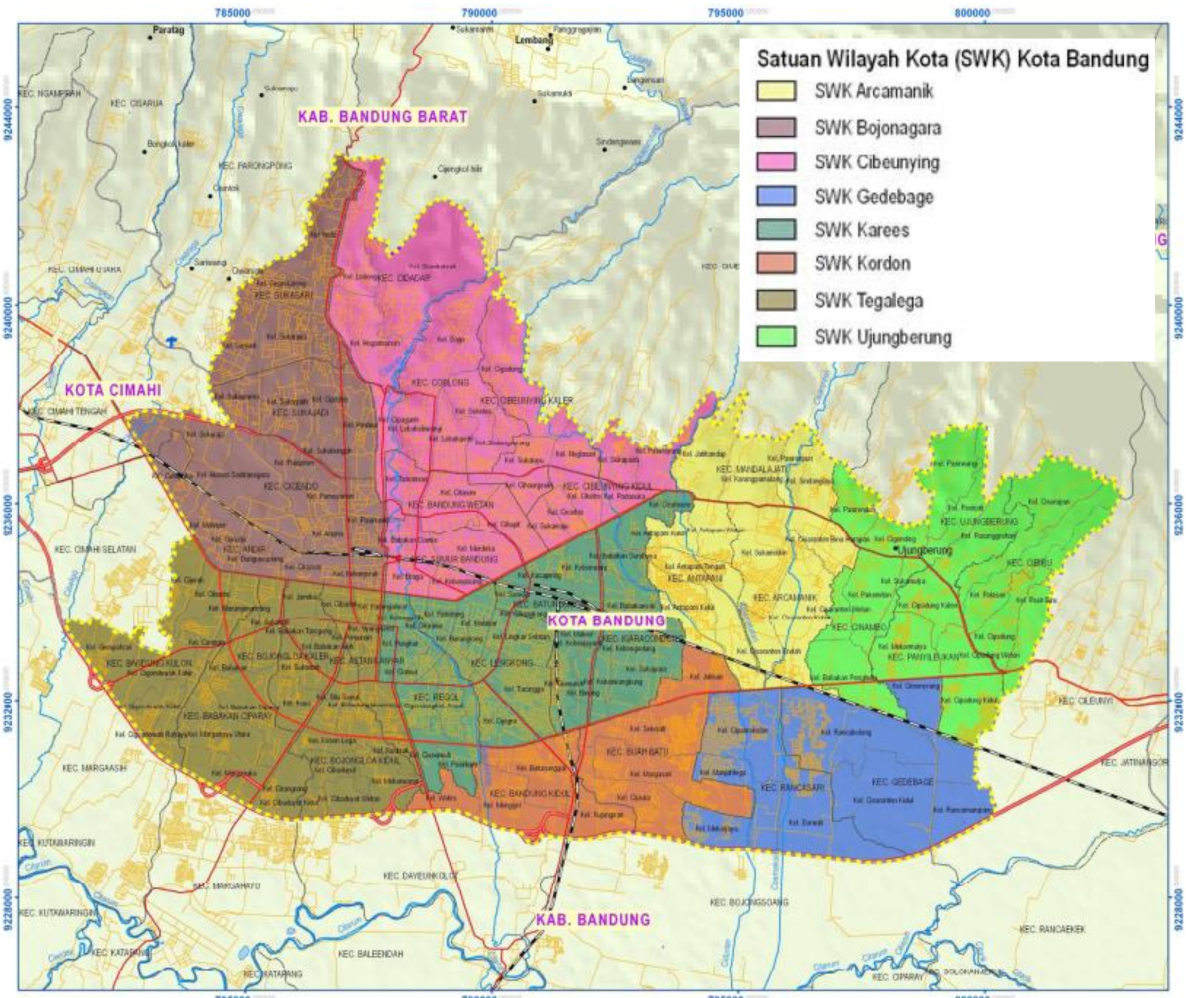


*Figure II.1 Bandung area*
*Source: Ministry of Public Works and Public Housing, 2014*

### II.5.2 Expansion plans of Bandung City's wastewater services

To ensure the proper management of municipal wastewater, especially fecal waste management, Bandung City conducted studies and developed a Wastewater Management Masterplan in 2011(PUPR, 2020). This masterplan was developed by city authority and regulators with the help of engineers. The plans showed several areas which will be the focus of wastewater service expansion plans in the time span of 2011 to 2032.  The east and west area of Bandung City areas to be the focus of on-site and off-site communal wastewater treatment development with plans of building a Fecal Sludge Treatment Plant (FSTP) in each area. This area has been previously dependent on on-site wastewater management with the use of septic tanks, the disposal of resulting fecal sludge is dependent on the Bojongsoang infrastructure. However, it resulted in high load for the infrastructure FSTP Gedebage will be used to lighten the load (Setiyawan et al., 2021).

Figure II.2 map displays the development plans and existing systems for waste management across the regions of Kota Bandung, Kota Cimahi, Kab. Bandung Barat, and Kab. Sumedang. Areas marked in light green represent the development plan, while red areas indicate the development plan for sewerage systems or communal septic tanks. Existing centralized waste systems are shown in bright green, and local systems or communal septic tanks are denoted in blue. The map highlights specific regions and their respective waste management infrastructure projects.

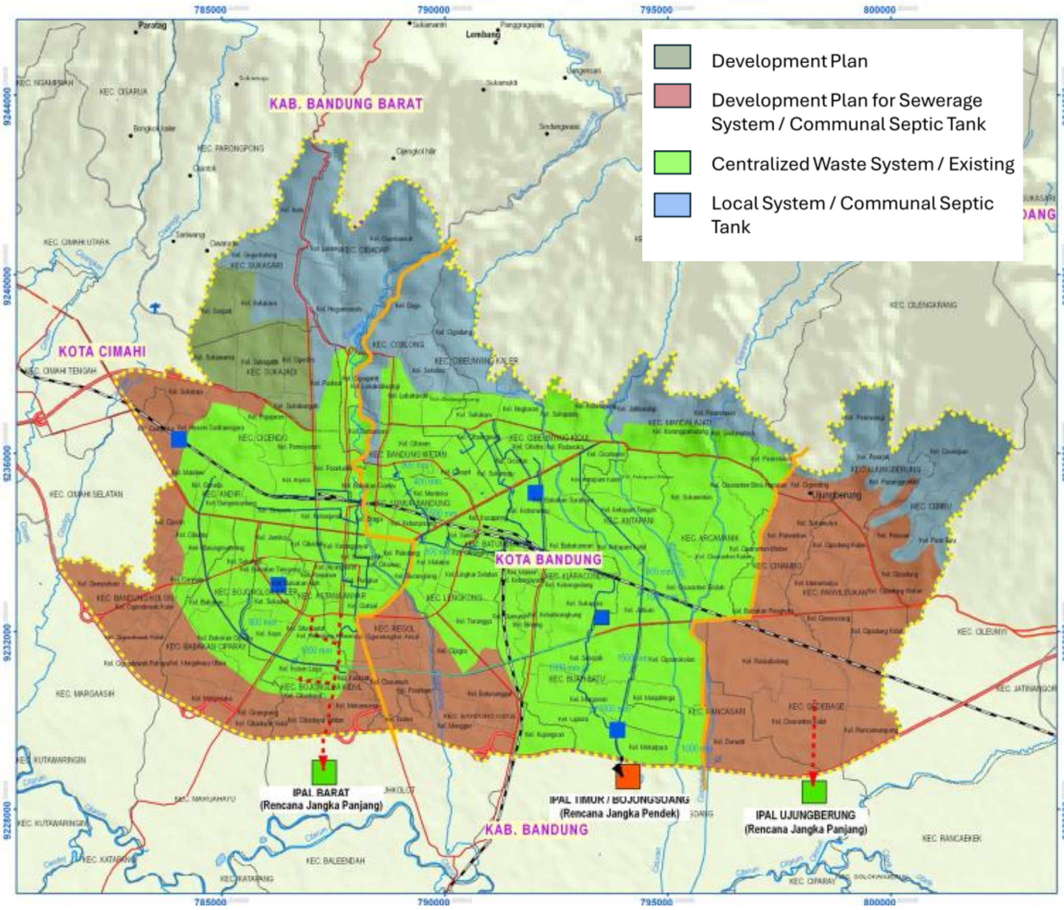


*Figure II.2 Wastewater treatment service of Bandung*
*Source: Indonesian Ministry of Public Works and Public Housing, 2014*

### II.5.3 Suitability of DEWATS in Bandung City

Bandung City is highly suitable for a decentralized wastewater system plan from several reasons. Firstly, the current centralized system, which relies heavily on the Bojongsoang treatment plant, cannot keep up with the increasing population and wastewater volumes, leading to frequent overflows and inefficiencies. Decentralized systems, by treating wastewater close to its source, can alleviate these pressures, making them more adaptable and scalable to the diverse topographical and population density variations within Bandung (Bernal et al., 2021a). Moreover, decentralized systems provide a cost-effective alternative, reducing the significant investment required for extensive sewer networks typical of centralized systems (Bernal et al., 2021a; Wilderer & Schreff, 2000). They also facilitate phased implementation, which key criteria is less disruptive and more financially manageable for urban environments like Bandung.

The potential for water reuse and resource recovery inherent in decentralized systems adds another layer of suitability. These systems can transform treated wastewater into valuable resources for irrigation, toilet flushing, and even groundwater recharge, which can be beneficial for Bandung's water conservation efforts (Bernal et al., 2021a; Xiao et al., 2018).

Finally, decentralized systems offer increased resilience to environmental and socio-economic stressors, such as natural disasters and urban growth, ensuring continuous and reliable wastewater management for the city (Bernal et al., 2021a). This approach not only addresses current infrastructure limitations but also aligns with sustainable urban development goals, making it a robust solution for Bandung's wastewater management needs.

## II.6 Underlying theories

### II.6.1 From perception to desire to intent

The logic of the belief to desire further developed by Georgeff et al. (1999) to model agency for practical and reasoning agents. This model is often used for a dynamic, and uncertain system. This model accounts for agents' response to uncertain and dynamic change in ways conventional models cannot. This BDI model is interesting to relate to computational modeling like Agent-based modeling as it has Artificial Intelligence in mind. In computational terms, *belief* represents knowledge of the dynamic world which also accounts for information outside the local system. *Desire*—can also be defined as *Goals*— represents a desired end state. In computation it can be in the form of a variable, a record structure, or a symbol of logic expression. The difference in the definition of desire between modeling and conventional computer software is that the goal is often represent "task completion" other that "desired end state". *Intentions* represent commitment to plans or procedures. BDI is a key component in the complexity of the decision-making process.

In the study developed by Mancha & Yoder (2015) explores the BDI model in context with green behavior and conservation with statistic methodology. The details of their hypothesis testing show results as follows:

1. Green Subjective Norm is positively related to Green Behavioral Intention
2. Preservation Attitude is positively related to Green Behavioral
3. Green Perceived Behavioral Control is positively related to Green Behavioral Intention
4. Interdependent Self-Construal is related to Green Subjective Norm Hypothesis
5. Interdependent Self-Construal is related to Preservation Attitude

6. Interdependent Self-Construal is related to Green Perceived Behavioral Control
7. Independent Self-Construal is related to Green Subjective
8. Independent Self-Construal is related to Preservation Attitude
9. Independent Self-Construal is related to Green Perceived Behavioral Control

In a nutshell, they found that norms contributed positively to behavioral intention, attitudes contribute positively to behavior, perceived behavior positively relates positively to behavioral intention, self-construct contributes positively to preservation attitude behavior and attitude.

### II.6.2 Information Diffusion

The field of information diffusion encompasses a wide range of theories and methodologies, highlighting its scientific depth and interdisciplinary nature. Zhang et al. (2016) review underscores the diverse contributions from social sciences, computer science, and physics, and discusses the challenges in information diffusion.

Chong-fu (1997) introduced the principle of information diffusion to address incomplete data issues, enhancing practical applications like risk assessment. This principle emphasizes the importance of filling gaps in data to better understand information relationships. Similarly, Jiang et al. (2013, 2014) propose an evolutionary game-theoretic framework to model information diffusion in social networks, focusing on the role of users' decisions, actions, and socio-economic connections. Their work demonstrates how these factors influence diffusion dynamics, providing valuable insights through simulations on real-world social networks rather than choosing a longitudinal approach.

The relevance of information diffusion theory is particularly evident when considering perception dynamics. Zhou et al. (2021) highlight this by introducing a periodic-aware intelligent prediction model, which identifies routine and emergency periods in social networks. This model integrates social factors such as user interests, social roles, and sentiment analysis, offering a nuanced understanding of how perceptions and adoption behaviors fluctuate over time.

Studies by Cao et al. (2016) and (Liu et al., 2020) further explore the dynamics of information diffusion, focusing on the role of heterogeneous social networks and adaptive processes. Cao et al. use an evolutionary game-theoretic perspective to demonstrate how different user payoffs lead to distinct diffusion dynamics. Liu et al. examine how adaptive social networks, through the rewiring of links, enhance information diffusion. Lastly, Baskerville & Pries-Heje (2001) provide complementary insights by analyzing information technology diffusion using three models: interactive, linked-chain, and emergent. These models offer a comprehensive understanding of the diffusion process, highlighting the distinct conceptual domains and practical implications of each approach.

### II.6.3 Cognitive Dissonance Theory

Cognitive Dissonance Theory (CDT), introduced by Festinger in 1957, posits that individuals experience psychological discomfort, or dissonance, when they hold conflicting cognitions. This discomfort motivates them to reduce the dissonance, often by altering their attitudes, beliefs, or behaviors to achieve cognitive consistency. In the context of management research, CDT has been widely utilized to explore various organizational behaviors and decision-making processes, providing insights into how individuals and groups navigate conflicts between their beliefs and actions.

At its core, CDT explains that dissonance arises from cognitive discrepancies, such as when individuals engage in behaviors that contradict their attitudes, make difficult decisions, or face ethical dilemmas. In organizational settings, this theory has been applied to understand how dissonance influences employee satisfaction, commitment, and decision-making. For instance, when employees perform tasks that clash with their personal values or when they perceive a misalignment between their role and the organization's goals, they experience dissonance. This dissonance can lead to changes in attitudes or behaviors as individuals seek to reduce the discomfort. Key studies have demonstrated that dissonance can impact phenomena such as escalation of commitment, where individuals continue to invest in failing projects to justify previous decisions, and emotional labor, where the dissonance between felt and expressed emotions affects job satisfaction (Festinger, 1957; Aronson & Mills, 1959; Pugh et al. , 2011).

Cognitive Dissonance Theory has undergone significant refinements since its inception, leading to several theoretical extensions that enhance its applicability in management research. One such extension is the self-consistency model, which emphasizes the role of self-concept in dissonance arousal. According to this model, individuals are motivated to maintain a consistent self-image, which can increase their commitment to initial decisions even when faced with negative outcomes (Aronson, 1969). Another important extension is the self-affirmation model, which suggests that individuals can reduce dissonance by affirming their overall self-concept rather than changing their specific attitudes. The action-based model further refines CDT by positing that dissonance arises from conflicting action tendencies, and reducing dissonance enhances the effectiveness of subsequent actions (Steele, 1988; Harmon-Jones et al, 2009).

### II.6.4 Social Influence and Diffusion of Innovation Theory

The diffusion of innovation is a complex process that is deeply influenced by social structures and cultural factors. Abrahamson & Rosenkopf (1997) highlight the critical role of social network structures, noting that the number of links and even minor idiosyncrasies within these networks can significantly impact the extent and speed of innovation diffusion. Their work underscores the importance of network analysis in understanding why certain innovations become widespread while others do not. Similarly, Delre et al. (2010) demonstrate that in markets with high social influence, the diffusion of innovations is more uncertain, particularly when highly connected individuals (VIPs) are involved. Their agent-based model shows that while these VIPs can inform many consumers, their role in driving widespread adoption is less about persuasive power and more about information dissemination. This insight is crucial for understanding how social influence operates within networks to either facilitate or hinder the adoption of new technologies.

Moreover, cultural dimensions also play a significant role in innovation diffusion. He & Lee (2020) explore how aspects of social culture, such as individualism, power distance, and uncertainty avoidance, influence the diffusion process. Their research suggests that while individualism can accelerate the initial adoption of innovations, high levels of uncertainty avoidance and power distance can slow down the diffusion, particularly in the later stages. This highlights the need for tailored strategies that consider cultural contexts when promoting innovation adoption. Additionally, Rogers' seminal work on the diffusion of innovations (1962) remains foundational, providing a comprehensive framework that emphasizes the importance of communication channels and social systems in the adoption process. Together, these studies offer a nuanced understanding of the various factors that influence the spread of innovations within different social and cultural contexts, providing valuable insights for designing effective diffusion strategies.

## II.7 Agent-based approach: modeling and simulation

Agent-based modeling (ABM) involves computationally studying systems composed of interacting autonomous entities, each exhibiting dynamic behavior and diverse characteristics. These "agents" engage with each other and their environment, giving rise to emergent outcomes at the macro level. Interactions may take the form of direct communication and physical engagement or indirect pathways through multiple feedback loops and aggregate results. The dynamic behavior of diverse agents is captured through decision-making functions, incorporating both rule-based and analytical approaches as suited to the decision-making context. ABM encompasses various perspectives, such as individual-based models (IBM) and multiagent systems. It is characterized by two key features: (1) interactions leading to emergent outcomes and (2) the explicit representation of the dynamic behavior of heterogeneous agents. In their 2010 study, Heckbert et al. stated that the fundamental principles governing the fascinating array of new phenomena that emerge when the numerous units in a complex system interact, utilizing analytical decision-making functions in agent-based modeling.

In brief, the characteristics of ABM can be listed as follows (Macy and Flache, 2011):

1. Heuristic, agents follow simple rules.
2. Adaptive, agents respond to feedback from their environment through learning and evolution.
3. Autonomous means agents have control over their own goals, behaviors, and internal states.
4. Behavioral and strategic interdependence constrains strategic interdependence. Behavioral interdependence means agents influence their neighbor’s response the local influence they receive. Whilst strategic interdependence means that the payoffs of a player’s strategy depend in part on the strategies of other players.
5. Heterogenous which means the model replaces a single integrated model of the population with a population of models, each corresponding to an autonomous decision maker.
6. Agents are embedded in networks such that population dynamics are an emergent property of local interaction.
7. Agent models use a dynamic or processual understanding of causation based on the analytical requirement that causes and effects must be linked by mechanisms, not just correlations.

Agent-based modeling exists among other methods for modelling complex systems. However, the distinction of ABM lies in their consideration of the autonomy of agents, heterogeneity of the agents modeled, and the adaptiveness of decision making. Other methods such as System Dynamics are more suitable to model more macrolevel processes and complexity without accounting for adaptiveness. The flow of decision can refer to the diagram in Figure II.3.

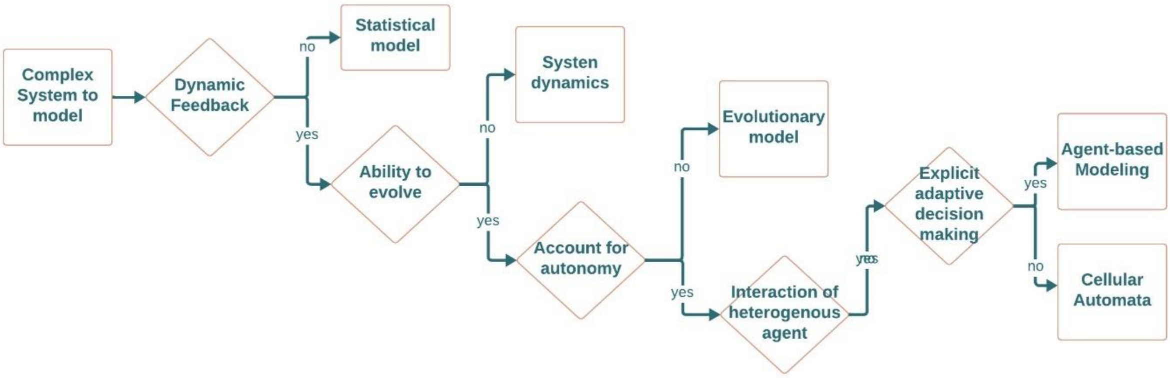


*Figure II.3 Decision tree for modeling complex systems*
*(source:* Heckbert et al., 2010; Novizayanti et al., 2021)

### II.7.1 Development of ABM in water management

Water management modeling and simulation studies characterize its systems as complex, adaptive entities with technical, environmental, and social components which all interact over time (Giacomoni & Berglund, 2015; Koutiva & Makropoulos, 2016). The agents in these systems behave dynamically and seek to adapt along with changes in their environment (Axelrod & Cohen, 1999; Pahl-Wostl, 2002; Schuster, 2005). This realization challenged the traditional “top-down” modeling approach as it no longer adequately represents the nature of the system by simply focusing on technical and physical aspects. The traditional method also only provides an overview of the system (Pouladi et al., 2019) which creates a gap in understanding crucial matters influencing the policy made. Better policy analysis can be achieved when social, physical, and technical systems are analyzed jointly (Bourceret et al., 2022; Koutiva & Makropoulos, 2019). Agent-based modeling offers the essential "bottom-up" refinement necessary for improved policy analysis in complex adaptive systems (Schlüter & Pahl-Wostl, 2007).

As early as 1999, Tillman et al used agent-based modeling in water decision-making, revealing dynamic stakeholder interactions and behavior in Swiss cities' water supply systems (Tillman et al., 1999). The research sought to give insight to facing the challenge of a strategy shift, from security to cost-centered along with dynamic change in expansion of water systems, uncertainty of public opinions and its influencing factors, customer expectations, changes to regulations, dynamic water demand, and introduction of evolving technology. Tillman chose this approach to understand the actor's fundamental behavior to point out gaps between best practice (engineering rules) and trends of declining water demand which could not be provided by the traditionally used "end-of-pipe" approach, where focus centered on technical issues. A follow up study was conducted to model actor interaction and created a catalogue of specific rules to describe how stakeholders characterize their typical interests (Tillman et al., 2001). Results from both studies were used to simulate development strategies for the water supply system aimed to highlight existing risks of the current design and management studies in water supply systems at that time and further identify possible ways of designing and operating schemes to minimize risks. The agent-based model comprised of the current rules of best practice and developed into a participatory process then validated with data sets from a real utility. Design strategies were then created by exploring multi-scenario testing and showed ideas of developing alternative management and design schemes.

Tillman et al.'s early studies introduced the method of agent-based modeling and simulation, comprising agent identification, defining interactions and rules, and simulating policy scenarios (Tillman et al., 1999; Tillman et al., 2005; Tillman et al., 2001). This framework became a reference for many subsequent studies initially in the same water supply systems. For example, Nickel et al., (2005) model for larger-scale water resources management and Galán et al., (2009)application in domestic water management analysis. This method has also been applied to many other aspects of water management from irrigation systems to wastewater and sanitation management.

Agent-based modeling has also been used to analyze best practices and policy in water resource management such as water resource management conflict (Akhbari & Grigg, 2013, 2015; Darbandsari et al., 2020a, 2020b; Saqalli et al., 2010), integrated resource management (Pahl-Wostl & Hare, 2004). (Bakhtiari et al., 2020; Giri et al., 2018), water-use policy (Berger, 2001; Jiménez et al., 2022; Schlüter & Pahl-Wostl, 2007; Wang et al., 2021) and community resource (Wise & Crooks, 2012).

### II.7.2 Water-related policy scheme simulations with ABM

In the realm of agent-based modeling and simulation, the ultimate objective is typically the identification of optimal scenarios or promising policy frameworks. Diverse methodologies are employed to integrate the insights derived from agent-based simulations with other established policy practices or theoretical bases. Prior investigations substantiate the promising potential of agent-based modeling as a policy formulation tool across multiple dimensions of water management.

Previous studies on water resource conflict resolution employed agent-based modeling (ABM) to analyze optimal policies, particularly in the context of water resource utilization. These conflict resolution models couple complex human and nature systems as sub-models and integrate them in policy evaluation and scenario analysis. Akhbari & Grigg (2015) used ABM as an integrative tool to model human-environmental interaction and develop a conflict-management tool. By employing three distinct models—namely, a watershed simulation model, an optimization model, and a behavioral simulation model—the researchers assessed the feasibility of various management scenarios in attaining targeted reductions in agricultural water allocations. Similarly, Darbandsari et al. (2020a) conducted research aimed at identifying promising policies in water resources management by evaluating various water management policies through simulating the behaviors of all stakeholders. This study incorporated the coupling of two simulation models, with the social and environmental model serving as the dynamic behavioral simulation model (ABM), and the leader-follower behavior of the governing "ruler" acting as the static decision-making model. These methods showcased the efficacy of incorporating agent-based modeling into a framework for water-resource conflict resolution, establishing it as a robust decision-support tool.

Agent-based modeling and simulation have also found application in research aimed at identifying optimal scenarios and supporting policies for new policy and infrastructure planning. Anthony & Birendr (2018) sought to seek insight on whether significant water saving in irrigation water management can be achieved when various scenarios of water reduction is in effect. This study used crops as agents by accounting their drought sensitivity, growth stage, soil type, and the crop coefficient value when allocating water. Guo et al. (2022) used agent-based modeling for water saving compensation policy in agricultural system but accounted a more complex and adaptive system by factoring in farmer behavior under changing physical and institutional environments. Whereas Bahrami et al. (2022a) proposed a framework combining agent-based modeling with established standard operating procedures (called ABM-SOP) to simulate dynamic operations of reservoirs in the long term along with the socioeconomic behaviors of the farmers.

On the other end of water management, several studies have also incorporated the use of agent-based modeling to wastewater management and water reuse infrastructure. Bitterman & Koliba (2020) proposed a governance of network design to mitigate water pollution and maintaining water quality standards by simulating the impacts of alternative collaborative governance arrangements in water quality projects. The agent-based model was coupled with land-use and existing hydrologic models, datasets, and pollution reduction targets. Another look at wastewater management governance and management was done by Oliva-Felipe et al. (2021) by proposing a model integrating social and organizational structure of the system. The model considered the legal regulations and technical limits that would impact decision-making using the ALIVE framework of dynamic service applications (Vázquez-Salceda et al., 2010). Further down the line of water management, Kandiah et al. (2019) had another goal of policy evaluation on projecting adoption water reuse and water infrastructure, focusing solely on the nature and behavior of the agents. This research simulated the dynamic opinion within a Risks Public framework (Binder et al., 2011) and capturing changes in perceptions about the risks and benefits of water reuse.

### II.7.3 Application of Agent Based Modeling in Public Perception Dynamics

Agent-based modeling (ABM) offers a powerful tool for understanding public perception dynamics by simulating the behaviors and interactions of individuals within a society. Society consists of individuals engaged in various activities, and to comprehend social reality, we must explore the intentional actions of these individuals. Unlike mere behavior, which includes unintentional actions, intentional actions are purposeful and aimed at achieving specific outcomes (Hedström, 2005). To provide an intentional explanation for these actions, it is crucial to consider the desires and beliefs that drive individuals' decisions (Elster, 2007).

In the context of DEWATS adoption, ABM allows us to model how individual perceptions and interactions influence collective outcomes. By incorporating factors such as public outreach effectiveness, interpersonal communication, and evolving perceptions, ABM helps us understand the dynamic interplay of these elements and predict potential adoption patterns. This approach provides valuable insights for decision-makers and managers, enabling them to design targeted strategies that effectively address public concerns and enhance community engagement

Actions involve the comprehension of the causal relationship between goals and the means to achieve them. If an individual desires outcome *b*, it can be assumed that they will act in a manner they believe will lead to *b*—say action *a*—especially if *a* is perceived as more effectively bringing about b compared to other available actions. This assumption holds, particularly when the individual believes that a aligns with shared fundamental values within their social context. Consequently, based on their desires and beliefs, it can be inferred that people act intentionally and rationally. Here, rationality is defined as the human process of seeking, processing, and drawing inferences.

Methods of collecting data about public belief and perception of wastewater management are done in various ways. Msaki et al., 2022 studied knowledge, attitude, and perceptions on wastewater treatment in general and reuse using descriptive statistics. Kandiah et al., (2017) used findings from empirical data through survey to instantiate an agent-based model of social amplification of public belief on the benefits of water reuse through interpersonal communication habits among social groups (Kandiah et al., 2019). Another study was done to see diffusion of environmental innovations was studied by Schwarz & Ernst (2009) in the context of water saving policies as an environmental innovation by empirical data collected by interviews and simulation. The population of their respondents were divided into categories based on the lifestyle they chose. Mallory et al. (2019) used agent-based modeling to simulate sustainable design public acceptance of a novel fecal waste treatment technology from a business perspective.

### II.7.4 Dynamic change of public belief

Despite their technical origins, agents inherently display social characteristics. As outlined by Wooldridge and Jennings (2002) and Gilbert and Troitzsch (2008), agents demonstrate both cognitive and social architectures. Cognitively, agents function heuristically and adaptively. In a social context, agents are identified as autonomous, interdependent, heterogeneous, and embedded. Local interaction between agents then generates population dynamics (Macy and Flache, 2011). The dynamics of population's belief give insight on measures and mechanisms to achieve a desired end state.

Cognitive models built upon theoretical frameworks frequently encounter a constraint when it comes to depicting adoption decisions as a straightforward transition between non-adopter and adopter states. Few models surpass this binary depiction, incorporating shifts in opinions alongside adoption decisions and replicating the influence of peer interactions on these opinions. Additionally, several diffusions of innovation models are lacking because the assumption that the worldwide success of technology diffusion and adoption is unavoidable (Kandiah et al., 2019). Thus, a novel way of approach is by accounting for the social interactions in forming public belief.

Kandiah et al., (2017) agent-based model grounded in the "risks-public framework," which is part of a multi-dimensional conceptual framework aimed at comprehending the dynamics of public opinion regarding local matters. These issues may include the establishment of new facilities with elevated risk factors or the introduction of unfamiliar technologies. The risk publics approach stemming the published work of Binder et al. (2011), initially designed to scrutinize community dynamics in the context of a high-risk biological and agro-defense research facility development. The 2017 study focused on public belief and risk perception regarding water reuse by dividing the population into distinct belief clusters or risk publics, and individuals in each cluster have a similar assessment of the risks and benefits associated with a specific technology. Then the model defines communications within and between clusters to effect a change in opinions. Communication characteristics are empirically derived from survey questions that test the relative frequency of communication within and among clusters based on political discussions as a proxy for overall discussion patterns.

Singh et al. (2016) made a conceptual framework integrating Belief-Desire-Intention (BDI) agents within ABM which offers a powerful approach to simulating the dynamics of perception and adoption behaviors. BDI agents, with their cognitive architecture, are adept at reacting to environmental changes and updating their beliefs and desires, accordingly, making them suitable for modeling complex decision-making processes. This integrated framework allows for the simulation of social and psychological factors influencing adoption, such as perceived benefits and peer influence. The flexibility to include both BDI and non-BDI agents facilitates the study of diverse populations and the spread of information within social networks. Consequently, this integration provides valuable insights into the factors driving public adoption of new initiatives, making it a critical tool for policy-making and strategic planning.

### II.7.5 Agent types and behavior in water related simulations

A significant challenge in agent-based modeling is defining the suitable actions for an individual actor based on a set of observed preferences or behaviors (Bruch & Atwell, 2015a). As the objective of this research is to comprehend the cumulative repercussions of real-world phenomena related to wastewater services, it is imperative to define agents' actions in a manner that is empirically justifiable.

Within complex adaptive systems, human agents assume a crucial role in attaining the system's objectives. This phenomenon is evident in water management systems. For instance, Nhim and Richter (2022) simulated the presence of an institutional trap within water governance. This trap emerges when the initial lack of cooperation among agents in the local community results in substandard infrastructure, further eroding cooperation and instigating a detrimental cycle. Additionally, stakeholder engagement has proven to be instrumental in environmental innovation management (Watson et al., 2018). Therefore, it is imperative to define the attributes, behavioral rules, memory, decision-making sophistication, and resources/flows of these agents within the system Akhbari & Grigg (2015) for a comprehensive and effective model.

Akhbari & Grigg (2015) proposed a framework to characterize different types of agents in water decisions. He made a typology of seven types of agents along with their attributes, rules of behavior, world of perception, memory, decision making sophistication, and flows. Kaiser et al. (2020) made additions and modifications on emergent agent types in water resource to enrich the knowledge. They identified five main agent types that often emerge in agent-based water related modeling and simulations which are urban/domestic types, this is often households of water users, government regulators which are often the policy makers regarding water management, utilities which are the types that hold the authority to manage and operate the water system, interest groups which are often non-governmental organization which represent specific public interest, and economic agents which are stakeholders who hold mainly economic interest. This typology will be beneficial to identify agents and their general behavior for agent-based modeling.

*Table II.1 Agent typology in municipal water system*

| Agent | Type | Roles | Attributes | Rule of Behavior | Memory | DM Sophistication | Flows |
|---|---|---|---|---|---|---|---|
| **Urban/domestic** | Reactive or Deliberative | Water demand<br>Conservers<br>Population growth | Housing type<br>Income<br>Appliance ownership | Optimize water allocations according to needs<br>Optimize the quality of allocated water (to reduce drinking water costs) | Past allocation rules<br>Water rights<br>Drinking water standards | Simple or medium | Amount of allocations |
| **Government Regulator** | Hybrid | Regulation maker<br>Infrastructure planner and management<br>Incentive/penalties<br>Data collection<br>Communication and socialization<br>Records and settles and disputes | Financial<br>Technical<br>Human resources<br>Political support | Optimize water allocations<br>Maximize river flow rate<br>Monimaze concentration of water quality variables | Past allocation rules<br>Water rights<br>Historical hydrological data<br>Historical water quality data<br>Environmental regulations | High | Quality and quantity of water along the river<br>Rate of allocations |
| **Utilities** | Reactive or Deliberative | Water distribution<br>Water treatment<br>Water use reduction goals<br>Water use restrictions<br>Water extraction<br>Infrastructure<br>Enforcement communication | Profit<br>Memoory<br>Growth projections<br>Technology<br>Regulation | Water use projection<br>Precipitation, streamflow, and groundwater withdrawal forecasts | Past allocation rules<br>Water rights<br>Historical hydrological data<br>Historical water quality data<br>Environmental regulations | High or medium | Profit maximalization |
| **Interest group** | Reactive or Deliberative | Advocacy<br>Capacity building<br>Social influence<br>Litigation<br>Outreach<br>Education<br>Report violations | Social capital<br>Environment<br>Memory<br>technology | stakeholder involvement<br>data from regulatory agent (water quality and streamflow) | | High or medium | Quality and quantity of water along the river<br>Rate of allocations<br>Social benefits |
| **Economic** | Reactive or Deliberative | Insurance<br>Water banking | Local& global markets<br>Social influence | Global demand<br>Taxes and tariffs<br>Willingness to pay<br>Willingness to sell | | High or medium | Economical benefits, resource allocation |

*source:* Akhbari & Grigg, 2015; Kaiser et al., 2020

## II.8 Research Gaps

Current research has provided insights into technical, policy, and health-related aspects, but several gaps remain. Contradictory findings reveal an evidence gap concerning the impact of public perception on DEWATS adoption. Additionally, a knowledge gap exists regarding the dynamic evolution of public beliefs and the role of socialization and interpersonal communication. Based on the research gaps definition by (Miles, 2017), there are several research gaps this study will contribute to.

The current body of research on DEWATS has provided valuable insights into various technical, policy, and health-related aspects. However, several gaps remain that need to be addressed to enhance our understanding and implementation of these systems.

1. Contradictory research findings and real-life events reveal an evidence gap concerning the perception on DEWATS adoption. Previous studies have shown the positive benefits of DEWATS, but reality shows that DEWATS are not always accepted by the public. Thus, creating an evidence gap on how contextually public perception can lead to rejection despite the potential of DEWATS.
2. A theoretical gap has also formed from the absence of studies addressing the dynamic evolution of public belief and the role of interaction and communication in shaping the perceptions towards DEWATS. Although there is previous research that has modeled the dynamic patterns emerging from the existence of interaction, there has not been any incorporating the different types of public outreach methods in their models and the picture of adoption that will ensure.
3. Methodologically, there is limited use of modeling and simulation to study public perception in the context of how socialization and inter-personal communication mechanisms contribute to dynamics. This research seeks to fill in methodological gaps by incorporating dynamic simulations, which may also contribute to practical suggestions in future managerial and planning of such a sanitation system.
4. There is an empirical gap due to the lack of contextual research on the dynamic changes in public perception regarding DEWATS. This study also attempts to fill in this research gap by incorporating empirical data analysis to the modelling and simulation approach.

## II.9 Proposed Research

The nature of public perception and adoption of DEWATS (Decentralized Wastewater Treatment Systems) is multifaceted. Each element is interconnected, highlighting the dynamic interplay between various factors influencing public outreach, interpersonal communication, and the overall perception of DEWATS. Figure III.3. represents this research's proposed framework which captures the multifaceted and complex nature of public perception formation and a household's potential to adopt DEWATS.

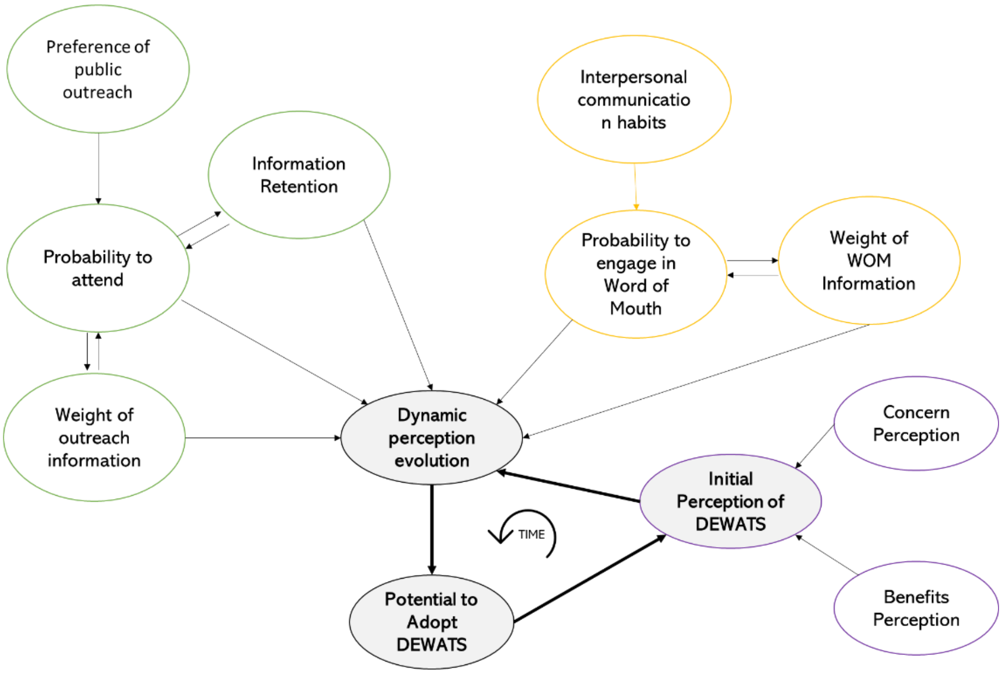


Figure III.3 Research Framework

*The Initial Perception of DEWATS* is shaped by existing knowledge and attitudes, including *Concern Perception* and *Benefits Perception*. These perceptions can either positively or negatively influence the public's overall view and willingness to adopt DEWATS. The framework culminates in the *Potential to Adopt DEWATS*, which is the outcome of the combined influences of outreach effectiveness, information retention, interpersonal communication, and evolving perceptions. This complex interplay illustrates that successful adoption of DEWATS depends on a comprehensive understanding and strategic management of all these interconnected factors.

*Preference of public outreach method* is a critical point. It reflects how the public prefers to receive information about DEWATS. This preference influences the *probability of attending* outreach events, which is crucial for direct information dissemination and engagement. The *weight of outreach information* signifies the perceived importance and credibility of the information received during these events, affecting how much the public values and retains the shared knowledge. *Information retention* is pivotal as it determines how well the public remembers and utilizes the information received. This retention is further influenced by *dynamic perception evolution*, which encapsulates how ongoing exposure and additional information continuously shape public perception over time.

*Interpersonal communication habits* significantly affect the probability to *engage in Word of Mouth (WOM)*. People with strong interpersonal communication tendencies are more likely to share their knowledge and opinions about DEWATS, thereby amplifying the information spread through informal channels. The *Weight of WOM Information* then reflects how influential this word-of-mouth communication is compared to other information sources. Public perception is further nuanced by initial biases and concerns.

The proposed research aims to develop an innovative agent-based model focusing on the dynamic evolution of public belief related to DEWATS services in Bandung City to garner potential adoption. This research represents a novel effort in the realm of understanding and fostering the adoption of Decentralized Wastewater Treatment Systems (DEWATS) in urban environments, with a focus on Bandung City. Its holistic approach gives this study an edge by integrating empirical data collection, advanced statistical analyses like path analysis, and agent-based modeling as an innovation. By fusing these methodologies, the research aims to unravel the intertwining factors shaping public perception and adoption potential of DEWATS.

The comprehensive understanding sought through empirical data collection also contributes to the novelty. This approach ensures that the research is grounded in real-world insights, capturing the nuances of existing perceptions and attitudes toward DEWATS within the targeted Bandung community. Moreover, the utilization of path analysis offers a systematic examination of the causal relationships between various variables, shedding light on the underlying mechanisms influencing public perception formation. The incorporation of clustering techniques further enriches the analysis by delineating distinct social groups based on their beliefs regarding DEWATS. This segmentation provides valuable insights into the complex nature of public perception formation, allowing for tailored interventions and targeted outreach strategies. The adoption of agent-based modeling represents a leap forward in simulating the dynamic evolution of public belief systems over time. By simulating the interplay of variables and scenarios in a loop system, this modeling approach offers a forward-looking perspective, enabling researchers to explore potential trajectories of DEWATS adoption and devise evidence-based strategies for promoting it.

### II.10 State-of-the-art research analysis

Agent-Based Modeling (ABM) presents a novel approach to exploring the dynamics of public perception and communication mechanisms in the context of DEWATS (Decentralized

Wastewater Treatment Systems). Previous research has primarily focused on technical, policy, and environmental aspects, often overlooking the complex interactions and evolution of public beliefs influenced by communication strategies. For instance, Singh et al. (2019; 2015) and Kerstens et al. (2012) primarily assessed the technical and environmental impacts of DEWATS, without delving into the public perception dynamics. Studies like Brunner et al., (2018) and Smyrilli et al. (2018) explored the affordability and implementation of decentralized systems, yet lacked a comprehensive analysis of the communication processes that shape public acceptance. By integrating ABM, this research aims to fill these gaps, providing a dynamic and nuanced understanding of how different communication strategies and public outreach efforts influence the adoption and perception of DEWATS.

The current study distinguishes itself by incorporating ABM to simulate the dynamic evolution of public beliefs regarding DEWATS, considering various communication and socialization methods. Prior works, such as those by and Gómez-Román et al.(2021) and Msaki et al. (2022), have examined public acceptance and knowledge, attitudes, and perceptions (KAPs) towards wastewater treatment. However, these studies did not explore the role of interpersonal communication and word-of-mouth (WOM) in shaping these perceptions over time. Similarly, Bernal et al. (2021b) and Kuttuva et al. (2018) focused on identifying key factors for implementing decentralized systems without an in-depth analysis of the dynamic interplay between public perception and communication strategies. This study aims to address these gaps by simulating the effects of different public outreach efforts and WOM on the public's evolving perception of DEWATS, thereby providing a more comprehensive and practical understanding of the factors influencing adoption.

Furthermore, integrating additional the study by Garnett & Cooper (2014) adds to the analysis by examining various communication mechanisms, including analytical-deliberative processes and the role of social enterprises. This study, while contributing valuable insights into the role of communication in public engagement, did not employ ABM or similar dynamic simulation methods to explore the evolving nature of public beliefs. By incorporating these elements, the current study not only advances the theoretical framework surrounding public perception and DEWATS but also offers practical implications for designing effective communication strategies. This research contributes  by providing a comprehensive, dynamic analysis that considers both the technical and social dimensions of DEWATS adoption, highlighting the critical role of communication and public engagement in the successful implementation of sustainable sanitation solutions.

*Table II.2 State of the art water related agent-based models*

| **No** | **Article** | **Study Objective** | **Sanitation Context** | | **Public Perception and Engagement** | **Communication and Socialization Methods** | | **Methodological Approach** | | | | **Area of Study** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **DEWATS** | **Other** | | **Social Outreach** | **WOM** | **Qualitative** | **Statistic** | **ABM** | **Others** | **Study Area** |
| **0** | **This Study** | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | | Bandung, Indonesia |
| | | **Sanitation: perception and implementation** | | | | | | | | | | |
| 1 | Singh et al. (2015) | Assessing decentralized wastewater treatment systems in small towns and rural areas in India | ✓ | | | | | ✓ | ✓ | | | India |
| 2 | Singh et al. (2019) | Evaluating DEWATS in Maharashtra, India, focusing on environmental and cost impacts | ✓ | | | | | | ✓ | | | India |
| 3 | Kerstens et al. (2012) | Discussing wastewater management in a Romanian petroleum chemical company | ✓ | | | | | | | | | Indonesia |
| 4 | Brunner et al. (2018) | Investigating affordable DEWATS in India | | ✓ | | | | ✓ | ✓ | | | India |
| 5 | Libralato et al. (2012) | Recent trends in water management | | ✓ | | | | | | ✓ | | Not Specified |
| 6 | Smyrilli et al. (2018) | Implementing decentralized systems in rural Peru | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | Peru |
| 7 | Gómez-Román et al. (2021) | Studying public acceptance | | ✓ | ✓ | ✓ | | ✓ | | | ✓ | Galicia, Spain |
| 8 | Msaki et al. (2022) | To assess the social knowledge, attitude, and perceptions (KAPs) on wastewater treatment, technologies, and reuse in Tanzania. | | ✓ | ✓ | ✓ | | ✓ | | | | Tanzania |
| 9 | Bernal et al. (2021) | To identify key factors for implementing decentralized wastewater systems in rural and peri-urban areas. | ✓ | | ✓ | ✓ | | ✓ | ✓ | | | Unspecified |
| 10 | Kuttuva et al. (2018) | To analyze factors affecting the extent of wastewater treatment and reuse in decentralized systems in Bengaluru, India. | ✓ | | ✓ | ✓ | | | ✓ | | | India |
| 11 | Mallory et al. (2019) | To use Agent-Based Modelling (ABM) for simulating faecal sludge management systems, addressing economic, social, and environmental factors in Malawi. | ✓ | | ✓ | | ✓ | | | ✓ | | Malawi |
| 12 | Garnett & Cooper (2014) | To explore the use of analytical–deliberative processes in waste management decision- | | ✓ | ✓ | ✓ | | ✓ | | | | United Kingdom |

| No | Article | Study Objective | Sanitation Context | | Public Perception and Engagement | Communication and Socialization Methods | | Methodological Approach | | | | Area of Study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DEWATS | Other | | Social Outreach | WOM | Qualitative | Statistic | ABM | Others | Study Area |
| | | making to enhance public involvement and acceptance. | | | | | | | | | | |
| 13 | Kaminsky & Javernick-Will (2014) | Investigate reasons for abandonment of sanitation infrastructure using legitimacy theory. | | | ✓ | ✓ | | | ✓ | | | Guatemala |
| 14 | Särkilahti et al. (2017) | Identify factors enabling sustainable urban waste management. | | | ✓ | ✓ | | ✓ | | | | Finland |
| 15 | Orgill-Meyer et al. (2019) | Develop a framework for social responsibility in public-private partnerships. | | ✓ | ✓ | ✓ | | | ✓ | | | Multiple locations |
| 16 | Pattanayak et al. (2009) | Enhance sustainable transitions in infrastructure sectors through planning processes. | | | ✓ | ✓ | ✓ | | ✓ | | | Global |
| 17 | Azzahra et al. (2022) | Explore social enterprise roles in sanitation innovation | | ✓ | ✓ | ✓ | | ✓ | | | | |
| 18 | Fernandez-Haddad & Ingram (2015) | Develop a management strategy for large-scale sustainable sanitation. | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | Middle East |
| | | **Interpersonal Communication through Word-of-Mouth** | | | | | | | | | | |
| 18 | Sweeney et al. (2008) | Explore factors that enhance the influence of positive WOM in professional services, focusing on the sender-receiver relationship, message richness, and situational factors. | | | ✓ | | ✓ | ✓ | | | | Australia |
| 19 | Adamopoulos et al. (2018) | Examine how personality traits influence the effectiveness of WOM in social media and their impact on purchase likelihood. | | | ✓ | | ✓ | | ✓ | | | US |
| 20 | Yang et al. (2012) | Consumers perceive WOM generation and consumption as complementary; product experience and media exposure influence these activities differently | | | ✓ | | ✓ | | ✓ | | | US |
| 21 | Kawakami & Parry (2013) | Investigate how WOM affects the perceived usefulness of innovations through credibility, adopter population, and complementary product availability. | | | ✓ | | ✓ | | ✓ | | | US |

| No | Article | Study Objective | Sanitation Context | | Public Perception and Engagement | Communication and Socialization Methods | | Methodological Approach | | | | Area of Study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DEWATS | Other | | Social Outreach | WOM | Qualitative | Statistic | ABM | Others | Study Area |
| 22 | Mason (2008) | Assess the role of WOM in turbulent markets and its relation to chaos theory, focusing on proactive company strategies. | | | ✓ | | ✓ | | | | ✓ | South Africa |
| 23 | Akil (2020) | Evaluate the impact of direct WOM on restaurant visit decisions and its effectiveness in increasing consumer attention. | | | ✓ | | ✓ | ✓ | | | | Jakarta |
| 24 | Singh et al (2016) | Integrate Belief-Desire-Intention (BDI) cognitive agents into Agent-Based Models (ABM) to enhance the simulation of complex cognitive processes and decision-making in social science scenarios. | | | ✓ | | ✓ | | | ✓ | | - |
| **Agent Based Modeling and Simulation in Sanitation Research** | | | | | | | | | | | | |
| 24 | Tillman et al., 2005 | Simulate and evaluate benefits and risks of existing best practice in water supply systems in Switzerland using an agent-based model | | ✓ | ✓ | | ✓ | | | ✓ | | Switzerland |
| 25 | Schwarz & Ernst, 2009 | Provide policy implications for water demand management and innovation diffusion using an agent-based model in Southern Germany | | ✓ | ✓ | | | | | ✓ | | Southern Germany |
| 26 | Kandiah et al., 2017 & 2019 | Develop a model for understanding community opinion dynamics on water reuse in the USA | | ✓ | ✓ | | ✓ | | | ✓ | | USA |
| 27 | Mallory et al., 2019 | Investigate FS reuse potential in Malawi using mixed methods and ABM | ✓ | | ✓ | | | | | ✓ | | Malawi |
| 28 | Darbandsari et al., 2020a | Develop a conflict resolution model for urban water resources management in Tehran using agent-based modeling | | ✓ | ✓ | ✓ | | | | ✓ | | Tehran, Iran |
| 29 | Oliva-Felipe et al., 2021 | Model stakeholder interactions in wastewater management using an agent-based approach | | ✓ | ✓ | | | | | ✓ | | Spain |

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# Chapter III Research Methodology

## III.1 Introduction

The present study investigates the dynamic evolution of public perception through top-down and bottom-level interactions. The research problem focuses on understanding how these interactions influence public perception formation to garner DEWATS adoption. To address this, the study adopts a quantitative analysis followed by an Agent-Based Model and computational simulation.

## III.2 Research Philosophy and Approach

Philosophically, this research adopts the pragmatism paradigm. This position suggests that the process is guided by what is possible and that the most important determinants of the research are the research questions and objectives (Saunders & Lewis, 2012). Pragmatism is suitable for social research regardless of whether it employs qualitative, quantitative, or mixed method (Morgan, 2014). In an epistemological and ontological standpoint, philosophical pragmatism argues that truth can be reduced to claims about what people genuinely do or might do. Nevertheless, they don't sum up into directives for actions (Powell, 2020). This argument is in accordance with the nature of simulation of social systems much more than other paradigms such as positivism.

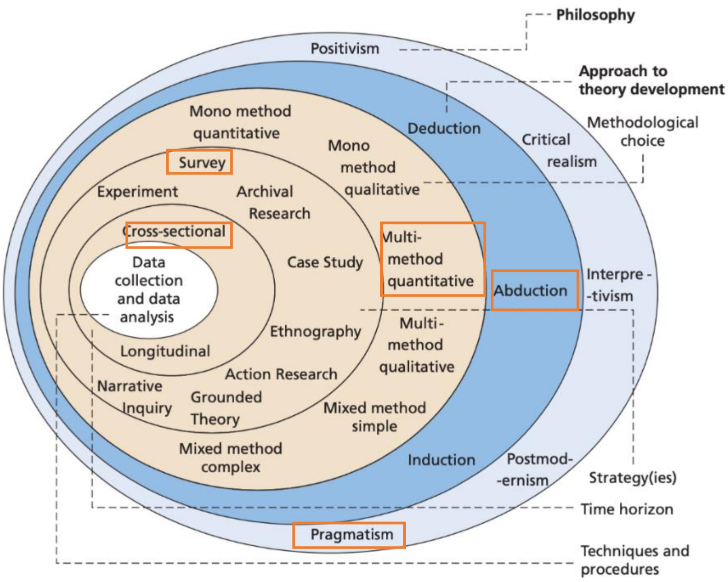


Figure III.1 The 'research onion'. (Sauders et al. (2012)

As an approach to theory development, this research adopts abduction. Abduction is increasingly recognized as a suitable method for exploratory research and the simulation of complex systems. Abduction is a cognitive process that generates explanatory hypotheses from observable phenomena, distinguishing it from other methods such as deduction and induction (Inshakova & Goncharov, 2017). This unique reasoning process aligns well with the needs of exploratory research, where the primary goal is to uncover new insights and explanations.

In the context of management research, abduction is valuable for developing new hypotheses and theories. By employing contrastive reasoning and recognizing different triggers, researchers can guide their exploration towards causal explanations that are both interesting and relevant (Folger & Stein, 2017). This makes abduction a powerful tool for generating innovative ideas and understanding complex interactions within a system.

The modeling philosophy in this research comes from the *synthetic method* which builds up theories of a system and thus constructs artificial systems which mirror the attributes of the natural system (Gershenson, 2002). This approach is a form of abductive reasoning, distinct from both deductive and inductive methods. While it shares similarities with the deductive approach through its use of preliminary generalization and abstraction from observable phenomena, and the adaptation of existing theories, it diverges by focusing on the creation of artificial computable systems. Unlike the inductive approach, which generates predictions from theory, the synthetic method prioritizes the creation and operation of simulations to observe emerging patterns and phenomena of behavior. The ultimate goal is not to produce observed facts, but to achieve observed performance, providing insights through the behavior exhibited by the artificial system.

### III.3 Research Choices

Regarding methodological choice, the study employs a multi-method quantitative and simulation approach. This choice allows for the use of different quantitative techniques to collect and analyze data, providing a more comprehensive understanding of the research problem (Benoit & Holbert, 2008). Specifically, this study uses path analysis, clustering, and agent-based modeling for its research choice. Combining quantitative data collection through surveys, path analysis of variables, clustering, and agent-based simulation offers a comprehensive and nuanced approach to understanding complex phenomena. This blend of methods captures both the broad patterns and detailed mechanisms underlying the research problem, providing a multi-layered perspective.

Surveys serve as the primary tool for quantitative data collection, offering a systematic way to gather information from a large sample. This method helps in identifying general trends, correlations, and basic relationships among variables (Msaki et al., 2022). The survey data then becomes the preliminary foundation for further analysis, ensuring that subsequent methods are grounded in robust empirical evidence (Kandiah et al., 2017).

Path analysis of variables allows for the exploration of causal relationships and the direct and indirect effects among variables. By modeling these relationships, the researcher can gain insights into the underlying structure of the phenomenon being studied. This method helps in understanding how different factors interact and influence each other, providing a clear picture of the causal pathways (Henseler et al., 2016a; Neunhoeffer & Teubner, 2018). The path analysis used in this research is more specifically the Partial Least Squared Path Modeling (PLS-PM).

Clustering techniques are employed to identify distinct groups or patterns within the data. This method is particularly useful for uncovering hidden structures and segmenting the data into meaningful categories (Klawonn, 2004; Neunhoeffer & Teubner, 2018). Clustering can reveal subgroups with similar characteristics or behaviors, offering a deeper understanding of the diversity within the sample and highlighting variations that might be overlooked in more traditional analyses.

Agent-based simulation brings a dynamic and interactive dimension to the research (Bruch & Atwell, 2015a; MacAl & North, 2010). By simulating the behavior of individual agents based on the findings from surveys, path analysis, and clustering, researchers can explore the emergent properties of the system. Simulations can model dynamic processes over time and allow for iterative testing and refinement of models, which is a distinctive characteristic not always found in standard quantitative research.

## III.4 Research Strategies

Although according to the literature by Saunders & Lewis (2012) surveys are usually used for explanatory study aimed at understanding the factor, the researcher argues that it is more suitable to be categorized as an exploratory approach by the path model analysis that is adopted.

The study involves empirical data collection through a cross-sectional survey, which focuses on capturing current public opinions and perceptions at a single point in time (Rindfleisch et al., 2008). This approach is suitable for understanding the present status quo of public perception.

In terms of quantitative techniques and procedures, the study involves detailed data collection and analysis. The process begins with the development of survey protocols, followed by the execution of door-to-door surveys to gather comprehensive data from participants. The collected data is then analyzed using advanced statistical techniques, including Partial Least Squares Path Modeling (PLS-PM) and fuzzy clustering which combination has been provided successful in previous research by Neunhoeffer & Teubner (2018). PLS-PM serves as a method to explore relationships and to analyze the influence of the different aspects on the complex phenomenon analyzed. The type of high order PLS-PM used is the reflective type model as the latent variables is considered to determine the set of perceptions observed from the public (Crocetta et al., 2021).

The choice to use ABM and simulation also serves an exploratory role. ABM can be used to explore new hypotheses by allowing this research to simulate different scenarios and observe potential outcomes (Noël & Cai, 2017). By creating simulations that model various conditions and interactions, this can generate new ideas and identify future novel research questions (Esmaelnezhad et al., 2023; Zellner, 2007). This exploratory use of ABM is valuable for pinpointing areas that require further investigation, potentially leading to discoveries and advancements in the social research of sanitation adoption.

ABM also has the capability to uncover emergent patterns and behaviors that are not immediately apparent from theoretical assumptions or empirical observations alone (Resnick, 1994; Sanford Bernhardt & McNeil, 2008)). Through detailed simulations, ABM can reveal complex dynamics and interactions within the system being studied (Edmonds & Meyer, 2013). This exploratory aspect of ABM is crucial for discovering new insights and understanding the underlying mechanisms that drive observed phenomena, contributing to a more comprehensive understanding of the system.

## III.5 Research Model

The purpose of the research model section is to outline the theoretical framework and methodological approach used to investigate the factors influencing household sanitation practices and perceptions.

### III.5.1 Statistic approach

The quantitative statistic research model for this exploratory study integrates a variety of latent and observed variables, guided by previous research, to understand the factors influencing household sanitation decisions. The model encompasses four main categories: Demographic Factors, Residential Factors, Familiarity and History, and Perception. Formation these latent variables and their determined related observed variables are guided by previous research from an array of sanitation (more specifically water) context, even though the previous literature is not previously about DEWATS as this research takes an exploratory position (Yong & Pearce, 2013).

Demographic Factors include the observed variables Decision Makers of the Family, Education Level, and Income Bracket. Decision makers are identified as the individuals in the household responsible for making sanitation-related decisions (Msaki et al., 2022). Education level refers to the highest degree or level of schooling completed by household members, which can influence their awareness and attitudes toward sanitation services (Msaki et al., 2022). Income bracket captures the total earnings of the household, potentially impacting their ability to afford and prioritize sanitation solutions (Msaki et al., 2022).

Residential Factors consider the observed variables Home Ownership and Residential Duration. Home ownership, whether the household owns or rents their home, can affect their investment in long-term sanitation infrastructure (De, 2018; Jain et al., 2019). Residential duration, or the length of time the household has lived at their current address, can influence their familiarity with local sanitation services and practices (De, 2018; Jain et al., 2019).

Familiarity and History variables include Familiarity with the Sanitation Service, Septic Tank Ownership, and Septic Tank Maintenance History. Familiarity with sanitation services assesses how well the household understands the local wastewater sanitation options (Gómez-Román et al., 2020). Septic tank ownership indicates whether the household possesses a septic tank, while septic tank maintenance history records past maintenance activities, which are crucial for effective sanitation management (Velazquez et al., 2015).

Perception and Support encompass several observed variables: Benefit, Concern, Technicality, Health and Benefit, Adherence, Social, Participation, and FSTP Support. These variables gauge the household's perceived benefits and concerns regarding the DEWATS (Decentralized Wastewater Treatment Systems) application, their understanding of the technical aspects, perceived health benefits, willingness to adhere to scheduled maintenance programs, and the perceived social effects (Kandiah et al., 2017; Mallory et al., 2019; Msaki et al., 2022; Schwarz & Ernst, 2009; Setiyawan et al., 2021). Participation measures their agreement to support wastewater sanitation services, and FSTP support assesses their acceptance of Faecal Sludge Treatment Plant infrastructure (Setiyawan et al., 2021).

The following table (Table III.1) outlines various factors influencing household sanitation practices and perceptions. These factors are categorized into demographic, residential, familiarity and history, and perception variables. Each latent variable is defined clearly, with corresponding observed variables of the questionnaire development. The reference which is used as guideline for the variable development is also cited. This structured overview aids in understanding the complex dynamics at play in household decision-making and attitudes toward sanitation services.

*Table III.1 Observed and latent variables to be explored*

| Latent variables | Observed Variables | Definition | Guiding References |
|---|---|---|---|
| Demographic Factor | 1. Decision Makers of the family | Individuals in the household responsible for making decisions regarding sanitation. | Msaki et al., 2022 |
| | 2. Education Level | The highest degree or level of school completed by members of the household. | Msaki et al., 2022 |
| | 3. Income Bracket | The total earnings or income bracket of the household. | Msaki et al., 2022 |
| Residential Factor | 1. Home Ownership | Whether the household owns or rents their home. | De, 2018; Jain et al., 2019 |
| | 2. Residential Duration | The length of time the household has lived at their current residence. | De, 2018; Jain et al., 2019 |
| Familiarity and History | 1. Familiarity with the sanitation service | How well the household knows and understands the local wastewater sanitation services. | Gómez-Román et al., 2020 |
| | 2. Septic tank ownership | Whether the household owns a septic tank. | Velazquez et al., 2015 |
| | 3. Septic Tank Maintenance History | The record of past maintenance (emptying) activities for the household's septic tank. | Velazquez et al., 2015 |

| Latent variables | Observed Variables | Definition | Guiding References |
|---|---|---|---|
| Perception and Support | 1. Benefit | Perceived benefit of DEWATS application in their area | Kandiah et al., 2017; Poortvliet et al., 2018; Schwarz & Ernst, 2009 |
| | 2. Concern | Perceived concerns of DEWATS application in their area | V. Kandiah et al., 2017; Poortvliet et al., 2018; Schwarz & Ernst, 2009 |
| | 3. Technicality | The perceived ease of use for implementing and maintaining septic tanks | Kandiah et al., 2017; Mallory et al., 2019 |
| | 4. Health and Environment | Perceived health and environmental benefits of DEWATS application | Kandiah et al., 2017; Msaki et al., 2022 |
| | 5. Adherence | Willingness to adhere to de-sludging scheduled programs and retribution fees | Setiyawan et al., 2021 |
| | 6. Social | Perceived social effects of DEWATS | Kandiah et al., 2017; Schwarz & Ernst, 2009 |
| | 7. Participation | Agreement to support of wastewater sanitation service | Setiyawan et al., 2021 |
| | 8. FSTP support | Support and acceptance of FSTP infrastructure building and operation | Setiyawan et al., 2021 |
| Communication Habbits | 1. Self identity | Self-evaluated religiosity | Kandiah et al., 2017 |
| | 2. Communication habbits 1 | Self-evaluated communication frequency with religious people | Kandiah et al., 2017 |
| | 3. Communication habbits 2 | Self-evaluated communication frequency with non- religious people. | Kandiah et al., 2017; |

To enhance the understanding of the outreach methods preferred by participants, the study also documented their communication habits. These habits were captured using a proxy question similar to the one employed by (Kandiah et al., 2017) in similar research. Specifically, self-evaluated religiosity was utilized as a proxy question. This approach was chosen because religion often serves as a significant aspect of personal identity in Indonesia, where individuals commonly self-identify through their religious beliefs. This practice is well-documented in studies such as those by Jonathan, (2017), Kharlie & Fathudin (2018), Setiawan & Sergeev (2023). By incorporating self-evaluated religiosity as a proxy, the study aimed to gain deeper insights into the participants' communication preferences, grounded in a culturally relevant and self-determined aspect of their identity.

This research will only be done in one timeframe (Rindfleisch et al., 2008) to assess the current opinions regarding the implementation of decentralized domestic wastewater service in the east of Bandung City. Therefore, the researcher will coordinate and confirm with local authorities and surveying experts. It is hoped by doing this, the researcher can get the best sample to represent in the model. By the end of the simulation, patterns of the dynamic change of agent belief will be analyzed.

### III.5.2 Modeling and simulation

This research will use the basic logic of the BDI (Belief-Desire-Intent) framework which assumes that agents within a system follow a logical pattern of belief to intention (Rao and Georgeff 1991; Singh et al., 2016). To understand the belief of the agents, empirical data is determined to be necessary. The data collected from the survey will be vital to the empirical behavioral data needed for the initial development of the model and simulation (Macal & North, 2006).

The synthetic method is applied to develop the agent-based model (ABM) that simulates the interactions and behaviors of agents based on the collected data (Steels, 1995; Gershenson, 2002). This method allows for the examination of dynamic changes in agent beliefs over time, providing a nuanced understanding of the complex factors influencing public attitudes towards wastewater services. By modeling these interactions, the research can identify emergent patterns and behaviors that are not immediately apparent from the raw data alone.

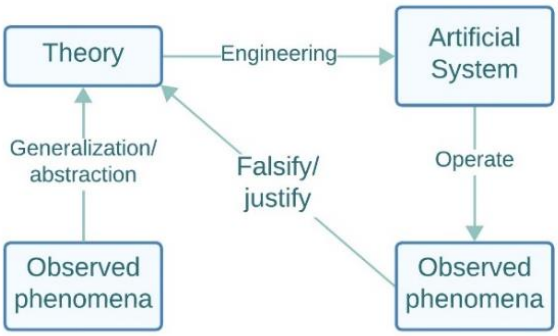


*Figure III.1 Process of the synthetic method*
*(adapted from Steels, 1995 and Gershenson, 2002)*

By adopting the synthetic method, this research can explore a range of "what-if" scenarios by altering agent rules, external influences, and interaction patterns. This flexibility in simulation enables the examination of the potential impacts of different variables and configurations. The exploratory approach of ABM helps researchers understand how changes at the micro-level can influence outcomes at the macro-level, providing valuable insights into the potential consequences of various interventions and strategies.

### III.6 Research Process

This research process serves as a guide to answer this research's problems. The initial step starts with identifying the issue being raised and setting clear objectives for this research. In this phase, gaps in existing literature are spotted, research questions are formulated, and expected results are predicted. The process of desk study and literature review follows, involving the examination of past related models and identification of their research limitations and future research trajectory. By reviewing existing studies, a conceptual framework is built, ensuring that the research brings novelty. These two processes set needed foundation for the research.

The data analysis process began with a door-to-door survey, which served as the initial step in gathering information on the existing public perception of DEWATS in the study area. The collected data provided valuable insights into the community's current attitudes and beliefs regarding decentralized wastewater treatment systems. This preliminary data not only set the foundation for a detailed analysis and the subsequent construction of the agent-based model but also offered a descriptive overview of the study area. These community insights are crucial for contextualizing and interpreting the modeling results, enabling a more nuanced discussion of the factors influencing public perception and potential adoption of DEWATS in the region.

The collected data is then used in path model analysis, specifically using the Partial Least Squared Path Model (PLS-PM) in R Studio. This analysis helps to understand the relationships between different variables in the study which will be used in the model and simulation. By applying this method, I can examine how different variables influence each other, identifying both direct and indirect effects within the dataset. This analysis is crucial for several reasons. First, it allows the validation of the measurement model by assessing the reliability and validity of the indicators used to measure each latent variable. Second, it enables the evaluation of the structural model, providing insights into the strength and significance of the relationships between variables being explored in the quantitative data analysis.

The next part of the quantitative analysis is agent clustering. The clustering process uses fuzzy clustering techniques in R to group agents based on their current status quo of public perception. Fuzzy clustering allows for agents to belong to multiple clusters with varying degrees of membership, providing a more nuanced understanding of their characteristics and behaviors. This method is particularly useful in capturing the diversity and complexity within the population, as it accounts for overlapping and ambiguous group memberships.

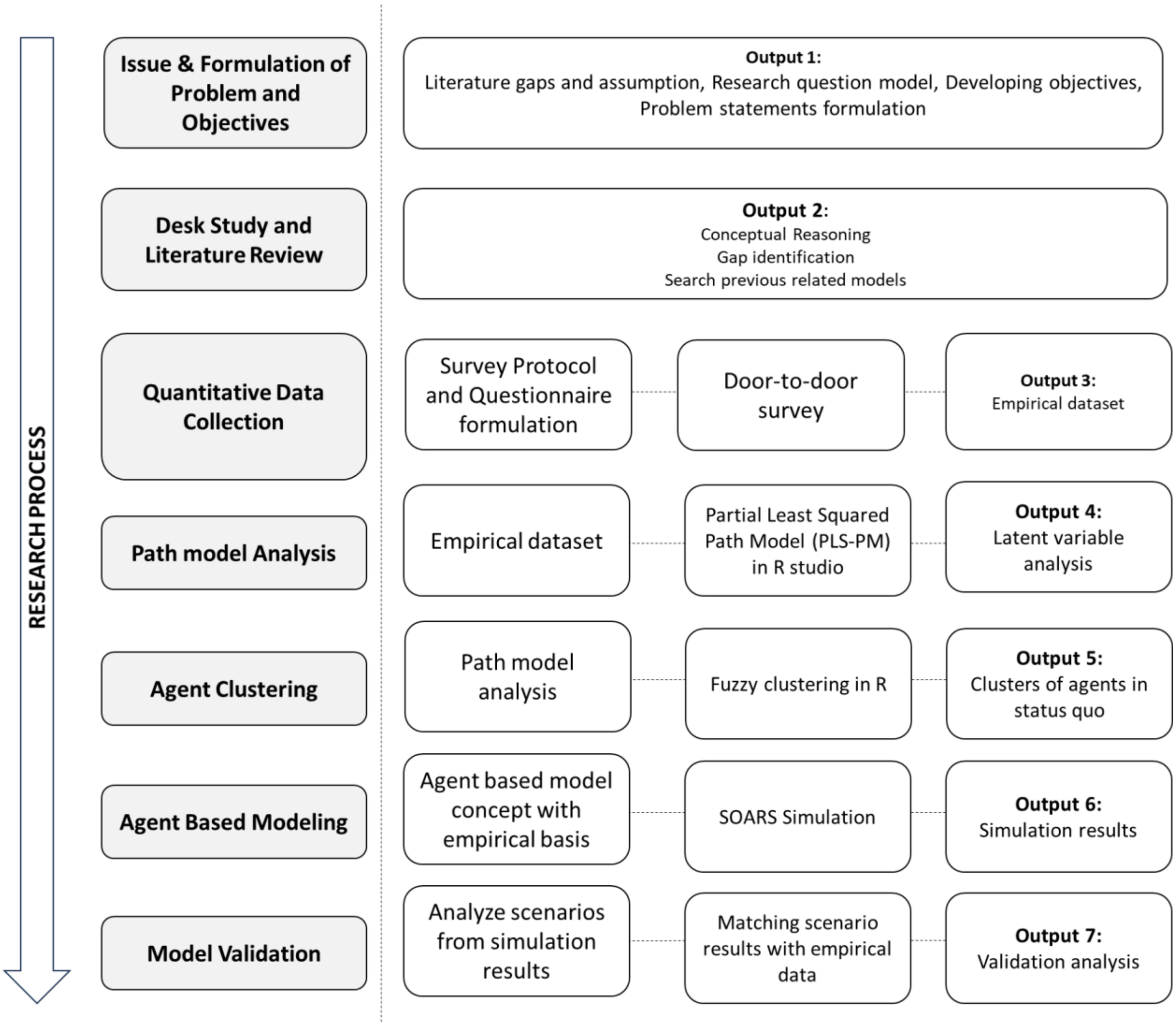


*Figure III.2 Research process*

Both quantitative data analysis techniques are crucial for the Agent Based Modeling phase. The insights gained from path model analysis and agent clustering are used to inform the development of the agent-based model. By incorporating these relationships into the model, the simulation accurately reflects the complexities of the real-world system being studied. This leads to more relevant simulations and better predictions of how different segments of the population might respond to various interventions or changes. Using the SOARS software, the model integrates these relationships to ensure realistic simulation outcomes. This approach also helps in identifying key leverage points where targeted actions can have the most significant impact.

Model Validation follows, which involves analyzing simulation results and conducting sensitivity analysis to test the model's reliability. This step ensures that the model's predictions are trustworthy. The research model produces detailed analysis and validation, offering a thorough understanding of the problem and potential solutions.

## III.7 Data Collection

The parameters are represented through questions that will be presented in a survey to acquire current empirical data. The questions are developed from the determined latent variables, with the questions reflecting the observed variable related to the latent variable.

### III.7.1 Population Sampling

To ensure the proper management of municipal wastewater, especially fecal waste management, Bandung City conducted studies and developed a Wastewater Management Masterplan in 2011 The plans showed several areas which will be the focus of wastewater service expansion plans in the time span of 2011 to 2032. The east districts of Bandung City areas to be the focus of on-site and off-site communal wastewater treatment development with plans of building a Fecal Sludge Treatment Plant (FSTP) in each area which is a common form of DEWATS (Setiyawan et al., 2021). The plan for new infrastructure creates an urgency to understand and see the perception of the local community in anticipation of rejection and to promote adoption.

The survey respondents are representatives from each household (Heads of Families). The family representative selected as a respondent is the mother/matriarch of the household. The number of respondents is determined to represent the population of 67,467 households in Gedebage District, Panyileukan District, and Rancasari District. By using the Slovin sampling method (confidence 95%), a total of 400 households from the selected sites were involved in the study.

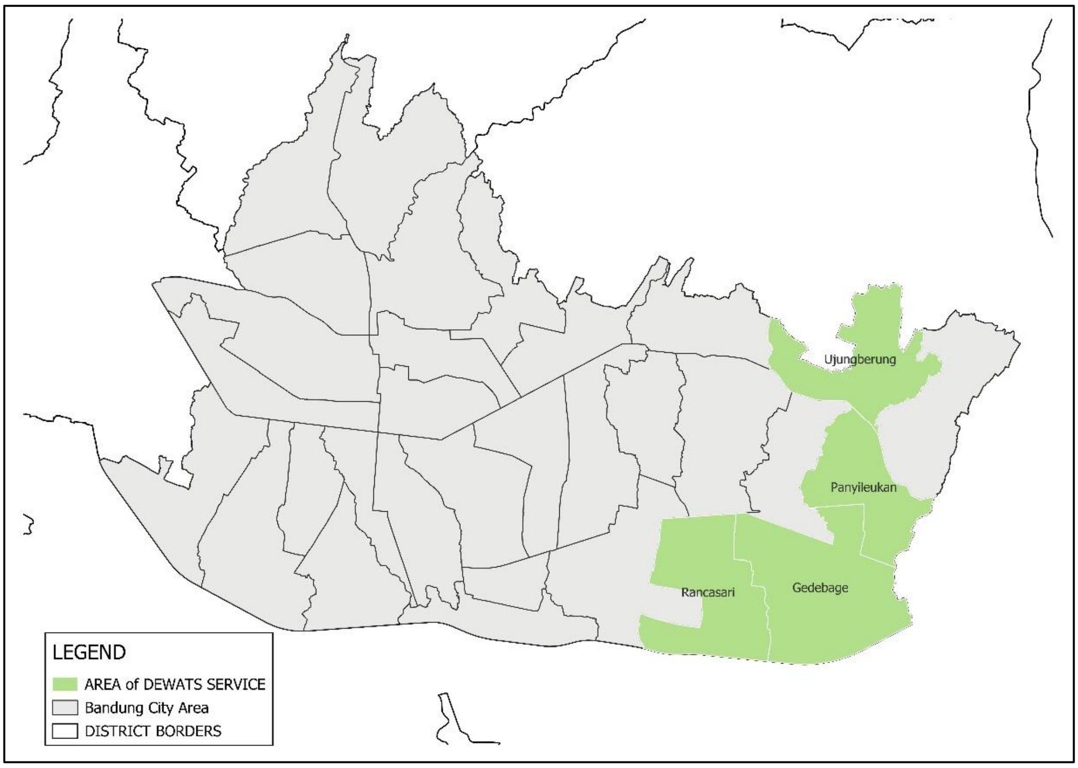


*Figure III.3 Study area - East of Bandung City*

In the district of Rancasari, several neighborhoods were surveyed. The neighborhood of Cipamokolan had 34 participants, accounting for 9% of the total sample from Rancasari. Derwati and Manjahlega had 33 and 39 participants, respectively, making up 8% and 10% of the sample from Rancasari. Mekarmulya had 23 participants, representing 6% of the sampled population in Rancasari. In Ujung Berung district, several neighborhoods were also included in the survey. Pasir Endah had 21 participants (5%), Cigending had 38 (10%), Pasirwangi had 25 (6%), Pasirjati had 26 (7%), and Pasanggrahan had 28 participants (7%) sampled from Ujung Berung. In the Gedebage district, neighborhoods such as Cisantren Kidul had 34 participants (9%), Rancabolang had 21 (5%), Rancanumpang had 8 (2%), and Cimenerang had 7 participants (2%). Lastly, the district of Panyileukan surveyed participants from Cipadung Kulon (25 participants, 6%), Cipadung Kidul (20 participants, 5%), Cipadung Wetan (6 participants, 2%), and Mekar Mulya (12 participants, 3%). This dataset provides a structured overview of participant sampling across various neighborhoods within the four districts of the study area, offering insights into the distribution and representation of surveyed individuals within specific geographical areas

### III.7.2 Data Collection Procedure

The initial step in our data collection involves conducting a door-to-door survey, which allows us to gather detailed and diverse data directly from the target population. This method employs a well-designed questionnaire to ensure consistency and comprehensiveness in the data collected. Personal interaction through door-to-door surveys increases the likelihood of accurate and honest responses, as interviewers can clarify questions for respondents in case of any confusion, reducing misunderstandings. This approach also facilitates the collection of qualitative insights through face-to-face interaction. However, this method can be time-consuming and resource-intensive, with potential interviewer bias and limited geographic coverage compared to questionnaires. The questionnaires are input to a *google form* which anticipated any empty responses and missing data.

### III.7.3 Questionnaire Design

The questions are formulated to measure various constructs relevant to our study, using a mix of open-ended, closed-ended, Likert scale, and multiple-choice questions. Measurement scales used in the questionnaire include nominal scales for categorical data without a specific order (e.g., gender, occupation), ordinal scales for ranked data (e.g., level of satisfaction), and ranking for preferences questions.

To measure the clusters the survey required respondents to evaluate their perception of DEWATS from a questionnaire consisting of relevant statements. Responses were reported on a Likert-type scale of 1 (strongly disagree) to 6 (strongly agree) as preferred by (Dolnicar & Grün, 2007) and a raking scale of 1 to 7 (1 is most preferred, 7 least preferred). An even number of response points is thought to be the suitable choice as it inhibits respondents from choosing the “neutral” or “undecided” middle point. The number of items (questions) is limited to anticipate fatigue or response distortions (Anastasi, 1976), thus a minimal of five items is chosen (Hinkin, 1998). The full version of the questionnaire developed can be seen in the appendix. However, the questions regarding perception of DEWATS can be seen in the Table III.2.

*Table III.2 Questions on perception*

| Code | Statement | Measurement |
|---|---|---|
| B1 | Self-maintaining personal facilities (septic tanks) and participating in scheduled sludge services is not burdensome for me | 6-point Likert scale (strongly agree to strongly disagree) |
| B2 | Local wastewater management is important for maintaining public health and environmental safety | 6-point Likert scale (strongly agree to strongly disagree) |
| B3 | The provision of local waste management is essential to prevent pollution from wastewater | 6-point Likert scale (strongly agree to strongly disagree) |
| B4 | I am willing to pay the set fee for wastewater services | 6-point Likert scale (strongly agree to strongly disagree) |
| B5 | Domestic wastewater management services will improve the welfare of the community where I live | 6-point Likert scale (strongly agree to strongly disagree) |
| B6 | I want to register for the local wastewater management service | 6-point Likert scale (strongly agree to strongly disagree) |
| B7 | I support the construction of a Faecal Sludge Treatment Plant (FSTP) in my area | 6-point Likert scale (strongly agree to strongly disagree) |
| C1 | Self-maintaining personal facilities (septic tanks) and participating in scheduled sludge services is burdensome | 6-point Likert scale (strongly agree to strongly disagree) |
| C2 | Local wastewater facilities can have adverse effects on public health and environmental safety in my area | 6-point Likert scale (strongly agree to strongly disagree) |
| C3 | Local wastewater facilities can disrupt comfort and cause damage to my living area | 6-point Likert scale (strongly agree to strongly disagree) |
| C4 | Paying the fee is burdensome for me | 6-point Likert scale (strongly agree to strongly disagree) |
| C5 | I am concerned that the authorities may not manage the facilities well, causing public unrest | 6-point Likert scale (strongly agree to strongly disagree) |
| C6 | I can manage wastewater on my own without joining the government services | 6-point Likert scale (strongly agree to strongly disagree) |
| C7 | I support the construction of a Faecal Sludge Treatment Plant (FSTP) in areas far from my residence | 6-point Likert scale (strongly agree to strongly disagree) |

Table III.3 presents various methods for public outreach related to sanitation services. It includes a range of options designed to gauge preferences for receiving information. These methods encompass public outreach with experts and government officials in public spaces

(M1), Focus Group Discussions (FGD) with experts, government officials, and community members (M2), and individual community outreach from door to door (M3). Additionally, it considers visits to wastewater treatment facility examples (M4), exhibitions about domestic wastewater treatment components and systems (M5), distribution of flyers and pamphlets to each house (M6), and making information available online or in public places (M7). This table aims to understand the preferred methods of communication and engagement for effectively disseminating information about sanitation services.

*Table III.3 Questions to measure outreach method preferences*

| Code | Item |
|---|---|
| M1 | Public outreach with experts and government officials in public spaces |
| M2 | Focus Group Discussions (FGD) with experts, government officials, and community members |
| M3 | Individual community outreach from door to door |
| M4 | Visits to wastewater treatment facility examples |
| M5 | Exhibitions about domestic wastewater treatment components and systems |
| M6 | Flyers and pamphlets distributed to each house |
| M7 | Information available online or in public places |

Table III.4 focuses on assessing communication habits within the community, particularly in relation to religious interactions. It includes questions that measure the respondent's self-assessed religiosity (K1) on a 6-point Likert scale ranging from very religious to very non-religious. It also explores the frequency of conversations with very religious individuals (K2) and with very non-religious individuals (K3), both measured on a 6-point Likert scale from very rarely to very frequently. This table is designed to capture the nuances of social interactions and communication patterns, which can influence community engagement and the dissemination of information regarding sanitation services.

*Table III.4 Questions to measure communication habits*

| Code | Item | Response |
|---|---|---|
| K1 | How religious do you consider yourself to be? | 6-point Likert scale (very religious to very non-religious) |
| K2 | How often do you talk with very religious people? | 6-point Likert scale (very rarely to very frequently) |
| K3 | How often do you talk with very non-religious people? | 6-point Likert scale (very rarely to very frequently) |

## III.8 Data Analysis

### III.8.1 Descriptive statistics

The collected data were catalogued into Microsoft Excel and imported to the R software for analysis. Descriptive statistics were used to compute frequencies and percentages of respondents' demographic characteristics. Pearson's correlation coefficient was used in this study to measure the strength and direction of a linear relationship between a respondent's knowledge on wastewater and reuse option by age and educational level. The correlation coefficient is represented by *r*. Pearson correlation analysis was chosen as it provided means to evaluate the strength and direction of the linear relationship between two continuous variables. It is considered the most effective method for assessing associations due to its reliance on covariance. This coefficient not only reveals the magnitude of the correlation but also its direction. All statistical tests were considered significant at a confidence level of 95% (P,0.05).

### III.8.2 Partial Least Squares Path Modeling (PLS-PM)

For data analysis, this research employs the Partial Least Squares Path Modeling (PLS-PM) method for Exploratory Factor Analysis, a statistical technique used to model complex relationships between observed variables and latent constructs (Crocetta et al., 2021) and suitable for the analysis of new technology acceptance (Henseler et al., 2016b). EFA is employed to merge potentially similar constructs into a smaller set of second-order constructs. This approach arguably allows for better interpretation and identification of latent factors which aids clustering analysis (Guttentag et al., 2018; Lawson et al., 2016) and ABMS process. EFA determines the underlying factors (i.e., second-order constructs) by calculating factor loadings of input factors (i.e., constructs) on the respective second-order constructs.

PLS-PM is particularly useful in exploratory research where the primary objective is to predict and explain variance. The process begins with model specification, defining the structural model (relationships between latent variables) and the measurement model (relationships between latent and observed variables). After data collection using the designed questionnaire, the PLS algorithm is applied to estimate the path coefficients using the R software with the *pls-pm* package. The model's reliability and validity are then evaluated, including composite reliability, average variance extracted (AVE), and discriminant validity. Finally, the results are interpreted to understand the relationships between constructs and derive actionable insights.

PLS-PM offers several advantages, such as suitability for small sample sizes, the ability to handle complex models with multiple constructs and indicators, and the capacity to manage both formative and reflective measurement models. It also does not require a normal distribution of data. This method is widely used in social sciences, marketing research, and business studies to understand phenomena like consumer behavior and organizational performance (Neunhoeffer & Teubner, 2018). By following these steps in our preliminary data analysis, we ensure a robust and systematic approach to understanding the data collected through our door-to-door survey, enabling us to derive meaningful insights and conclusions.



### III.8.3 Fuzzy Clustering Analysis

In addition to PLS-PM, we utilize the fuzzy clustering method to analyze the data. Fuzzy clustering is a form of clustering where data points can belong to multiple clusters with varying degrees of membership, represented by membership grades. This method is particularly effective in dealing with ambiguous and overlapping data, providing a more nuanced understanding of the underlying data structure (Klawonn, 2004).

The fuzzy clustering process begins with the initialization of cluster centroids and the assignment of membership grades to each data point for each cluster. The algorithm iteratively updates the centroids and membership grades to minimize an objective function, typically based on the distance between data points and cluster centers. This process continues until convergence, resulting in a set of clusters with associated membership grades for each data point. Fuzzy clustering offers several advantages, including the ability to handle data with overlapping clusters, providing more flexibility and insight compared to hard clustering methods (Klawonn, 2004). It is particularly useful when dealing with complex and heterogeneous data, allowing for the identification of subtle patterns and relationships that might be missed by traditional clustering techniques (Di Zio et al., 2021; Hirschinger et al., 2015).

By integrating fuzzy clustering with PLS-PM, we enhance our ability to model and interpret complex data structures (Neunhoeffer & Teubner, 2018). Fuzzy clustering helps identify distinct yet overlapping segments within the data, which can then be analyzed using PLS-PM to understand the relationships between latent and observed variables within each segment to achieve a mirroring of real-life conditions (Sun et al., 2012). This combined approach ensures a comprehensive and robust analysis, leading to more accurate and actionable insights from the data collected through the door-to-door survey.

The clustering method will be adapted from clustering approach of Neunhoeffer & Teubner (2018) using state-of-the-art fuzzy clustering algorithms (Kassambara, 2017). This clustering method anticipates high homogeneity and the unlikeliness of emerging clear-cut clusters as it will employ continuous second-order constructs (perception, belief) instead of discrete variables (e.g., gender, age, and occupation) (Rousseeuw, 1987). Clusters are formed by apportioning membership degrees—the probability of each data point's respective cluster membership—to each one (Klawonn, 2004). For eventual cluster allocation, an object is assigned to that cluster for which it exhibits the highest membership degree. Clustering will be computed with R software using the *cluster* and *factoextra* R packages (Kassambara, 2017).

## III.9 Model building and Simulation

An adaptation of the *Risks Publics* technique will be applied to the preliminary survey to obtain the model parameter that will be employed in the modeling process. However, as the current model does not represent a system with a "hazardous event" like the previous applications of the technique (Binder et al., 2011; Kandiah et al., 2017), the concept of "risk" is replaced with "concern" as it is deemed more representative of the agent belief in this real-world system. To better understand the function of external influences from public figures or governmental institutions and interpersonal communication channels, the study also measured social and communicative variables and will be developed into the communication parameters used to simulate the dynamic change of opinion.

The model building steps used in this research consists of five steps, adapted from the steps used by Akhbari & Grigg (2013) for agent-based model building in the water sector, which was also based on the guidelines made by Macal & North (2006). The steps are briefly visualized in Figure III.4 and elaborated below.

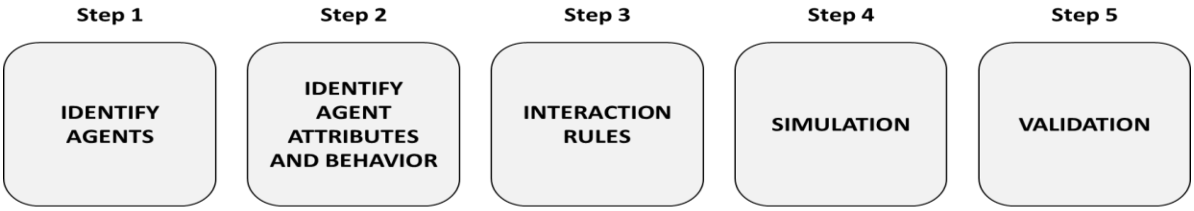


*Figure III.4 Agent Based Model development*
*(adapted from* Macal & North, 2006)

### III.9.1 Step 1: Identify agent type and behavior

According to Macal & North (2005), agents are required to have certain characteristics to be able to be modeled practically. This list of characteristics is used as a guideline to identify the agents that will be used in this research. The characteristics are as followed:

1. Identifiable, a discrete of individuals with a set of characteristics and rules governing its behaviors and decision-making capability.
2. Situated, agents are living in an environment that enables them to interact with other agents. There are mechanisms of interaction between agents and capability to respond to the environment.
3. Goal-directed, agents have goals to achieve with respect to their behaviors.
4. Agents have autonomy which means agents can function independently in it environment and dealings with other agents.
5. Agent has the flexibility to learn and adapt its behaviors over time based on their experience. This means they may have rules that modify their behavior.

To identify the agents that will be modeled in this research, typology by Akhbari & Grigg (2013) and Schwarz & Ernst (2009)—explained in more detail in Chapter 2—is referred. Although typology was developed for agent-based simulation in water resource demand, this typology is relevant as the people who need wastewater services in the end initially are water resource users. We concluded that the agents that will be modeled are the Urban/domestic type.

In accordance with Akhbari & Grigg's (2013) typology, we predict that this type of agent is reactive and deliberative. Reactive agents occupy a certain space in their surroundings. Their behavior is a result of how they interpret stimuli, or things that happen in their surroundings that have an impact on behavior. Either the surroundings or other agents contribute to their behavior. As a result, the behaviors of reactive agents are defined as a collection of condition-action rules together with a selection method that aids in determining what to do when certain rules are triggered. The selection process is more intricate for deliberative agents, also known as cognitive agents. Their actions stem from their recollections and memory of prior events as well as their agent knowledge of the surroundings.

In this case, the environment the agents are situated in is East of Bandung City. Their role is to participate in the public outreach programs scheduled by the authorities and participate in inter-agent communication. Their participation will affect the update of perceptions. In this model, their decision making is assumed to derive from the latent values in perception of the DEWATS plans which become the agent's attributes. The agent's goal is assumed to gain the most social, economic, and sanitation benefit.

### III.9.2 Step 2: Identify agent attributes and behavior

In this agent-based model, agents will be put into social group clusters based on the empirical results of the survey/preliminary data collection. The cluster analysis will be adapted from the belief model based on the risk publics theory from (Binder et al., 2011) which consists of a multi-dimensional conceptual framework for understanding public opinion dynamics of local issues such as the development of new facilities. This model has also been previously used by Kandiah et al. (2019) to model of a simulation of the public's perception of risk and benefit regarding plans of DEWATS in the Bandung City East area. This initial cluster analysis will instantiate the dynamic movement of the agents between the clusters after the form of communication in the simulation.

Agent relationship and their mechanisms of interpersonal interaction is acquired from the preliminary survey. The survey consists of questions that can present their personal beliefs of the service. "Benefits" is defined as the belief from perceived social, economic, and environmental advantages of a wastewater service system for both personal and surrounding community. Whereas "Concerns" represents the belief in social, economic, and environmental potential disadvantage of the service. The answers will represent constructs that will be grouped to second-order construct which ultimately influence the clustering of agents (Neunhoeffer & Teubner, 2018).

Agents in this simulation represent households of the four east area districts of Bandung, each agent serving as a proxy for 500 heads of household. Agents are divided into three clusters, proportionate to the *fuzzy clustering* results previously mentioned. Unlike the model by Kandiah et al. (2017), where perceptions are generalized to "benefits" and "concern", every agent is initialized with eight distinct values, each representing elements of perception regarding DEWATS. These perception elements undergo dynamic changes in response to the influence of outreach programs and interactions among agents. The attributes of agents are defined as follows:

1. Benefits – general perception DEWATS implementation benefits.
2. Concerns – general concerns about implementing DEWATS.

3. Technical Familiarity – prior knowledge and assumptions on impacts on the living environment.
4. Environment and Health – effect of DEWATS on the local environment and public health.
5. Adherence to Obligations – willingness to pay the set amount retribution fee for DEWATS service.
6. Social – views of social issues arising because of DEWATS implementation.
7. Awareness to participate – sense of urgency to participate in a government issued DEWATS service.
8. Support for infrastructure – support for the development, implementation, and operation of a FSTP in the area as part of a DEWATS service.

Positive perception growth is reflected by a decrease in the values of the 'concerns' and 'social' variables, alongside an increase in the values of all other variables. The overall range of values used as agent attributes can be seen in Table III.5.

*Table III.5 List of agent parameters for ABM*

| **Parameter** | **Range of Values** | **Meaning** |
|---|---|---|
| Cluster membership | {The Enthusiastic, The Conflicted, The Ambivalent} | Initial membership of each agent acquired from empirical data analysis |
| Adopter status (Adopt) | {0,1} | Indicates if agent gains adopter status, measured by willingness to participate |
| Connected Agents | 4 | Number of agents that influence through Word of Mouth interactions |
| Latent Variables | | |
| 1. Benefit *(B)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 2. Concern *(C)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 3. Technical Difficulty *(T)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 4. Health and Environment Implications *(HnE)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 5. Social Implications *(S)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 6.Willingness to Participate *(Part)* | [-2,2] | -2 indicates perception of variable is negatiive; 2 indicates perception of variable is positive |
| 7. Adherence to Policy *(A)* | [-2,2] | -2 indicates willingness is low; 2 indicates willingness is high |
| 8. Support of Infrastructure *(Sp)* | [-2,2] | -2 indicates willingness is low; 2 indicates willingness is high |

| Parameter | Range of Values | Meaning |
|---|---|---|
| Probability to Attend *(p_Attend)* | [0,1] | Probability to attend program according to preferences analyzed from empirical data |
| Weight of information from program *(w_Program)* | [0,1] | Weight of the likelihood the information is accepted according to program type |
| Probability Word of Mouth *(p_WOM)* | [0,1] | Probability to engage in Word of Mouth information exchange |
| Weight of information from heterogenous interaction *(w_WOMhet)* | [0,1] | Weight of the likelihood the information is accepted from heterogenous interaction |
| Weight of information from homogenous interaction *(w_WOMhom)* | [0,1] | Weight of the likelihood the information is accepted from homogenous interaction |
| Septage Generated *(Sept_total)* | 0.63 | Total septage generated by every agent in the simulation (litre/capita/day) |
| Septage to be Treated *(Sept_treat)* | [0, 0.63] | Total septage generated by agents according to adoption status, likely to be treated by the on-site system (litre/capita/day) |
| Time step | {0, 1, ….. 180 days} | The period of time the simulation is run |

### III.9.3 Step 3: Rules for dynamic change of belief

The simulation model assigns computational agents that represent households to a belief cluster and then randomly generates an initial set of benefit and concern perception values for each agent based on a cluster-specific value distribution. The first stage of communication, a household agent receives information from an outreach program in the form of three most preferred public outreach methods (1) Public Socialization, (2) Focus Group Discussion, (3) Public Exhibition. Then, the agents communicate through word-of-mouth mechanisms.

During their interactions, agents within the simulation update their values for all variables using specific equations. The variable updates ($P_{i,t+1}$) influenced by interactions are represented by the following equations:

$$P_{i,t+1} = P_{i,t} + (k \times \omega\_program)$$

$$P_{i,t+1} = P_{i,t} + (k \times \omega\_WOM)$$

In these equations, $P_{i,t}$ represents the initial values of any of the eight perception variables and $k$ constant value set to 0.01 that represent added value. The terms $\omega\_program$ and $\omega\_WOM$ denote the respective influences of program interactions and word-of-mouth interactions on the perception updates. The word of mouth model can be seen in Table III.6.

*Table III.6 Value update rules for WOM*

| | | Benefit | Concern | Technicality | Health and Environment | Adherence | Social | Participation | FSTPsupport |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.03462 | 0.04687 | -0.00931 | 0.00005 | -0.00082 | 0.029725 | -0.00797 | 0.0004 |
| positive | HOM 1 | + | - | + | + | + | - | + | + |
| negative | HOM2 | - | + | - | - | - | + | - | - |
| mixed | HOM3 | + | + | + | + | + | + | + | + |
| positive | HET | + | - | + | + | + | - | + | + |

Septage generation is simulated ($SG_{total}$), assuming a specific septage generation rate for all agents ($x$ liters per capita per day). The ratio of septage ($R_{sewage}$) generated by agents with TRUE adopter status ($SG_{adopt}$) is then calculated and divided by the total septage generation to simulate the septage treatment rate. This is to give insight on the rate of sewage that is ready to be transported to the FSTP and the need for scheduled transportation services.

$$R_{sewage\,(\%)} = \frac{SG_{adopt}}{SG_{total}}$$

### III.9.4 Step 4: Simulation

This study utilized SOARS (Spot Oriented Agent Role Simulator), designed to depict dynamic agent behaviors based on their roles within social and organizational structures (Tanuma et al., 2005), as its simulation platform. This Japanese-developed icon-based simulation program has previously been employed to analyze the effectiveness of social programs (Ii, 2006). SOARS is an open-source, lightweight, easy-to use simulation software (Abar et al., 2017) built upon the Java programming language. It is completed with built-in support for visual, intuitive graphic tools that facilitate model development through flexible drag-and-drop interfaces. The SOARS real-time visualization through charting and plotting is also utilized for assistance in observing the adaptation, evolution, and functional profiles of the models (Abar et al., 2017; MacAl & North, 2010). I chose this platform in part to demonstrate how the simplicity and friendly-to-use design offer are suitable for persons with novice simulation skills, mainly practitioners and policy makers, to explore agent-based modeling simulation to help future decision-making processes. Figure III.5 show the simulation design implemented in SOARS.

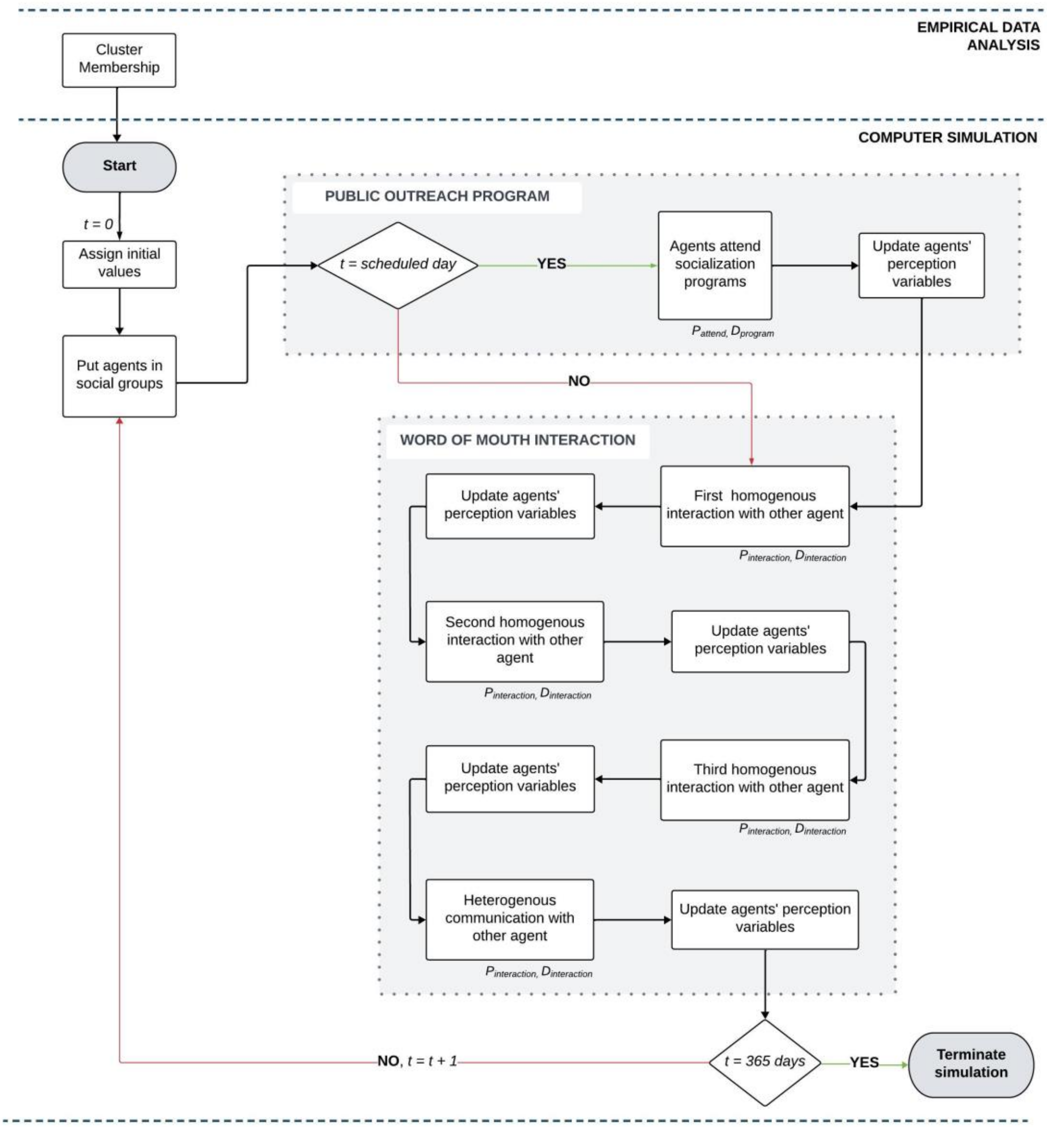


*Figure III.5 Agent-based model simulation design*

Agents enter the simulation with the cluster membership derived from the empirical result of survey. Then they are initialized based on whether they reside in the east of Bandung City in *t=0*. In each time step, active agents (1) receive external influence and messages from top-down public outreach programs, and (2) exchange messages with other agents either from the same or different clusters, (3) Agents update their values of perception variables and their adoption status.

### III.9.5 Step 5: Model Validation

The modeling validation process used in this study is by using empirical data. Bruch & Atwell (2015) emphasize the importance of using empirical data in ABMs to enhance theoretical understanding and policy relevance. They advocate incorporating diverse data sources and testing models against real-world behaviors to ensure accuracy and reliability. Windrum et al., 2007) also address methodological challenges in empirical validation, highlighting approaches such as indirect calibration to align model predictions with observed data. These methodologies help bridge the gap between theoretical constructs and empirical observations, essential for accurately simulating public perception and adoption behaviors concerning DEWATS.

Furthermore, Boero & Squazzoni (2005) underscore the necessity of empirical embedding in ABMs, allowing for effective calibration and validation of model outcomes. They recommend employing various empirical methods, including qualitative, quantitative, and participatory approaches, to ensure comprehensive data collection and model accuracy. This study adopts a similar comprehensive approach by integrating data from door-to-door surveys, statistical analyses, and fuzzy clustering for model validation. By adhering to these established practices, the study aims to develop a robust and empirically validated ABM, capable of providing reliable insights into the factors influencing DEWATS adoption.

# Chapter IV Results and Discussion

## IV.1 Introduction

This chapter presents the results of the data analysis conducted on the information collected through the door-to-door survey. The analysis aims to address the research questions and hypotheses outlined in earlier chapters. It includes a detailed description of the preliminary data analysis, application of the Partial Least Squares Path Modeling (PLS-PM) method, and the fuzzy clustering method. The chapter also includes a discussion of the findings and their implications.

## IV.2 Questionnaire Administration

The survey was conducted in February 2024 by following the procedures outlined in the data collection methodology, ensuring a systematic and thorough approach to gathering information. The initial step involved conducting a door-to-door survey, which enabled the collection of detailed and diverse data directly from the target population. Utilizing the pre-designed questionnaire which was inputted in google forms, ensured consistency and comprehensiveness in the responses obtained. Personal interaction through these door-to-door visits did increase the likelihood of accurate and honest responses, as interviewers were able to clarify any questions for respondents and garnered zero missing responses.

Despite the advantages, this approach presented several challenges. The door-to-door survey was time-consuming and resource-intensive, requiring significant manpower and coordination. The enumerators who participated in data collection were experts with years of experience. There were four enumerators which needed 12 days to complete the survey of 400 respondents. As the surveyors were more than one, there was the potential for interviewer bias, as the presence and demeanor of the interviewer could influence responses. Geographic coverage was also limited compared to other methods such as online surveys, potentially restricting the diversity of the sample.

## IV.3 Descriptive Analysis

### IV.3.1 Demographic Characteristics

To gain a comprehensive understanding of the respondents, the researcher conducted a descriptive analysis of their demographic characteristics. By exploring the demographic factors, the researcher aimed to identify patterns and trends that could influence respondents' beliefs and behaviors regarding DEWATS. Understanding the demographic profile of the respondents allows us to contextualize their responses and provides a foundation for more detailed analysis of their perceptions and attitudes. This demographic overview also helps in identifying any significant correlations between respondents' characteristics and their views on wastewater management, thereby informing targeted outreach and intervention strategies.

Figure IV.1 presents a breakdown of respondents' occupational statuses in the survey. Most participants, accounting for 56%, identified as housewives, making this the largest single group. Manual laborers constitute the second-largest group at 17%, followed by private sector employees at 13%. Business owners and entrepreneurs make up 7% of the respondents. Those who are currently unemployed or not yet employed represent 3% of the sample. Freelance workers, including digital content creators, account for 2%, while retirees, individuals in the "others" category, and online transportation partners/drivers each constitute 1% of the respondents. Notably, there are no student or university student respondents, as this category is represented by 0%. This distribution highlights the diverse occupational backgrounds of the survey participants, with a significant representation of non-working individuals and manual laborers.

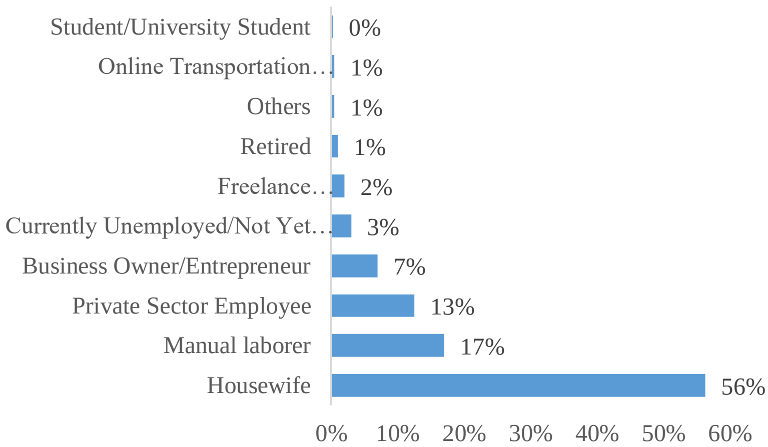


*Figure IV.1 Occupation of respondents.*

The respondents had an average age of 42 years old. The educational distribution within the surveyed population reveals a predominant presence of individuals with a high school education (SMA), constituting the majority at 57%. This is followed by respondents who completed junior high school (SMP) at 30%, while primary school graduates (SD) comprise a smaller yet notable portion at 13%. Notably, only a minimal percentage of participants hold a bachelor's degree (S1), representing just 1% of the sample. Surprisingly, no respondents reported having education beyond the undergraduate level (Higher Education). This breakdown underscores the prevalence of high school education among the surveyed group, suggesting potential implications for educational completion levels and their impact on various aspects of the population's perspectives and experiences.

The income distribution among respondents highlights a significant majority falling within the middle-income bracket, with 67% reporting monthly earnings between Rp 2.500.000 and Rp 4.999.999. Additionally, 12% of participants reported earning between Rp 5.000.000 and Rp 9.999.999 per month. Surprisingly, none of the respondents reported an income below Rp 2.500.000. This distribution suggests a concentration of respondents within the middle-income range, possibly reflecting broader economic trends and the financial circumstances of the surveyed population.

In the specific context of this research, the living environment plays a critical role in influencing behaviors and decisions. For example, in areas related to environmental interventions, public health, or infrastructure usage, the immediate physical environment—represented by living spaces—will be more directly relevant than individual educational or economic backgrounds. This approach allows for a more contextually appropriate analysis, focusing on the most impactful variable for the study’s objectives. Additionally, preliminary analysis revealed weak correlations between income and perception (ranging from 0.1 to 0.3), such as a weak positive correlation between income and positive perception ($r = 0.1610$, $p = 0.001$***) and a weak negative correlation between income and negative perception ($r = -0.1090$, $p = 0.029$*). These findings suggest that economic status alone may not be a dominant factor in shaping perceptions within this context. Consequently, by focusing on living spaces, the analysis remains clear and effective, aligning with the specific goals and context of the research, while addressing the minimal influence that economic factors appeared to have in preliminary findings.

### IV.3.2 Home ownership and habitual duration

In gaining community insight, the researcher examined home ownership status and residential duration. In terms of home ownership, a significant majority of respondents, 74% (294 individuals), reported having full ownership rights over their homes. A smaller portion, 1% (2 individuals), indicated they have rights to use or lend the property for a specified period as per an agreement with the owner. Meanwhile, 26% (104 individuals) are renting their homes, paying a certain amount to the property owner for the use of the house or land for a designated period.



Regarding residential duration, 18% (70 individuals) of respondents have lived in their current residence for 0–5 years, 14% (56 individuals) for 5–10 years, 13% (51 individuals) for 10–20 years, and a majority of 56% (223 individuals) have resided in their homes for more than 20 years. Understanding home and habitual factors provides context for interpreting the respondents' views and behaviors regarding wastewater management and helps in identifying patterns that could inform targeted outreach and intervention strategies.

### IV.3.3 DEWATS history

To get a better understanding of the DEWATS position among the public, the researcher also inquired about septic tank ownership and maintenance history.Regarding septic tank ownership, 61% of respondents reported having an individual septic tank, indicating that a majority manage their own wastewater treatment at home. This suggests a significant level of responsibility placed on individual households for wastewater management. However, 23% of respondents use communal facilities, which indicates reliance on shared resources for wastewater treatment, potentially pointing to varied infrastructural provisions within the community. The remaining 16% were unsure about their septic tank ownership status, reflecting a lack of awareness that could impact proper maintenance and management practices.

In terms of familiarity with septic tank systems, only 28% of respondents indicated they were familiar with the systems, suggesting that a majority might lack adequate knowledge about how these systems operate. Another 28% had limited familiarity, while 44% were not familiar at all. This lack of familiarity is significant as it could influence the effectiveness of maintenance practices and overall system efficiency.

The maintenance history of septic tanks further underscores potential challenges in wastewater management. A striking 76% of respondents reported never having performed maintenance on their septic tanks, which raises concerns about the potential for system failures and environmental contamination. Only 7% had performed maintenance more than five years ago, 10% within the past 2-5 years, and another 7% within the last two years. The low levels of recent maintenance activity highlight the need for increased awareness and intervention to ensure regular upkeep of septic systems.

The high percentage of individual septic tank ownership, coupled with low familiarity and maintenance activity, suggests a critical need for targeted outreach and education programs. Such initiatives could enhance understanding and practices related to septic tank management, ultimately contributing to improved wastewater management in the community. Addressing these gaps could help inform more effective intervention strategies, fostering better public health and environmental outcomes.

To gain a stronger understanding of how DEWATS history contribute to the public DEWATS perception, the researcher conducted a correlation analysis. The analysis reveals several significant correlations between DEWATS history and perceptions of decentralized wastewater treatment systems (DEWATS) in Bandung City (Table IV.1).

*Table IV.1 Summary of correlation analysis*

| **Association** | **Pearson's r** | **P-value** |
|---|---|---|
| ***Moderate Correlation (r = 0.3 – 0.5)*** | | |
| Maintenance history and Negative Perception | -0.3910 | 0.000*** |
| Septic Tank ownership and Negative perception | -0.3890 | 0.000*** |
| Familiarity of Service and positive perception | 0.3920 | 0.000*** |

A moderate negative correlation exists between maintenance history and negative perception ($r = -0.3910$, $p < 0.001$), and septic tank ownership and negative perception ($r = -0.3890$, $p < 0.001$). This suggests that familiarity and involvement in septic tank maintenance reduce negative attitudes towards DEWATS. Conversely, familiarity with the service correlates moderately with positive perception ($r = 0.3920$, $p < 0.001$), emphasizing the importance of awareness and experience in shaping favorable opinions.

The correlation analysis further highlights the importance of delivering information about the importance and availability of maintenance services to the public, such as septic tank emptying. This can foster initial public engagement and positive perception. The significance of these associations can inform targeted strategies to encourage proactive maintenance behaviors, ultimately leading to better community health outcomes. These results align with Gómez-Román et al.'s (2020) findings, though the significance of experience in maintenance history is a new insight.

## IV.4 Application of Partial Least Square Path Model (PLS PM)

The Partial Least Square Path Model (PLS-PM) was analyzed in R software using the *plspm* package. R's comprehensive set of packages and strong community support make it an ideal choice for conducting complex statistical modeling. The *plspm* package in R is specifically designed for PLS-PM analysis, offering various tools and functionalities to handle various aspects of the modeling process efficiently.

The variables in the analysis have been codified to ensure clarity and consistency in their measurement and interpretation. The latent variables are labeled as LV1 to LV8, each representing a specific aspect of the study. LV1 corresponds to "Benefit," capturing the perceived advantages of the wastewater treatment systems. LV2 is "Concern," which measures the worries or negative perceptions associated with the systems. LV3, labeled "Technicality," encompasses the technical aspects and complexities involved. LV4, "HnE" (Health and Environment), includes indicators related to the impact on health and environmental conditions. LV5, "Adherence," evaluates compliance with relevant guidelines and practices. LV6, "Social," assesses the social implications and community engagement. LV7, "Participation," measures the level of public involvement and awareness. Lastly, LV8, "FSTP_support," gauges the support for Fecal Sludge Treatment Plants. This structured codification allows for a systematic analysis of the various factors influencing the adoption and perception of wastewater management systems.

### IV.4.1 Model specifications

This section outlines the procedures for specifying and analyzing the Partial Least Squares Path Model (PLS-PM).

***Standardization***

Eventhough normally the PLS-PM method does not require normal distribution of data, this researcher still conducted standardization for the purpose of the next steps of analysis (clustering and ABM simulation). This standardization process ensures that each variable has a mean of zero and a standard deviation of one, allowing for comparability across different scales. The standardization function, defined in the code, calculates the mean and standard deviation for each specified column, then transforms the data into a standardized format. This was applied to selected columns (B1 to B7 and C1 to C7) to prepare the data for further analysis.

Code:

```
standardize <- function(column) {
  mean_val <- mean(column, na.rm = TRUE)
  sd_val <- sd(column, na.rm = TRUE)
  standardized_column <- (column - mean_val) / sd_val
  return(standardized_column)
}
columns_to_standardize <- c("B1", "B2", "B3", "B4", "B5", "B6", "B7", "C1",
"C2", "C3", "C4", "C5", "C6", "C7")
specified_columns[columns_to_standardize] <-
lapply(specified_columns[columns_to_standardize], standardize)
print(specified_columns)
```

***Defining outer model***

The outer model specifies how measured variables (indicators) relate to their corresponding latent variables (constructs). In this analysis, constructs such as Benefit, Concern, Technicality, Health and Environment (HnE), Adherence, Social, Participation, and FSTP_support were defined with their respective indicators. This categorization helps in structuring the relationships for the PLS-PM analysis.

Code:

```
# Define the outer model
blocks <- list(
  Benefit = c("B1", "B2", "B3", "B4", "B5", "B6", "B7"),
  Concern = c("C1", "C2", "C3", "C4", "C5", "C6", "C7"),
  Technicality = c("B1", "C1", "C6"),
  HnE = c("B2", "B3", "C2", "C3"),
  Adherence = c("B4", "C4", "B6"),
  Social = c("B5", "C3", "C5"),
  Participation = c("B1", "B6", "C6"),
  FSTP_support = c("B2", "C2", "B7", "C7")
)
```

***Defining the inner model***

The inner model matrix represents the hypothesized relationships between latent variables. This matrix is a lower triangular matrix indicating the directional paths between constructs, with 1 indicating a path and 0 indicating no path. This structure is crucial for defining the relationships that the PLS-PM algorithm will analyze.

Code:

```
path_matrix <- matrix(c(0, 0, 0, 0, 0, 0, 0, 0,
                        1, 0, 0, 0, 0, 0, 0, 0,
                        1, 1, 0, 0, 0, 0, 0, 0,
```

```
                        1, 1, 1, 0, 0, 0, 0, 0,
                        1, 1, 1, 1, 0, 0, 0, 0,
                        1, 1, 1, 1, 1, 0, 0, 0,
                        1, 1, 1, 1, 1, 1, 0, 0,
                        1, 1, 1, 1, 1, 1, 1, 0), nrow = 8, ncol = 8, byrow
= TRUE)
```

***Performing the PLS-PM Analysis***

The PLS-PM analysis is executed by combining the standardized data, outer model (blocks), inner model (path matrix), and specifying the mode (reflective). The analysis computes the path coefficients, loadings, and weights, providing insights into the relationships between constructs and their indicators.

Code:

```
mode_reflective <- rep("A", 8)
plspm_results2 <- plspm(specified_columns, path_matrix, blocks,
mode_reflective, scheme = "centroid", scaled = FALSE)

summary(plspm_results2)
plot(plspm_results2)
plot(plspm_results2, what = "loadings", arr.width = 0.1)
plot(plspm_results2s, what = "weights", arr.width = 0.1)

summary(plspm_results2)
```

### IV.4.2 Model measurement and fit analysis

Table IV.2 shows information on the type, size, mode, and unidimensionality metrics (Cronbach's alpha, Dillon-Goldstein's rho, and eigenvalues of the first and second components) for each block in the PLS-PM model. This is done to evaluate and validate the measurement model, which defines how latent variables (constructs) are measured by their associated observed variables (indicators).

*Table IV.2 Blocks analysis tabulation*

| Block | Code | Type | Size | Mode | C.alpha | DG.rho | eig.1st | eig.2nd |
|---|---|---|---|---|---|---|---|---|
| **Benefit** | **LV1** | Exogenous | 7 | Reflective | 0.804 | 0.85617 | 3.22 | 1.224 |
| **Concern** | **LV2** | Endogenous | 7 | Reflective | 0.873 | 0.90342 | 4.04 | 0.903 |
| **Technicality** | **LV3** | Endogenous | 3 | Reflective | 0.331 | 0.62258 | 1.56 | 1.047 |
| **HnE** | **LV4** | Endogenous | 4 | Reflective | 0.31 | 0.12705 | 2.01 | 1.284 |
| **Adherence** | **LV5** | Endogenous | 3 | Reflective | 0 | 0.52683 | 1.94 | 0.745 |
| **Social** | **LV6** | Endogenous | 3 | Reflective | 0.375 | 0.65688 | 1.6 | 1.024 |
| **Participation** | **LV7** | Endogenous | 3 | Reflective | 0.299 | 0.65457 | 1.31 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **FSTP_support** | **LV8** | Endogenous | 4 | Reflective | 0.407 | 0.00348 | 1.52 | 1.462 |

LV1 (Benefit), an exogenous reflective block with seven indicators, demonstrates strong reliability and unidimensionality, evidenced by a Cronbach's alpha of 0.804 and a Dillon-Goldstein's rho of 0.856. The eigenvalues of the first (3.22) and second (1.224) components further confirm a dominant primary dimension, indicating a well-defined construct. Similarly, LV2 (Concern), an endogenous reflective block with seven indicators, shows high internal consistency with a Cronbach's alpha of 0.873 and a Dillon-Goldstein's rho of 0.903. The eigenvalues (first: 4.04, second: 0.903) also suggest a strong primary dimension, underscoring its reliable measurement.

LV3 (Technicality), with three indicators, exhibits moderate reliability. The Cronbach's alpha of 0.331 points to potential issues with internal consistency, while the Dillon-Goldstein's rho of 0.623 indicates some reliability. The eigenvalues (first: 1.56, second: 1.047) suggest the presence of multiple dimensions, hinting at possible issues with the construct or its indicators. LV4 (HnE), another endogenous reflective block with four indicators, shows significant limitations. Both its Cronbach's alpha (0.31) and Dillon-Goldstein's rho (0.127) are low, and the eigenvalues (first: 2.01, second: 1.284) indicate multidimensionality, suggesting that the construct may not be well-defined or that the indicators are inadequate.

LV5 (Adherence), with three indicators, also presents significant challenges. Its Cronbach’s alpha of 0.0 indicates no internal consistency, and the Dillon-Goldstein's rho of 0.527 suggests some reliability, though the eigenvalues (first: 1.94, second: 0.745) indicate two dimensions. This necessitates further investigation or revision to improve measurement quality. LV6 (Social), with three indicators, shows a low Cronbach's alpha of 0.375 but moderate reliability with a Dillon-Goldstein's rho of 0.657. The eigenvalues (first: 1.6, second: 1.024) point to multidimensionality, indicating potential issues with construct definition or indicator quality.

LV7 (Participation), another block with three indicators, shows moderate reliability, with both Cronbach's alpha (0.299) and Dillon-Goldstein's rho (0.655) being relatively low. The eigenvalues (first: 1.31, second: 1.0) indicate a near-equal split between dimensions, suggesting the need for additional indicators to strengthen the construct. LV8 (FSTP Support), with four indicators, demonstrates low reliability. Its Cronbach's alpha of 0.407 and a very low Dillon-Goldstein's rho of 0.003 highlight significant measurement issues, and the eigenvalues (first:

1.52, second: 1.462) suggest a balanced dimension structure, pointing to the need for additional indicators to enhance robustness.

The goodness-of-fit (GoF) value for the model is 0.5999. This metric, which provides a measure of how well the observed data matches the model, suggests a moderate fit. While not indicative of a perfect model, a GoF value of 0.5999 is generally considered acceptable in many practical applications of PLS-PM (Partial Least Squares Path Modeling). This suggests that the model has a reasonable level of predictive power and the constructs are adequately capturing the variance in the data. However, given the reliability issues observed in some latent variables (LV3, LV4, LV5, LV6, LV7, and LV8), there is still room for improvement. Enhancing the indicators and refining the constructs could further strengthen the model's fit and overall reliability.

### IV.4.3 Outer model results and analysis

The analysis of the reflective PLS PM outer model results involves examining the factor loadings of each latent variable and the reflection of each observed variable. In reflective PLS-PM, factor loadings indicate the extent to which each observed variable reflects the latent variable it is intended to measure. To ensure the reliability and validity of the constructs, a common threshold for factor loadings of 0.65 is chosen. Indicators with loadings above this threshold are considered to have a strong relationship with their respective latent variables indicating strong reflection, while those below 0.65 may be undefined. Table IV.3 presents the cross-factor loading results for each indicator across different latent variables, highlighting which indicators meet the cutoff value of 0.65 and which do not.

*Table IV.3 Cross-factor loading result (cut-off 0.65)*

| | LV1 | LV2 | LV3 | LV4 | LV5 | LV6 | LV7 | LV8 |
|---|---|---|---|---|---|---|---|---|
| **B1** | | | | | | | | |
| **B2** | 0.6986 | | | | | | | |
| **B3** | 0.6887 | | | | | | | |
| **B4** | 0.6586 | | | | 0.832 | | | |
| **B5** | 0.7289 | | | | | | | |
| **B6** | | | | | 0.79 | | | |
| **B7** | 0.6971 | | | | | | | |
| **C1** | | 0.8308 | 0.895 | -0.66 | | 0.655 | | |
| **C2** | | 0.8683 | 0.722 | -0.836 | | 0.7404 | | -0.81 |
| **C3** | | 0.8722 | 0.705 | -0.834 | | 0.8876 | | -0.682 |
| **C4** | | | | | -0.768 | | | |
| **C5** | | 0.7056 | | | | 0.718 | | |

| | LV1 | LV2 | LV3 | LV4 | LV5 | LV6 | LV7 | LV8 |
|---|---|---|---|---|---|---|---|---|
| **C6** | | 0.7815 | 0.802 | -0.722 | | | -0.738 | |
| **C7** | | | | | | | | |

For LV1, significant loadings are found for variables B2, B3, B4, B5, and B7, with values ranging from 0.6586 to 0.7289. This indicates a strong association between these variables and LV1, suggesting they are critical in indicating this latent construct. However, B1 and B6 do not show significant loadings, which may indicate that the perceived burden of self-maintenance (B1) and the desire to register for services (B6) are not caused by the construct of Benefits.

In the case of LV2, variables C1, C2, C3, C5, and C6 exhibit significant loadings, with notably high values for C1, C2, and C3 (0.8308, 0.8683, and 0.8722, respectively). These high loadings underscore the reflective strength Concern latent variable (LV2) has on them. However, C4 (concern about the fee being burdensome) and C7 (support for FSTP far from residence) do not exhibit significant loadings, suggesting these items might need modification or reevaluation to better capture the construct of concern. Similarly, LV3 sees significant contributions from variables C1, C2, C3, and C6, with C1 showing the highest loading at 0.895. This discrepancy indicates that the burden of self-maintenance (B1) may not be reflected by Technicality, suggesting a need for refinement in the model or reconsideration of this variable's role.

LV4 presents a different pattern, with negative loadings observed for variables C1, C2, and C3 (-0.66, -0.836, and -0.834, respectively). The negative loadings indicate an inverse relationship between these variables and LV4, which may suggest that as these variables increase, LV4 decreases. Variables B2 and B3 (importance of local wastewater management for health and environmental safety, and prevention of pollution), originally modeled in this latent variable, are significantly loaded on LV1, while C2 and C3 (adverse effects and disruption caused by wastewater facilities) show significant loadings on multiple LVs, reinforcing their reflection in this construct.

Adherence is represented by B4, C4, and B6 in the outer model. The factor loading results for LV5, which aligns with Adherence, show a significant positive loading for B4 (0.832) and B6 (0.79), indicating that willingness to pay (B4) and desire to register (B6) are strongly reflected by this construct. C4 also shows a significant loading albeit negative, suggesting that the concern about fees (C4) is as reflected in Adherence as initially thought. This partial alignment indicates that all variables effectively capture the Adherence latent variable.

The Social (LV6) construct, defined by B5, C3, and C5, is supported by significant loadings for these indicators on LV5 and LV6. The indicators—improvement of community welfare (B5), disruption and damage concerns (C3), and concern about facility management (C5)—are significantly reflected by the Social latent variable. However, the presence of mixed loadings for some indicators indicates that the relationships might be more nuanced.

LV7 (Participation) has only one significant loading. This singular significant loading indicates a specific inverse association between C6 and LV7. Originally, Participation includes B1, B6, and C6. While C6 (ability to manage wastewater independently) shows significant loadings of -0.738. B1 and B6 (self-maintenance not being burdensome and desire to register for services) do not consistently exhibit strong loadings, suggesting that the model might need adjustment to better capture the observable variables reflected by Participation.

The FSTP Support latent variable (LV8), represented by B2, C2, B7, and C7 in the outer model, finds strong support in the cross-factor loading results. C2 (adverse effects) show significant loadings on LV8, underscoring their reflection in this construct. Additionally, C3 (disruption and damage concerns) also shows significant loadings, indicating its strong reflection. However, B7 (support for FSTP in the area) and C7 (support for FSTP far from residence) do not consistently meet the significant cutoff, suggesting these indicators may need reevaluation to ensure they accurately represent the FSTP Support construct. This partial alignment highlights the need for a closer examination of B7 and C7 to determine their pontential modification.

### IV.4.4 Inner model results and analysis

The inner model analysis reveals distinct insights into the reliability and explanatory power of various constructs. Constructs such as LV1 (Benefit) and LV2 (Concern) exhibit strong reliability and well-defined constructs, while others such as LV3 (Technicality), LV4 (HnE), LV5 (Adherence), LV6 (Social), LV7 (Participation), and LV8 (FSTP Support) show varying levels of reliability and explanatory power. Table IV.4 summarizes the results.

*Table IV.4 Inner model summary*

| Variable | Type | R2 | Block_Communality | Mean_Redundancy | AVE |
|---|---|---|---|---|---|
| LV1 | Exogenous | 0 | 0.459 | 0 | 0.459 |

| | | | | | |
|---|---|---|---|---|---|
| LV2 | Endogenous | 0.0523 | 0.575 | 0.0301 | 0.575 |
| LV3 | Endogenous | 0.8141 | 0.518 | 0.4215 | 0.518 |
| LV4 | Endogenous | 0.8127 | 0.502 | 0.4079 | 0.502 |
| LV5 | Endogenous | 0.7865 | 0.636 | 0.5001 | 0.636 |
| LV6 | Endogenous | 0.8677 | 0.51 | 0.4422 | 0.51 |
| LV7 | Endogenous | 0.8106 | 0.36 | 0.2916 | 0.36 |
| LV8 | Endogenous | 0.9465 | 0.378 | 0.3575 | 0.378 |

LV1 (Benefit) is an exogenous variable with a Block Communality and AVE of 0.459, indicating moderate shared variance among its indicators. However, with an $R^2$ of 0.0000, it does not explain any variance in endogenous variables. This suggests that while LV1 is moderately reliable on its own, it does not contribute to explaining other variables in the model. In contrast, LV2 (Concern) is an endogenous variable with an $R^2$ of 0.0523, indicating it explains a small portion of the variance in other constructs. With a Block Communality and AVE of 0.575, LV2 demonstrates good reliability and convergent validity, showing that its indicators are consistent and valid measures of the construct.

LV3 (Technicality) stands out with a high $R^2$ of 0.8141, indicating it explains a significant amount of variance in other constructs. Its Block Communality and AVE of 0.518 reflect moderate reliability and convergent validity, suggesting LV3 is a crucial construct within the model, significantly influencing other variables. Similarly, LV4 (HnE) has an $R^2$ of 0.8127, also explaining a substantial portion of variance in other constructs. It shows moderate reliability and convergent validity with a Block Communality and AVE of 0.502, indicating that LV4 plays an important role in the model but could benefit from further refinement to enhance its reliability.

LV5 (Adherence) exhibits strong explanatory power with an $R^2$ of 0.7865. Its Block Communality and AVE of 0.636 demonstrate high reliability and convergent validity, highlighting LV5 as a well-defined construct with a significant influence on the model, supported by consistent and valid indicators. LV6 (Social), with an $R^2$ of 0.8677, explains a significant amount of variance in other constructs. It has a Block Communality and AVE of 0.510, indicating moderate reliability and convergent validity. LV6 is thus another key construct within the model, though further improvements could enhance its measurement quality.

LV7 (Participation) has an $R^2$ of 0.8106, suggesting it explains a considerable portion of variance in other constructs. However, its Block Communality and AVE are 0.360, indicating lower reliability and convergent validity compared to other constructs. This suggests that LV7 requires additional indicators or refinement to improve its measurement robustness. LV8 (FSTP Support) demonstrates the highest explanatory power among the constructs with an $R^2$ of 0.9465, explaining a substantial amount of variance in other variables. However, its Block Communality and AVE are 0.378, pointing to significant measurement issues. This underscores the need for substantial improvements in defining and measuring LV8 to enhance its reliability and validity.

In summary, while constructs like LV1 (Benefit) and LV2 (Concern) exhibit strong reliability and are well-defined, others such as LV3 (Technicality), LV4 (HnE), LV5 (Adherence), LV6 (Social), LV7 (Participation), and LV8 (FSTP Support) show varying levels of reliability and explanatory power. These findings highlight the importance of continuous refinement and development of constructs to ensure robust and reliable measurement in future research. This may involve incorporating more rigorous methodologies and qualitative data collection to improve the model's overall fit and validity.

Table IV.5 presents the correlation coefficients between the various latent variables (LV1 to LV8) in the study. The values range from -1 to 1, indicating the strength and direction of the linear relationship between pairs of latent variables. A positive value suggests a direct relationship, where an increase in one variable corresponds to an increase in the other, whereas a negative value indicates an inverse relationship, where an increase in one variable corresponds to a decrease in the other. The diagonal values, which are always 1, represent the correlation of each latent variable with itself. This table is essential for understanding the interrelationships among the latent variables, providing insights into how changes in one latent variable may influence others in the model.

*Table IV.5 Correlation between variables*

| | **LV1** | **LV2** | **LV3** | **LV4** | **LV5** | **LV6** | **LV7** | **LV8** |
|---|---|---|---|---|---|---|---|---|
| LV1 | 1 | -0.229 | -0.426 | 0.52 | 0.652 | -0.391 | 0.648 | 0.558 |
| LV2 | -0.229 | 1 | 0.872 | -0.833 | -0.395 | 0.863 | -0.678 | -0.797 |
| LV3 | -0.426 | 0.872 | 1 | -0.779 | -0.395 | 0.725 | -0.83 | -0.737 |
| LV4 | 0.52 | -0.833 | -0.779 | 1 | 0.315 | -0.834 | 0.697 | 0.888 |
| LV5 | 0.652 | -0.395 | -0.395 | 0.315 | 1 | -0.344 | 0.584 | 0.366 |
| LV6 | -0.391 | 0.863 | 0.725 | -0.834 | -0.344 | 1 | -0.616 | -0.747 |

| | LV1 | LV2 | LV3 | LV4 | LV5 | LV6 | LV7 | LV8 |
|---|---|---|---|---|---|---|---|---|
| LV7 | 0.648 | -0.678 | -0.83 | 0.697 | 0.584 | -0.616 | 1 | 0.671 |
| LV8 | 0.558 | -0.797 | -0.737 | 0.888 | 0.366 | -0.747 | 0.671 | 1 |

LV1 (Benefit) shows moderate to strong positive correlations with LV4 (HnE) at 0.520, LV5 (Adherence) at 0.652, LV7 (Participation) at 0.648, and LV8 (FSTP Support) at 0.558. These positive correlations suggest that as the perceived benefits increase, so do the levels of HnE, adherence, participation, and FSTP support. However, there are negative correlations with LV2 (Concern) at -0.229, LV3 (Technicality) at -0.426, and LV6 (Social) at -0.391, indicating that higher perceived benefits are associated with lower concerns, technical issues, and social factors.

LV2 (Concern) is strongly positively correlated with LV3 (Technicality) at 0.872 and LV6 (Social) at 0.863, suggesting that concerns are closely linked to technical and social issues. Negative correlations with LV4 (HnE) at -0.833, LV7 (Participation) at -0.678, and LV8 (FSTP Support) at -0.797 indicate that higher levels of concern are associated with lower levels of HnE, participation, and support.

LV3 (Technicality) also shows strong positive correlations with LV2 (Concern) at 0.872 and LV6 (Social) at 0.725, reflecting the interdependence between technical challenges and concerns, as well as social issues. It has negative correlations with LV4 (HnE) at -0.779, LV7 (Participation) at -0.830, and LV8 (FSTP Support) at -0.737, indicating that technical difficulties are associated with lower levels of HnE, participation, and support.

LV4 (HnE) has strong positive correlations with LV1 (Benefit) at 0.520, LV7 (Participation) at 0.697, and LV8 (FSTP Support) at 0.888, highlighting that HnE is significantly linked to perceived benefits, participation, and support. Negative correlations with LV2 (Concern) at -0.833, LV3 (Technicality) at -0.779, and LV6 (Social) at -0.834 suggest that higher HnE is associated with lower levels of concern, technical issues, and social factors.

LV5 (Adherence) shows moderate to strong positive correlations with LV1 (Benefit) at 0.652, LV4 (HnE) at 0.315, LV7 (Participation) at 0.584, and LV8 (FSTP Support) at 0.366. These correlations suggest that higher adherence is linked to higher benefits, HnE, participation, and support. There are negative correlations with LV2 (Concern) at -0.395, LV3 (Technicality) at

-0.395, and LV6 (Social) at -0.344, indicating that increased adherence is associated with reduced concerns, technical issues, and social factors.

LV6 (Social) has strong positive correlations with LV2 (Concern) at 0.863 and LV3 (Technicality) at 0.725, indicating a close relationship between social factors, concerns, and technical issues. Negative correlations with LV1 (Benefit) at -0.391, LV4 (HnE) at -0.834, LV5 (Adherence) at -0.344, LV7 (Participation) at -0.616, and LV8 (FSTP Support) at -0.747 suggest that higher social issues are linked to lower levels of benefits, HnE, adherence, participation, and support.

LV7 (Participation) is positively correlated with LV1 (Benefit) at 0.648, LV4 (HnE) at 0.697, LV5 (Adherence) at 0.584, and LV8 (FSTP Support) at 0.671, indicating that higher participation is associated with higher levels of benefits, HnE, adherence, and support. Negative correlations with LV2 (Concern) at -0.678, LV3 (Technicality) at -0.830, and LV6 (Social) at -0.616 show that increased participation is linked to reduced concerns, technical issues, and social factors.

LV8 (FSTP Support) has strong positive correlations with LV1 (Benefit) at 0.558, LV4 (HnE) at 0.888, LV7 (Participation) at 0.671, and moderate positive correlation with LV5 (Adherence) at 0.366. These suggest that support is closely related to benefits, HnE, participation, and adherence. Negative correlations with LV2 (Concern) at -0.797, LV3 (Technicality) at -0.737, and LV6 (Social) at -0.747 indicate that higher support levels are associated with lower concerns, technical

### IV.4.5 Implication from PLS-PM results

The theoretical implications of the outer model and measurement analysis highlight the importance of accurately defining and measuring constructs in PLS-PM. The strong reliability and one-dimensionality of LV1 (Benefit) and LV2 (Concern) validate the theoretical constructs of benefits and concerns in the context of DEWATS. This finding is supported by literature that emphasizes the necessity of well-defined constructs for ensuring model validity, particularly in environmental technology contexts where perceived benefits significantly predict acceptance (Poortvliet, Sanders, Weijma, & Vries, 2018). However, the observed reliability issues in latent variables such as LV3 (Technicality), LV4 (HnE), LV5 (Adherence), LV6 (Social), LV7 (Participation), and LV8 (FSTP Support) highlight potential areas for theoretical refinement. The literature indicates that such multidimensional constructs often require more refined indicators to avoid ambiguity and enhance accuracy (Poortvliet, Sanders, Weijma, & Vries, 2018) To address these issues, further refinement through qualitative methodologies is recommended, as this can provide a more nuanced understanding and accurate representation of these constructs (Gómez-Román et al., 2021).

The inner model analysis offers practical insights that can guide policy decisions based on the correlations among latent variables. For LV1 (Benefit), which shows positive correlations with LV4 (HnE), LV5 (Adherence), LV7 (Participation), and LV8 (FSTP Support), it is recommended that outreach policies emphasize the benefits of DEWATS, particularly its positive impacts on health, environment, and community welfare. This is consistent with findings in the literature, where effective communication of benefits is crucial for fostering public acceptance, especially when introducing new technologies (Gómez-Román et al., 2021; Poortvliet, Sanders, Weijma, & Vries, 2018).Addressing the negative correlations with LV2 (Concern), LV3 (Technicality), and LV6 (Social) through improved communication and community involvement is also crucial. For LV2 (Concern), which correlates strongly with LV3 and LV6, efforts should focus on enhancing technical reliability and addressing social factors (Capps et al., 2020). Literature highlights the importance of building trust and transparency, noting that specific concerns, such as those related to health and safety, must be directly addressed to mitigate public apprehension (Poortvliet, Sanders, Weijma, & Vries, 2018). Moreover, addressing negative correlations with LV4, LV7, and LV8 through targeted campaigns and community engagement can help foster positive perceptions.

The strong link between LV3 and LV2 and LV6 suggests that policies should prioritize reliable and sustainable technology and technical training to build community trust and address concerns about health and participation. The literature supports this approach, indicating that enhancing the perceived reliability and safety of technologies is vital for acceptance (Gómez-Román et al., 2021). Promoting health and environmental outcomes (LV4) should be an integral part of DEWATS outreach efforts, with a focus on transparent communication to counteract negative perceptions and proactively address potential concerns (Capps et al., 2020; Poortvliet, Sanders, Weijma, & Vries, 2018).

To encourage adherence (LV5), policies should offer incentives and address financial and technical barriers, a strategy shown to be effective in increasing the acceptance of new technologies (Poortvliet, Sanders, Weijma, & Vries, 2018) Increasing community participation

(LV7) is also crucial, and policies should involve communities in participatory decision-making processes or initiatives such as collective, scheduled desludging programs. Finally, fostering support for FSTP (LV8) involves highlighting the benefits and addressing technical and social issues to build community support and trust. This is aligned with literature advocating for differentiated communication strategies that account for the diverse values and concerns of different target groups (Poortvliet, Sanders, Weijma, & Vries, 2018).



## IV.5 Application of Fuzzy Clustering

### IV.5.1 Clustering Process

This research adopts the clustering method of Neunhoeffer & Teubner (2018) to determine the number of clusters (*k*). Said research is arguably suitable to be adopted as it also aims at clustering consumer belief of an infrastructure (in their context, shared economy). They determined number of clusters without pre-determining the input value for *k* by employing the Gap Statistic introduced by Tibshirani et al. (2001). They argued that the best gap scores are found between $k=2$ and $k=4$ with the aim of finding a trade-off between fact-based validation and reasonable segmentation.

Fuzzy clustering is K-means clustering is used to create clusters with an initial guess of 4 clusters. To determine the optimal number of clusters, three methods are utilized: within-cluster sum of squares (wss), silhouette method, and gap statistics. These methods are visualized using *fviz_nbclust*. Fuzzy clustering is performed with 3 clusters, and the results are visualized.

```
kmeans(outer_model_factorload, centers = 4, iter.max = 100, nstart = 100)
fviz_nbclust(outer_model_factorload, kmeans, method = "wss")
fviz_nbclust(outer_model_factorload, kmeans, method = "silhouette")
fviz_nbclust(outer_model_factorload, kmeans, method = "gap_stat")

kmeans_result <- kmeans(outer_model_factorload, centers = 3, nstart = 30)
clust_plot <- fviz_cluster(kmeans_result, data = outer_model_factorload)
print(clust_plot)
```

The number of data points in each cluster and the percentage of data points in each cluster are calculated and printed. Additionally, the centroids of each cluster and summary statistics for each cluster are computed and printed.

```
cluster_counts <- table(kmeans_result$cluster)
percentage_in_cluster <- prop.table(cluster_counts) * 100
print(percentage_in_cluster)
```

```
centroids <- kmeans_result$centers
print(centroids)

cluster_summary <- by(outer_model_factorload, kmeans_result$cluster,
summary)
print(cluster_summary)
```

The figure below provides visualization of fuzzy clustering process provides a clear depiction of how different data points are grouped based on their characteristics. This visualization helps in understanding the procedure of cluster profile analysis within the dataset and their respective attributes.

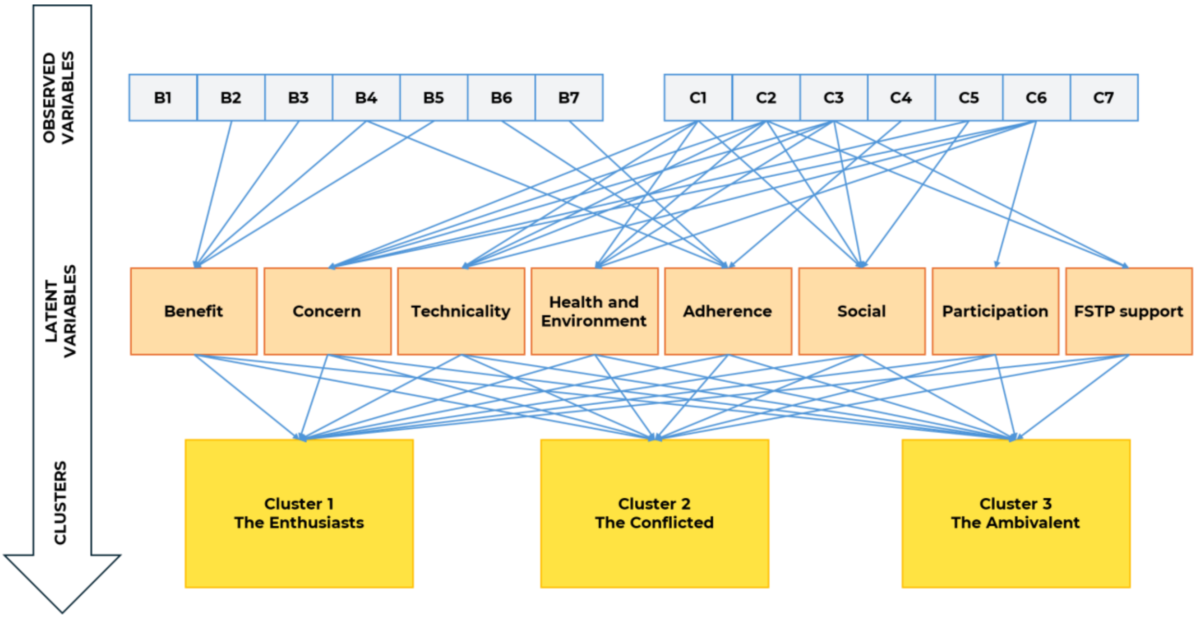


*Figure IV.2 Fuzzy clustering process*

### IV.5.2 Fuzzy clustering results

The clustering results, depicted in the cluster plot, provide a visual representation of the three distinct groups identified through fuzzy clustering. The plot illustrates the distribution of data points across two dimensions, Dim1 (46.6%) and Dim2 (18.3%), which together explain a significant portion of the variance in the data. Each cluster is represented by a different color and shape: Cluster 1 (red circles), Cluster 2 (green triangles), and Cluster 3 (blue squares). The clusters show clear separation, indicating distinct patterns in the underlying data. This visual differentiation underscores the varied attitudes and behaviors within the dataset.

Cluster 1 demonstrates generally positive means for most latent variables. Specifically, Benefit (mean = 0.5296), Concern (mean = -0.6434), and Technicality (mean = -0.3338) indicate that members of this cluster perceive benefits and technical aspects positively but also have significant concerns. The median values are also positive, with Benefit at 0.4553, Concern at -0.6984, and Technicality at -0.3853, supporting the overall trend of positive perceptions. However, this cluster shows substantial variability in Adherence (mean = 0.1862, min = -0.6427, max = 1.1330), suggesting a mixed response in commitment levels. Social (mean = -0.2003) and HnE (mean = -0.1589) variables indicate a moderately negative view on social and health/environmental factors. Participation (mean = 0.1663) and FSTP support (mean = -0.0526) also have varied means, indicating mixed engagement and support for DEWATS.


*Figure IV.3 Fuzzy clusters formed*

In contrast, Cluster 2 exhibits generally negative means across most variables, suggesting a less favorable outlook compared to Cluster 1. Benefit (mean = -0.6956), Concern (mean = -0.3214), and Technicality (mean = -0.5283) are all below zero, indicating dissatisfaction or concern in these areas. The median values reflect similar trends, with Benefit at -0.6171, Concern at -0.3110, and Technicality at -0.5851. HnE (mean = -0.4834) and Adherence (mean

= -0.4061) are also negative, suggesting poor health/environmental outcomes and adherence levels. Social (mean = -0.5273) further indicates social issues within this cluster. Participation (mean = -0.6952) and FSTP_support (mean = -0.5704) are significantly negative, highlighting low engagement and support for fecal sludge treatment plants.

Cluster 3 displays a mixed outlook with positive means for Benefit (mean = 0.0477) but negative means for Concern (mean = 0.7056) and Technicality (mean = 0.6028). This suggests that while members of this cluster see benefits, their perception of concerns and technical issues are significant. The median values reinforce this, with Benefit at -0.0043, Concern at 0.6812, and Technicality at 0.6209. HnE (mean = 0.4387) is positive, indicating moderate satisfaction with health/environmental aspects. Adherence (mean = 0.1225) and Social (mean = 0.4993) are slightly positive, suggesting moderate adherence and social factors. Participation (mean = 0.3270) and FSTP support (mean = 0.4138) show mixed results, with participation being slightly positive and support for FSTP being relatively higher.

### IV.5.3 Cluster Profiles and Strategy Insights

***Naming the clusters***

The cluster profiles are determined through a detailed analysis of the minimum, maximum, mean, and median values of the Benefit (LV1) and Concern (LV2) latent variables. This measurement is chosen as the PLS-PM analysis shows these two constructs strong reliability and one-dimensionality of LV1 (Benefit) and LV2 (Concern) validate the theoretical constructs of benefits and concerns in the context of DEWATS. It is assumed that by focusing on these key variables, the analysis can accurately capture the appropriate profiles of the clusters according to their perception towards DEWATS.

Members of Cluster 1, where 41% of respondents is placed, exhibit a mix of positive and negative perceptions. For the Benefit variable, the mean value is 0.5296, with a range from -0.4957 to 1.4607, indicating a generally positive but highly variable perception of benefits from DEWATS. The median benefit value is 0.4553, which is above neutral. In terms of Concern, the mean is -0.6434, and the median is -0.6984, with a range from -0.4957 to 0.2546, suggesting that this group has moderate concerns, despite recognizing some benefits. This cluster shows generally positive benefit values with mean and median values well above zero, indicating a positive perception of benefits. However, the concern values are also negative, indicating some level of skepticism or caution. The name "The Enthusiasts" reflects their optimistic view of benefits but with a healthy dose of concern.

Cluster 2 (27%) is characterized by generally negative perceptions across the variables. For Benefit, the mean is -0.6956, with a range from -2.4686 to 0.1439, and a median of -0.6171, indicating a predominantly negative perception of benefits. Regarding Concern, the mean is -0.3214, with a median of -0.311 and a range from -1.5131 to 1.1993, showing less overall concern compared to Cluster 1 but still reflecting negative sentiments. This cluster exhibits significantly negative benefit values with both mean and median below zero, indicating a generally negative perception of benefits. The concern values are also negative but less extreme compared to benefits, suggesting a general sense of indifference. The name "The Ambivalent" reflects their overall negative outlook towards benefits and moderate concerns.

The rest of the respondents make up 32% of the sample and are categorized in Cluster 3. This cluster is characterized by predominantly positive perceptions. For the Benefit variable, the mean value is 0.0477, with a range from -0.9666 to 1.5977, and a median of -0.0043, indicating a varied but generally positive perception of benefits. In terms of Concern, the mean is 0.7056, and the median is 0.6812, with a range from 0.0091 to 2.0802, suggesting that members of this cluster have significant concerns but also see benefits. This cluster has a slightly positive mean value for benefits, with a median close to zero, indicating a varied but generally positive perception of benefits. However, they exhibit high concern values with both mean and median being positive. Despite the concerns, the positive perception of benefits is notable, earning them the name "The Conflicted" due to their considerable positive perception towards the benefits coupled with notable concerns.

Comparison of clusters and their definitions can be seen in Table IV.6.

*Table IV.6 Definition of Concern and Benefit Perception by Belief Clusters*

| Cluster | Definition |
|---|---|
| 1. Enthusiasts | Members of this cluster exhibit a generally positive perception of benefits despite some concerns. They are optimistic about DEWATS but concerns that still needs addressing. |
| 2. Ambivalent | This cluster is characterized by predominantly negative perceptions of benefits and moderate concerns. Members are largely concerned and indifferent towards DEWATS. |

| Cluster | Definition |
|---|---|
| 3. Conflicted | Generally moderate positive perception of benefits, but also notable concerns. They recognize the benefits of DEWATS but remain conflicted by their concerns. |



The diverse profiles identified in the fuzzy clustering analysis suggest that a one-size-fits-all approach may overlook some engagement potential. To effectively engage The Conflicted, it is crucial to address their concerns while reinforcing the perceived benefits. Educational campaigns focusing on the positive impacts of DEWATS, coupled with transparent communication to address and mitigate their concerns, will likely enhance their overall perception and acceptance. The ambivalent requires a targeted approach to convert their negative perceptions into neutral or positive ones. Initiatives such as showcasing successful case studies, providing tangible evidence of benefits, and actively involving community members in the planning and implementation phases can help shift their attitudes. Addressing their specific grievances and demonstrating real-life improvements will be key to changing their outlook. To maintain and further strengthen the positive perceptions of the Enthusiasts, continuous engagement and reinforcement of benefits are essential. Providing regular updates on the progress and success of DEWATS projects, facilitating community participation, and ensuring that their concerns are promptly addressed will keep their enthusiasm high. Additionally, leveraging this cluster as advocates or champions for DEWATS can help influence other clusters positively.

***Preferences of outreach programs***

The clustering analysis can also provide the probability of different groups attending various community engagement events, including Public Socialization, Focus Group Discussions (FGD), and Public Exhibitions. The probabilities are provided for each cluster, reflecting their likelihood to participate in these activities. The probabilities are calculated from the equations below:

$$p_{attend} = \frac{Program\ Score\ each\ cluster}{Maximum\ Score}$$

$$Maximum\ score = 7 \times Cluster\ data\ points$$

The probability of attendance ($p_{attend}$) is calculated by dividing the program score for each cluster by the $Maximum\ score$. The program score represents the preference value assigned to a specific program by a particular cluster. The maximum score is derived from multiplying the total number of preference categories (in this case, 7) by the number of data points in the cluster. This normalization ensures that the probability is scaled appropriately, providing a Public Socialization events appear to be moderately attractive across all clusters. Cluster 1 has a probability of 0.51, Cluster 2 is slightly lower at 0.50, and Cluster 3 shows a higher probability of 0.74. This indicates that public socialization activities have varying appeal across clusters, with particularly strong interest from Cluster 3.

The probability of attending FGDs (Focus Group Discussions) is higher compared to public socialization events. Cluster 1 has a probability of 0.67, Cluster 2 is slightly lower at 0.62, and Cluster 3 shows the highest probability of 0.97. This suggests that FGDs are a highly viable engagement strategy, particularly for Cluster 3.

Public Exhibitions show a moderate level of attendance probability among the clusters. Cluster 1 has a probability of 0.55, Cluster 2 is lower at 0.39, and Cluster 3 has a moderate probability of 0.57. This indicates that public exhibitions are relatively less appealing compared to FGDs and public socialization events, with varying levels of interest across clusters.

*Table IV.7 Cluster probability to attend programs*

| **Probability to Attend ($p_{attend}$)** | **Cluster 1** | **Cluster 2** | **Cluster 3** |
|---|---|---|---|
| Public Socialization | 0.51 | 0.5 | 0.74 |
| FGD | 0.67 | 0.62 | 0.97 |
| Public Exhibition | 0.55 | 0.39 | 0.57 |

***Communication habits***

The analysis of communication habits focuses on the probability of respondents engaging in word-of-mouth (WOM) communication within homogeneous (HOM) and heterogeneous (HET) networks. These probabilities reveal insights into how different clusters spread information and influence their communities. The communication habits are measured with these formulas

$$p_{WOMhom} = (K1 \times K2) + ((1 - K1) \times K3)$$

$$p_{WOMhet} = (K1 \times K3) + ((1 - K1) \times K2)$$

$K1$ represents an individual's self-evaluation of their religiosity. $K2$ denotes the frequency with which the individual communicates with people who are very religious. $K3$ signifies the frequency of communication with people who are very non-religious. The term $(K1 \times K2)$ captures the likelihood of an individual who considers themselves religious to engage with similarly religious people. On the other hand, the term $((1-K1) \times K3)$ accounts for the likelihood of an individual who considers themselves less religious to engage with similarly less religious people. Summing these two terms gives the overall probability of engaging in word-of-mouth communication within homogeneous networks, thereby reflecting interactions within groups that share similar levels of religiosity. The term $(K1 \times K3)$ captures the likelihood of a religious individual communicating with non-religious people. Conversely, the term $((1-K1) \times K2)$ reflects the likelihood of a less religious individual communicating with very religious people. Summing these two terms provides the overall probability of engaging in word-of-mouth communication within heterogeneous networks, which indicates interactions across groups with differing levels of religiosity.

The probability of engaging in word-of-mouth communication within homogeneous networks varies across the clusters. The Enthusiasts have a probability of $\mathbf{\frac{2}{3}}$, indicating a high engagement within homogeneous groups. The Ambivalent have a slightly lower probability of $\mathbf{\frac{3}{5}}$, suggesting a comparable but slightly reduced level of engagement. The Conflicted also show a probability of $\mathbf{\frac{2}{3}}$, indicating that members of this cluster are equally likely to engage in word-of-mouth communication within similar groups. This suggests that both The Enthusiasts and The Conflicted are particularly effective at spreading information within their own social circles, which can be leveraged for targeted messaging within these homogeneous networks.

The probability of engaging in word-of-mouth communication within heterogeneous networks also varies among the clusters. The Enthusiasts have a probability of $\frac{2}{\mathbf{3}}$, indicating a high level of engagement across diverse groups. The Ambivalent have a probability of $\mathbf{\frac{4}{7}}$ reflecting a moderate level of communication behavior across different network types. The Conflicted maintain the same probability of $\frac{2}{3}$ as in homogeneous networks, showing consistent engagement regardless of the network type. This indicates that The Enthusiasts and The

Conflicted are effective in communicating both within their own groups and across different social groups, making them valuable in spreading information broadly in the future.

### IV.5.4 Suitability of Fuzzy Clustering for This Research

Fuzzy clustering is particularly suitable for this research due to the nuanced and overlapping nature of community perceptions and attitudes towards DEWATS, as depicted in Figure IV.3. These clusters demonstrate clear yet overlapping boundaries, which is a key characteristic that fuzzy clustering can effectively handle. The figure reveals that while there are distinct groupings, the boundaries between clusters are not entirely clear-cut. Many data points lie near the edges of the clusters, indicating that they share characteristics with multiple clusters. This overlap is typical in social and behavioral research, where individuals' perceptions and attitudes are not binary but rather exist on a spectrum. Fuzzy clustering allows each data point to belong to multiple clusters with varying degrees of membership, reflecting the real-world complexity of community opinions.

Fuzzy clustering provides membership degrees, which quantify the degree to which each data point belongs to each cluster. This is particularly useful for this research, as it recognizes the fluidity and spectrum of public perception towards DEWATS. For instance, an individual might partially identify with both the "Conflicted" and "Enthusiastic" clusters, and this clustering method can capture this nuanced membership, providing richer insights into community segmentation. In contexts like DEWATS implementation, where an individual’s responses are influenced by a variety of factors, ambiguity and uncertainty in attitudes are expected. This clustering does not force a hard assignment of data points to clusters. Instead, it allows for a more realistic representation of how community members relate to different aspects of DEWATS, accommodating the inherent uncertainty in their perceptions.

## IV.6 Agent-Based Modeling (ABM) Results

This section presents the results from the Agent-Based Modeling (ABM) approach, which simulates the interactions of agents to assess their effects on the system as a whole.

### IV.6.1 Parameters and assumptions

Table IV.8. provides a detailed breakdown of the key parameters and assumptions used to model the behaviors and characteristics of three distinct agent groups—The Enthusiasts, The Ambivalent, and The Conflicted—in the context of a DEWATS adoption simulation. The table outlines critical factors such as adopter status, connected agents, and a variety of perception variables, each with specified minimum and maximum values that define the range of perceptions held by each group. Additionally, it includes probabilities of attendance at various types of public putreach programs (Public Socialization, Focus Group Discussions, Public Exhibitions), and the corresponding weights of information derived from these activities. The table also considers the influence of word-of-mouth communication, differentiating between homogenous and heterogeneous interactions, along with their associated probabilities and weights. Lastly, it quantifies the septage generated per capita per day and the proportion to be treated based on adopter membership, providing a comprehensive framework for understanding how different agent groups might respond to and engage with DEWATS initiatives.

*Table IV.8 Agent parameters for simulation*

| Parameter | The Enthusiasts | The Ambivalent | The Conflicted |
|---|---|---|---|
| Adopter status (Adopt) | 1 | 0 | 0 |
| Connected Agents | 4 | 4 | 4 |
| **Perception Variables** | | | |
| Benefit | | | |
| > min | -0.4957 | -2.4686 | -0.9666 |
| > max | 1.4607 | 0.1439 | 1.5978 |
| Concern | | | |
| > min | -1.6101 | -1.5131 | 0.0091 |
| > max | 0.2546 | 1.1993 | 2.0802 |
| Technicality | | | |
| > min | -0.9998 | -1.3512 | -0.6907 |
| > max | 0.7841 | 0.7841 | 1.9958 |
| HnE | | | |
| > min | -2.0651 | -1.4689 | -0.6686 |
| > max | 0.4315 | 0.6302 | 1.93 |
| Adherence | | | |
| > min | -0.6427 | -1.8928 | -1.63 |
| > max | 1.133 | 0.3608 | 1.8895 |
| Social | | | |
| > min | -1.2363 | -1.6644 | -0.7501 |
| > max | 0.6935 | 0.8024 | 2.0359 |
| **Probability of attendance (p_attend)** | | | |
| Public Socialization | 0.85 | 0.80 | 0.87 |
| FGD | 0.75 | 0.67 | 0.71 |
| Public Exhibition | 0.52 | 0.63 | 0.92 |
| **Weight of information (w_Program)** | | | |
| Public Socialization | 1/2 | 1/2 | 1/2 |
| FGD | 2/3 | 2/3 | 2/3 |
| Public Exhibition | 3/4 | 3/4 | 3/4 |
| **Word of Mouth** | | | |
| Probability Word of Mouth HOM (p_WOMhom) | 2/5 | 3/7 | 1/3 |
| Probability Word of Mouth Het (p_WOMhet) | 2/5 | 2/5 | 1/3 |

| Parameter | The Enthusiasts | The Ambivalent | The Conflicted |
|---|---|---|---|
| Weight of information from homogenous interaction (w_WOMhom) | 3/4 | 3/4 | 3/4 |
| Weight of information from homogenous interaction (w_WOMhet) | 1/2 | 1/2 | 1/2 |
| Septage Generated (Sept_total) | 0,63 litre/capita/day | 0,63 litre/capita/day | 0,63 litre/capita/day |
| Septage to be Treated (Sept_treat) | Sept_total × Adopter membership | Sept_total × Adopter membership | Sept_total × Adopter membership |

### IV.6.2 Simulation Setup

This section details the computational models, input parameters, and simulation environment, including the initial conditions and assumptions underlying the simulation. The ABM programming was done with the VisualShell feature with memory setting of 1300 MB (figure IV.4).

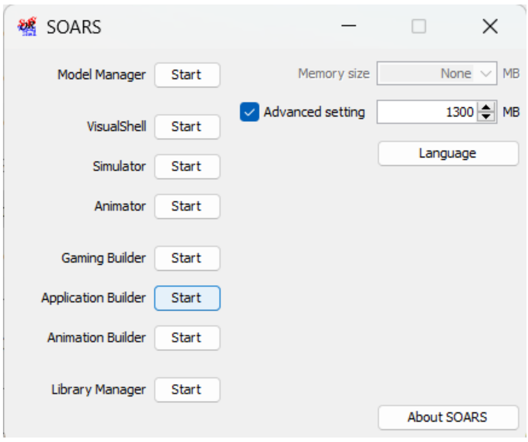


*Figure IV.4 SOARS settings used for simulation*

Functions were utilized in the program, with simple mathematical expressions used for substitution rules in the program (Figure IV.5). The model set up was set so that each step represented 2 hours and the simulation was ran for 1 year (357 days).

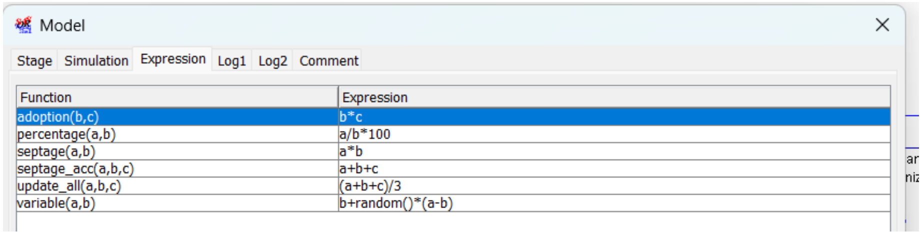


*Figure IV.5 Functions*

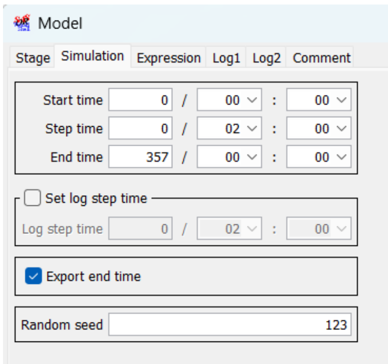


*Figure IV.6 Model Setup for Simulation*

The simulation used agents and spots (Figure IV.7). The spots are used to represent the places were agents meet to communicate, except the social_group spot which represents the spot where they "go home". The WOM spots are a proxy for a type of agent which influences the perception values, so although it is a spot, in real-life they represent a fellow public member.

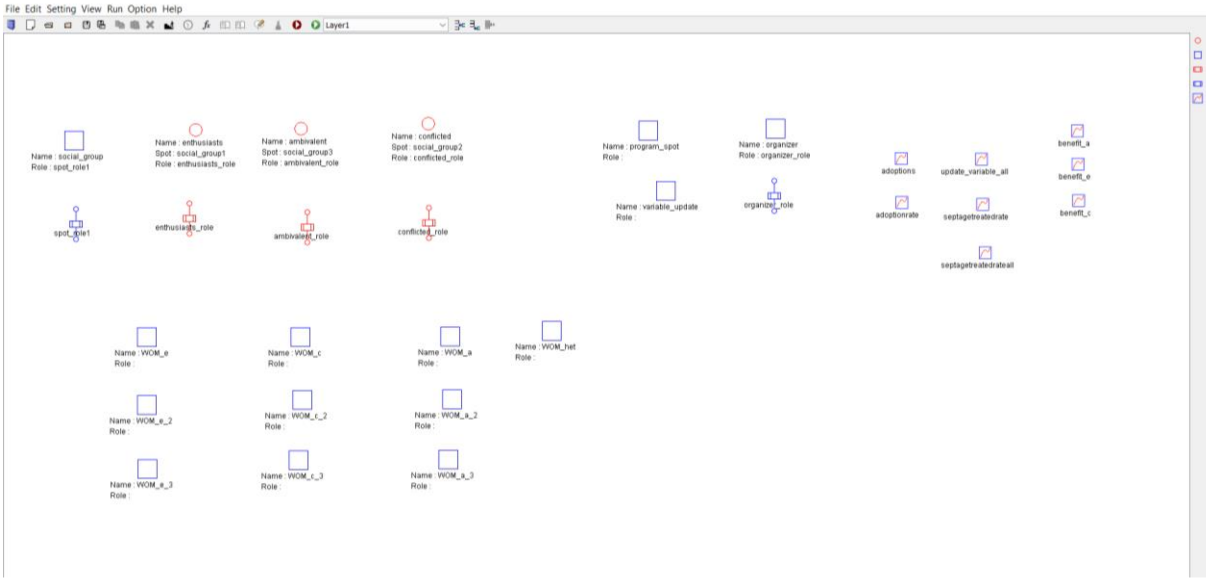


*Figure IV.7 Elements of Simulation (Spots and Agents)*

### IV.6.3 Simulation stages

The step-by-step process is employed in the simulation to model the adoption dynamics of DEWATS among different agent clusters. It begins with the assignment of agents to clusters based on initial perception values, which are randomized according to the cluster's defined thresholds for each perception element. This stage establishes the baseline for agents' attributes and initial adopter status, particularly aligning with the median values observed in The Enthusiasts cluster for true adoption (with the median values of the Enthusiasts being the threshold). Following this, the scheduling of outreach programs is detailed, specifying the frequency and retention periods for public socialization, focus group discussions, and public exhibitions, all aimed at disseminating information and engaging the community systematically. The simulation then proceeds to simulate agents receiving information during these outreach activities, with a structured schedule designed to maximize information retention and community engagement. Finally, the simulation incorporates word-of-mouth interactions among agents, occurring outside standard working hours, to reflect the organic spread of information and influence adoption decisions.

1. Cluster assignment, initial perception values.

At the beginning of the simulation, the agents are assigned initial randomized values of perception in accordance with their cluster membership and placed in according “Spots”. The thresholds for each perception element, determined through the clustering analysis, establish the minimum and maximum values for attributes within the simulation. The agents would also attain initial adopter status, with the median empirical values of *The Enthusiasts* cluster serving as the threshold for achieving TRUE adoption status.

2. Scheduling of Outreach programs

The "Scheduling of Outreach Programs" involves organizing various public outreach program methods at different frequencies to disseminate information about DEWATS. The retention of information from each of the program method is also simulated.

*Table IV.9 Scheduling set up for outreach programs*

| | Low | High | Retention |
|---|---|---|---|
| Public Socialization | 2/year | 4/year | 1 week |
| Focus Group Discussion | 2/year | 4/year | 2 week |
| Public Exhibition | 2/year | 3/year | 3 week |

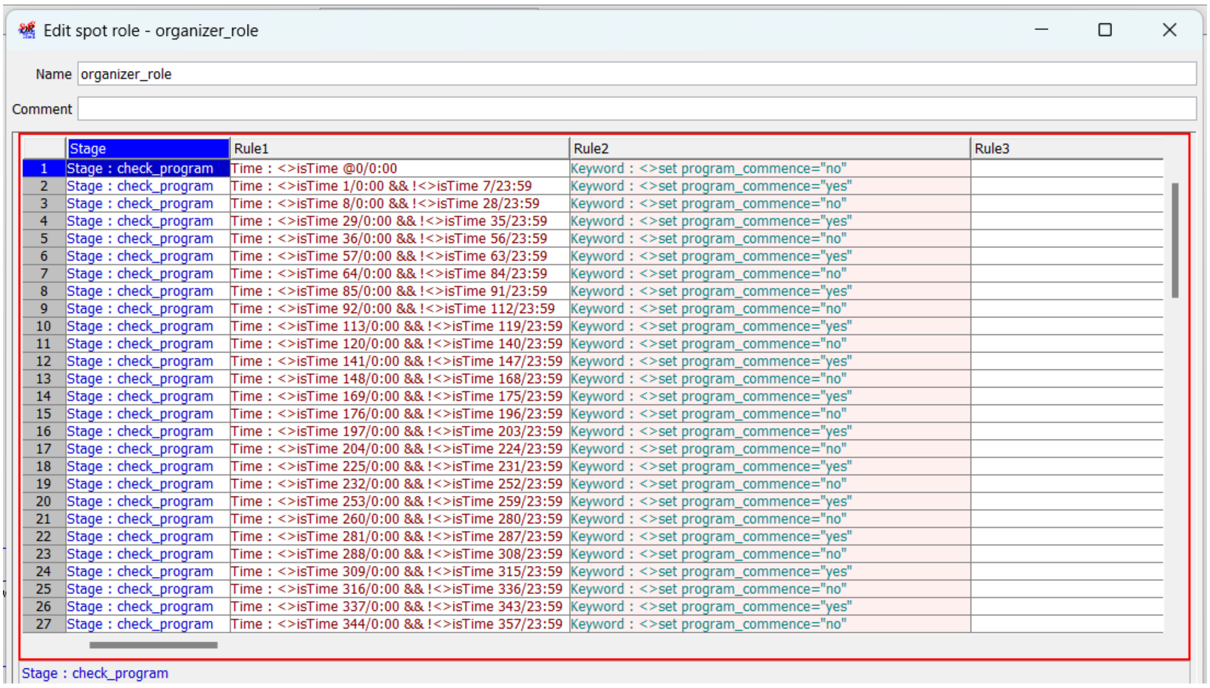


*Figure IV.8 Scheduling setup in program*

3. Receiving information through outreach programs.

Agents will attend or receive information from the local government of Bandung City in scheduled information dissemination programs. When a program is scheduled, the agent will move to the “program spot” to receive information. For simplicity, we designed the information to be held and distributed within general working hours between 08:00 – 14:00.

The program scheduling for the public socialization efforts in the DEWATS project is laid out in a structured manner, with scenarios planned to engage the community quarterly. This scheduling aims to ensure consistent and systematic engagement with the public, thereby maintaining a steady flow of information and reinforcing key messages about DEWATS. The use of quarterly intervals allows for adequate time between sessions for the community to absorb and reflect on the information presented, promoting better information retention.

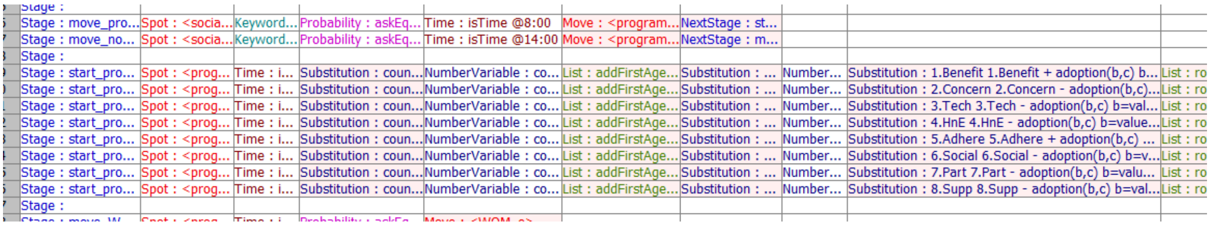

*Figure IV.9 Agent role setup for outreach program*

4. Word-of-mouth interaction.

The agents would then continue to exchange information with other agents through a word-of-mouth interaction with other agents. Word-of-mouth interaction occur outside general working hours between 14:00 - 20:00. The agents will engage in three types of word of mouth as seen in Table III.6.

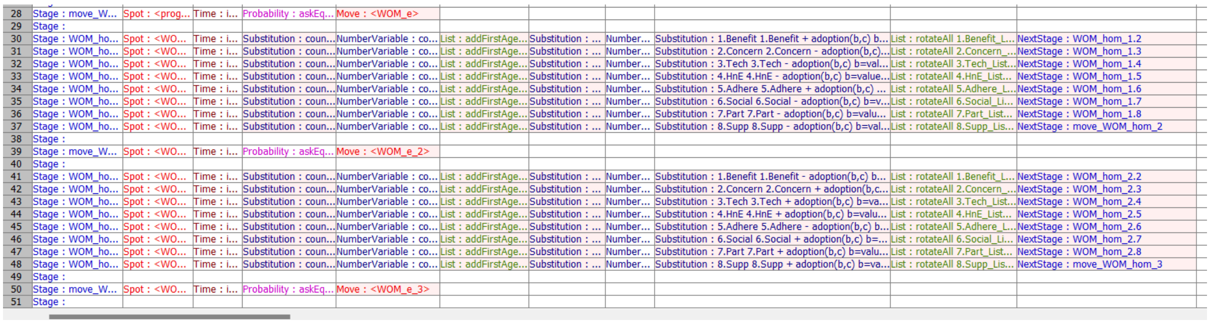

*Figure IV.10 Agent role set up for WOM*

### IV.6.4 Simulation Results

#### IV.6.4.1 Adoption Rates

The analysis of the ABM simulations across six different scenarios highlights diverse adoption rates for DEWATS technology, demonstrating the significant influence of external factors, outreach effectiveness, and social dynamics on the technology's uptake. In Scenario 1, the adoption rate reaches 100% relatively quickly, around day 150, indicating a highly conducive environment for adoption. This rapid adoption suggests strong initial enthusiasm, effective outreach strategies, or favorable conditions that minimize resistance and barriers.

Scenario 2 shows a similar trend but with a slight delay, reaching full adoption around day 180. This scenario might reflect a slightly less aggressive outreach effort or external factors that slightly slow the adoption process compared to Scenario 1. In contrast, Scenarios 3 and 4 reach complete adoption around day 160, slightly faster than Scenario 2 but slower than Scenario 1. The moderate pace in these scenarios could be attributed to a balanced combination of outreach effectiveness and community receptivity, where the perceived benefits are recognized but not as overwhelmingly compelling as in the fastest-adopting scenario.

Scenario 5 presents the slowest adoption rate, reaching full adoption only around day 200. This scenario likely represents the most challenging conditions for adoption, potentially due to significant barriers such as high resistance, insufficient outreach efforts, or a lack of perceived immediate benefits among the agents. The slower adoption pace underscores the importance of addressing these barriers to improve the effectiveness of DEWATS implementation strategies.

Finally, Scenario 6 also exhibits a rapid adoption rate, similar to Scenario 1, with full adoption occurring shortly after day 150. This scenario likely combines optimal outreach strategies, favorable social dynamics, and strong community support, creating an environment where the adoption of DEWATS technology is both rapid and complete. These findings emphasize the critical role of tailored communication strategies and understanding local dynamics in enhancing the adoption rates of innovative technologies like DEWATS across different contexts.

Based on the analysis of the adoption rates simulated, Scenario 3 (FGD, 4/year) and Scenario 4 (FGD, 2/year) showed the most rapid adoption rates, reaching 100% adoption around day 110. This indicates that these scenarios provide the most conducive environments for the adoption of DEWATS technology, likely due to effective outreach strategies and strong initial enthusiasm. Scenario 1 (Public Socialization, 4/year) follows closely, reaching full adoption by day 110 with The Conflicted cluster following closely behind, suggesting slightly less aggressive outreach or external factors slowing the process. Scenarios 5 and 6 (Public Exhibition, 4/year and 1/year respectively) show moderate adoption rates, achieving full adoption around day 100 but with The Conlicted having similar adoption rates with The

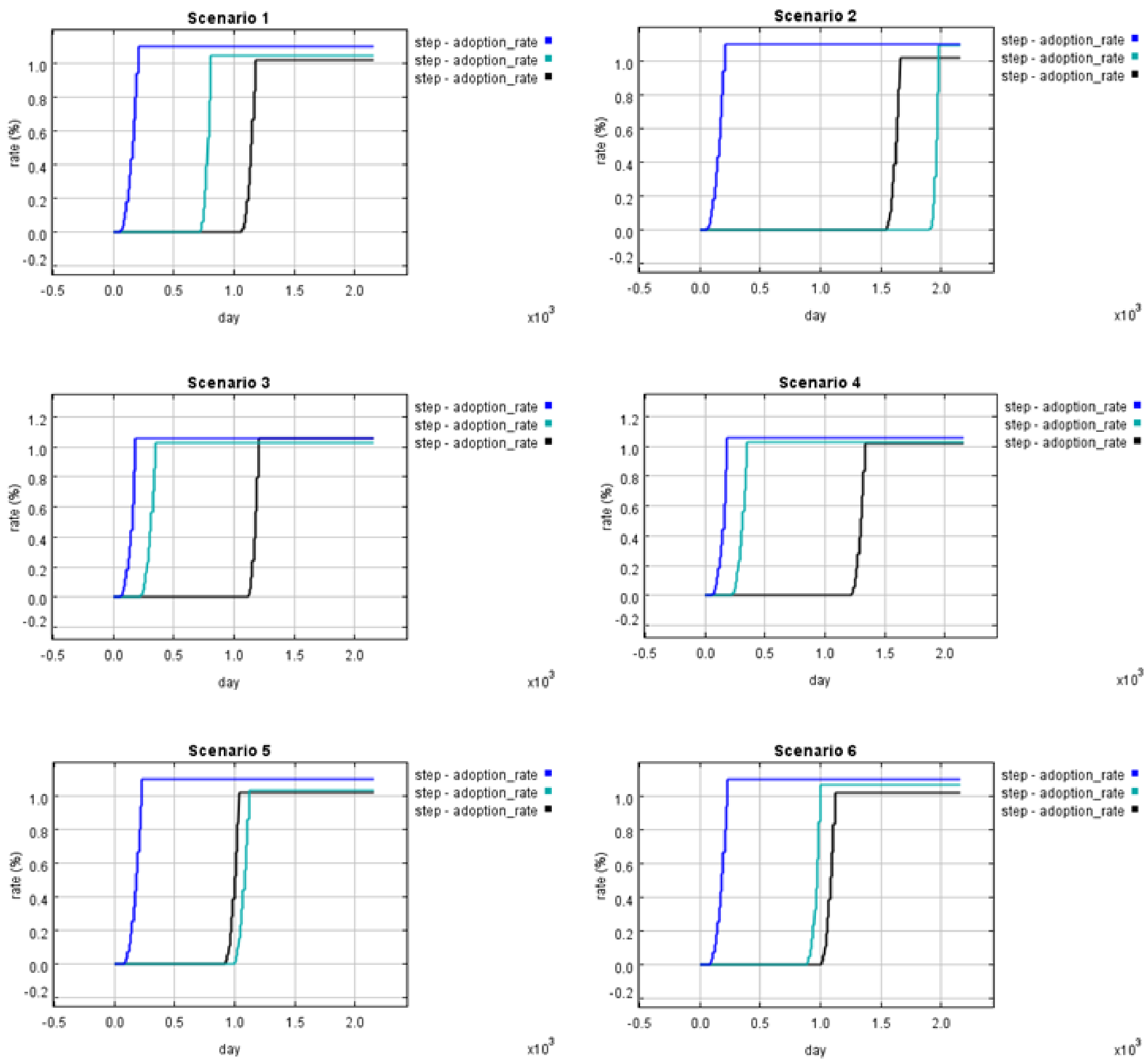


*Figure IV.11 Adoption rates emergent from scenarios*

Ambivalent. Scenario 2 (Public Socialization, 2/year) is the slowest, reaching complete adoption around day 200, indicating significant barriers to adoption in this context.

Comparing these scenarios to the preferences of different clusters, Focus Group Discussions (FGDs) have the highest attendance probability, particularly for Cluster 3, with a probability of 0.97. This suggests that FGDs are a highly effective engagement strategy for this group. Public Socialization and Public Exhibitions are moderately appealing, with Public Socialization being more attractive to Cluster 3 (0.74) than the other clusters. Overall, while FGDs appear to be the most effective in terms of preference, the rapid adoption observed in Public Socialization and Public Exhibition scenarios suggests that these methods may be particularly effective in certain contexts or with certain community dynamics.

The analysis revealed that program preference emerged as the most impactful factor influencing outcomes, indicating that the success of an initiative is heavily dependent on how well it aligns with the target audience's preferences. Following closely, information retention was identified as the second most significant factor, emphasizing the importance of ensuring that the audience retains the information provided to them. While increasing the frequency of program delivery does lead to improved adoption rates, the effect is only marginal, suggesting that saturation may occur beyond a certain point. Additionally, word-of-mouth, while valuable, was found to be less effective in reinforcing messages compared to public campaign programs, highlighting the greater impact of organized, wide-reaching campaigns over informal, interpersonal communication.

#### IV.6.4.2 Variable Update

The variable update results from the agent-based modeling (ABM) simulation provides a comprehensive view of how different perceptions evolved across various scenarios. In Scenario 1, the perception of benefit (blue line) consistently increased, suggesting that information dissemination effectively enhanced public recognition of DEWATS benefits. Conversely, concerns (green line) and social adherence (orange line) showed a downward trend, indicating a decreasing perception of social and technical issues as barriers to adoption.

In Scenario 2, similar trends were observed, with the perception of benefits continuing to rise significantly. However, the rate of increase was slightly lower compared to Scenario 1, reflecting a slower shift in public sentiment. This scenario also showed a notable decrease in concerns, albeit less pronounced than in Scenario 1. The patterns indicate that while the public still gained a positive view, the pace of change was more gradual.

Scenario 3 depicted the most substantial increase in benefit perception and the sharpest decrease in concerns and adherence issues. This suggests that the communication strategies employed were highly effective in this scenario, leading to a rapid shift in public perception. The significant changes in variables highlight the scenario's potential in fostering positive public sentiment towards DEWATS.

Scenario 4 displayed a moderate increase in benefits and a slower decrease in concerns, similar to Scenario 2. This indicates a consistent yet moderate improvement in public perception, suggesting a steady but less impactful communication effort. The differences between scenarios in the speed and extent of perception change emphasize the varying effectiveness of different outreach and communication strategies. In Scenarios 5 and 6, the patterns were similar to previous scenarios but with slight variations in the rate of change. Scenario 5 showed a more rapid increase in the benefit perception than Scenario 6, but both scenarios demonstrated effective communication strategies that positively influenced public opinion.

The variable update results from the agent-based modeling (ABM) simulation reveal trends in public perception across various scenarios, with some similarities in the patterns of change. In Scenario 1, the perception of benefit consistently increased, while concerns and social adherence decreased, indicating effective information dissemination. Similar trends were observed in Scenario 2, although the rate of perception change was slightly slower. Scenario 3 showed the most significant shifts in benefit perception and concerns, suggesting highly effective communication strategies. Scenarios 4, 5, and 6 exhibited moderate to rapid changes in perception, with some variations in the rate of change. While the graph shows similarities across scenarios, these patterns were anticipated and are discussed in the manuscript, highlighting the varying degrees of effectiveness in communication strategies and the expected outcomes in public perception.

The evaluation of variables across the different scenarios highlights distinct trends that warrant closer attention. The perception of health and environmental benefits, along with support for infrastructure, demonstrated a significant rise, indicating that these aspects are well-received by the public and can serve as strong pillars in promoting DEWATS initiatives. However, the awareness to adhere to policy exhibited a much slower increase, signaling a potential challenge in ensuring compliance and suggesting that this area requires targeted communication strategies to improve understanding and commitment as also highlighted and mentioned in previous studies (Capps et al., 2020; Gómez-Román et al., 2021; Setiyawan et al., 2021). Additionally, the perception of urgency to participate showed stagnant progress, underscoring the need for further efforts to motivate public engagement (Gómez-Román et al., 2021). To effectively capitalize on the existing support for Faecal Sludge Treatment Plants (FSTPs), it is crucial to build trust within the community and address the "not in my backyard" mentality. By focusing on these areas, the overall adoption and success of DEWATS can be significantly enhanced.



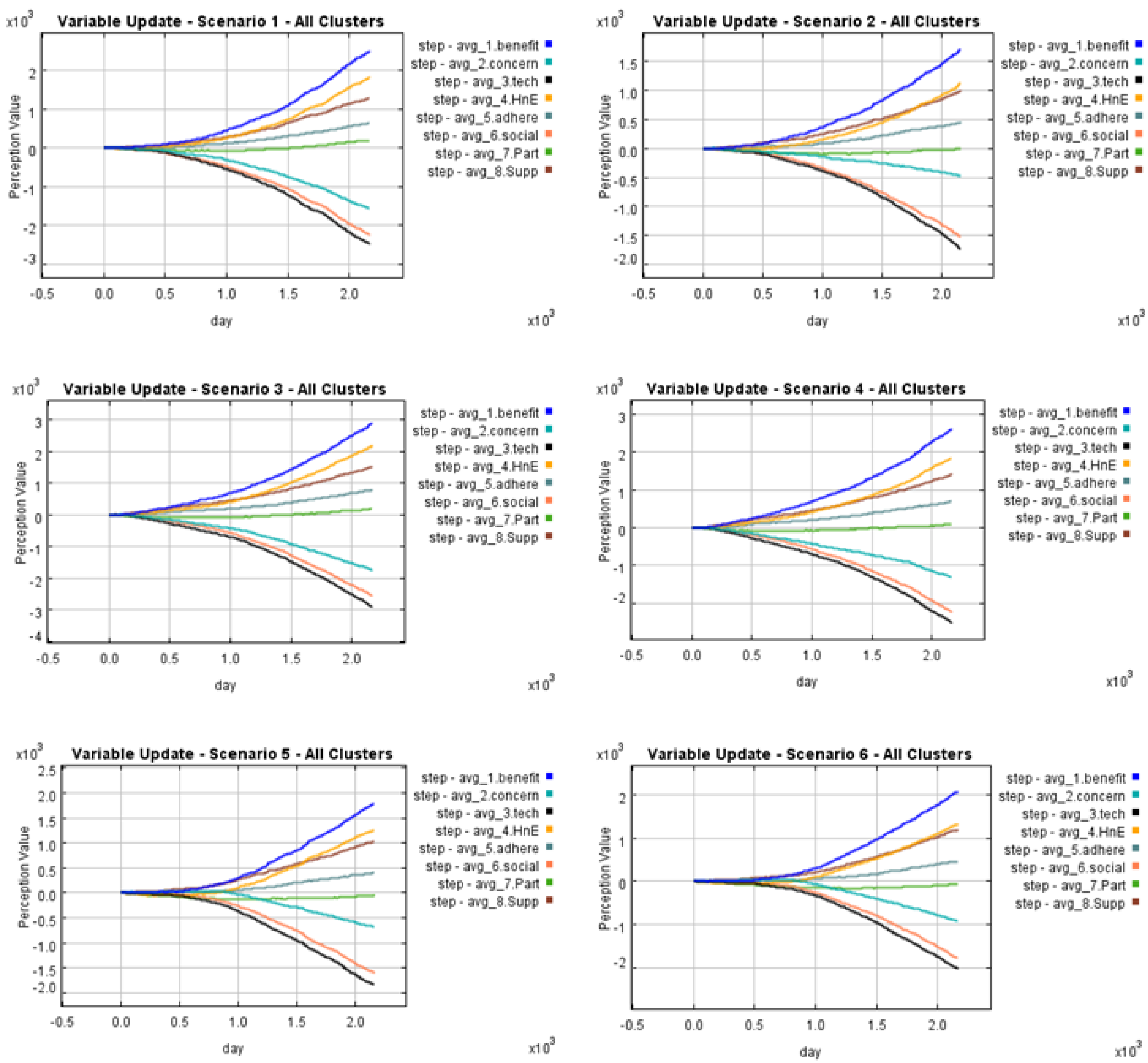


*Figure IV.12 Variable update from simulation*

#### IV.6.4.3 Treatable septage rate

The analysis of septage treated rates further reinforces the findings on adoption rates, providing a clear picture of the effectiveness of different scenarios in the ABM simulation. Scenario 1, which shows the highest rate of septage treated, aligns with its strong adoption rate, indicating that this scenario's strategies were successful in encouraging widespread participation. In contrast, Scenarios 2 and 3, with their lower rates of septage treated, suggest slower or less effective adoption, potentially due to barriers in public engagement or communication efforts. Scenarios 4, 5, and 6 exhibit moderate septage treatment rates, reflecting their intermediate adoption speeds and the varying levels of public response.

Scenario 3, despite its slower adoption rate, emerges as the most effective in terms of rapid adoption and higher rates of septage treatment, likely due to the combination of targeted strategies and public outreach. However, Scenario 4 lags behind, highlighting the challenges in sustaining momentum and ensuring continued public participation. The other scenarios demonstrate moderate success, which underscores the importance of tailoring strategies to specific conditions modeled in the ABM simulation.

A critical insight from these findings is the potential risk of premature operation. Low adoption rates can lead to insufficient sludge collection, which not only undermines the sustainability of the system but also increases costs per capita. This highlights the need for careful planning and timing of operations to ensure that the infrastructure is not only functional but also economically viable. To mitigate these risks, it is recommended that simulations of sludge collection be conducted in pilot projects, both before and after public socialization efforts. This approach would provide valuable data on the effectiveness of different communication strategies and allow for adjustments to be made to optimize adoption rates and overall system sustainability.

## IV.7 Summary of Key Findings

The analysis of the PLS-PM results highlights significant theoretical and practical implications for understanding and improving the acceptance of DEWATS technology. Theoretical implications underscore the importance of accurately defining and measuring constructs within PLS-PM, as evidenced by the strong reliability and one-dimensionality of latent variables such as LV1 (Benefit) and LV2 (Concern). These findings validate the theoretical constructs in the context of DEWATS, aligning with literature that emphasizes the necessity of well-defined constructs for ensuring model validity, especially in environmental technology contexts (Poortvliet et al., 2018). However, reliability issues in constructs like LV3 (Technicality), LV4 (Health and Environment), LV5 (Adherence), LV6 (Social), LV7 (Participation), and LV8 (FSTP Support) indicate potential areas for theoretical refinement. Further qualitative methodologies are recommended to gain a nuanced understanding and accurate representation of these constructs (Gómez-Román et al., 2021; Garnett & Cooper, 2014).

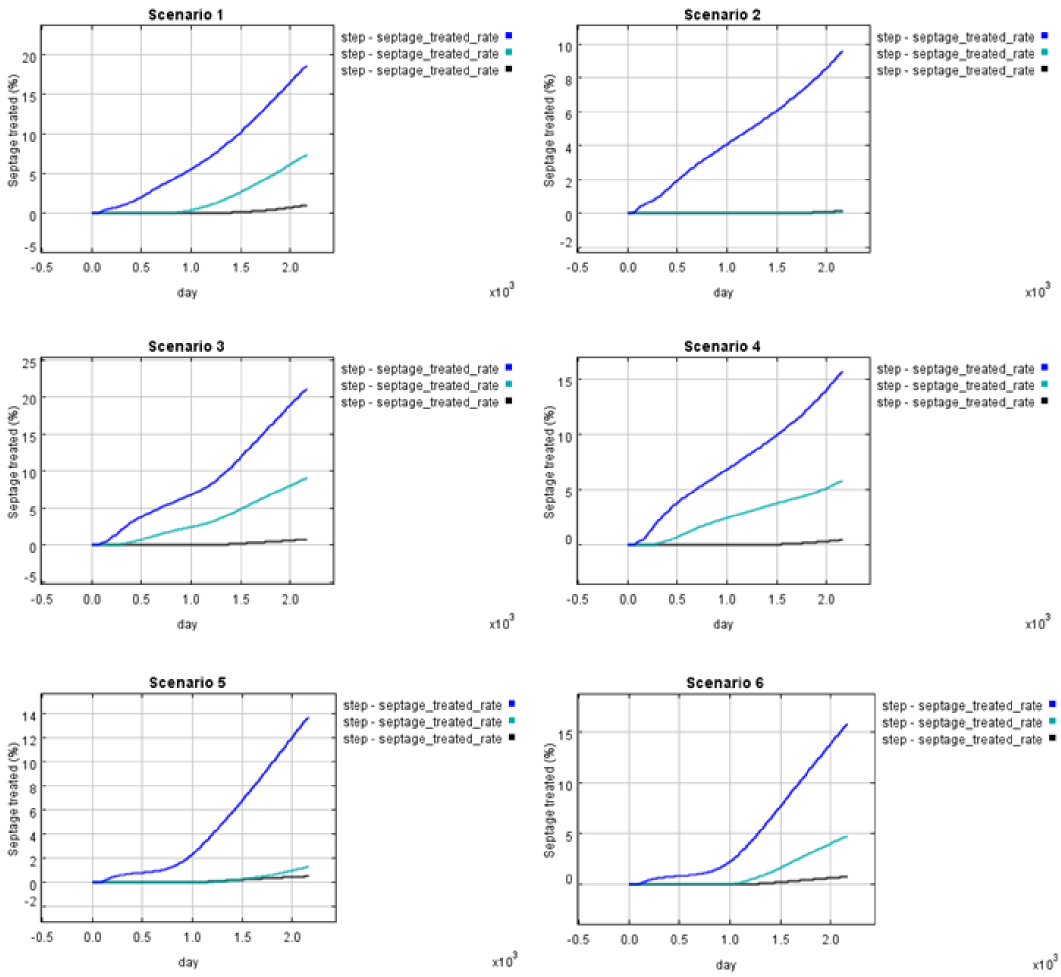


*Figure IV.13 Septage generation simulated*

Practical implications from the inner model analysis provide valuable insights for guiding policy decisions based on correlations among latent variables. Positive correlations between LV1 (Benefit) and constructs such as LV4, LV5, LV7, and LV8 suggest that outreach policies should emphasize the benefits of DEWATS, particularly its positive impacts on health, environment, and community welfare. This approach aligns with literature findings that effective communication of benefits is crucial for fostering public acceptance of new technologies (Gómez-Román et al., 2021; Poortvliet et al., 2018). Addressing negative correlations with LV2 (Concern), LV3 (Technicality), and LV6 (Social) through improved communication and community involvement is essential. Government could foster this further by arranging a scheduled de-sludging program for the area, to preliminary introduce the system by direct public engagement. Efforts should focus on enhancing technical reliability and addressing social factors to build trust and mitigate public apprehension (Poortvliet et al., 2018).

The cluster profiles reveal diverse perceptions towards DEWATS among different groups, indicating the need for tailored engagement strategies. "The Enthusiasts" exhibit a generally positive perception of benefits despite some concerns, while "The Ambivalent" are characterized by predominantly negative perceptions of benefits and moderate concerns. "The Conflicted" shows a generally positive perception of benefits but also have significant concerns. To effectively engage these groups, targeted communication and engagement strategies are necessary. Educational campaigns that focus on the positive impacts of DEWATS, coupled with transparent communication to address and mitigate concerns, will likely enhance overall perception and acceptance (Garnett & Cooper, 2014). Simulation results further emphasize the importance of tailored communication strategies and understanding local dynamics, as scenarios with effective outreach efforts showed the fastest adoption rates. Policymakers and practitioners should prioritize addressing concerns, building trust, and highlighting the benefits of DEWATS to foster positive public perceptions and drive successful implementation.

The ABM simulations across six scenarios provide a comprehensive view of DEWATS technology adoption, highlighting the significant influence of outreach effectiveness, social dynamics, and external factors on the uptake of this technology. A key variable that emerged from this analysis is the perception of benefits, which was tracked alongside concerns, social adherence, and awareness of policy adherence. Scenario 3 (FGD, 4/year) and Scenario 4 (FGD, 2/year) demonstrated the most rapid adoption, achieving 100% around day 110, suggesting that these scenarios provided highly conducive environments with effective outreach strategies and strong initial enthusiasm. Scenario 1 (Public Socialization, 4/year) followed closely, also reaching full adoption by day 110, but with slightly slower momentum, indicating the effectiveness of public socialization, though possibly tempered by external factors or less aggressive outreach efforts. Scenarios 5 and 6 (Public Exhibition, 4/year and 1/year respectively) showed moderate adoption rates, reaching full adoption around day 100, reflecting a balance between outreach effectiveness and community receptivity. In contrast, Scenario 2 (Public Socialization, 2/year) lagged significantly, only reaching full adoption by day 200, underscoring substantial barriers such as insufficient outreach or lower initial enthusiasm.

The analysis of septage treated rates further reinforces these findings, with Scenario 1 showing the highest rate of septage treatment, closely aligned with its strong adoption rate, indicating successful strategies in encouraging widespread participation. Scenarios 2 and 3, with their lower septage treatment rates, suggest slower or less effective adoption, potentially due to barriers in public engagement or communication. Scenarios 4, 5, and 6 exhibited moderate septage treatment rates, consistent with their intermediate adoption speeds and varying public responses. Despite the slower adoption rate, Scenario 3 stands out as the most effective in terms of rapid adoption and higher septage treatment, likely due to targeted outreach and public engagement strategies, though Scenario 4 lags in sustaining momentum and public participation.

The variable update results from the ABM simulation offer additional insights into the evolution of public perceptions across different scenarios. In Scenario 1, the perception of benefit consistently increased, while concerns and social adherence decreased, indicating effective information dissemination. Similar trends were observed in Scenario 2, although the rate of perception change was slightly slower. Scenario 3 showed the most significant shifts in benefit perception and concerns, suggesting highly effective communication strategies. Scenarios 4, 5, and 6 exhibited moderate to rapid changes in perception, with some variations in the rate of change. The perception of health and environmental benefits and support for infrastructure demonstrated a significant rise across scenarios, indicating these aspects are well-received by the public and can serve as strong pillars in promoting DEWATS initiatives.

However, the awareness to adhere to policy exhibited a much slower increase, signaling a potential challenge in ensuring compliance and suggesting that this area requires targeted communication strategies to improve understanding and commitment, as highlighted in previous studies (Capps et al., 2020; Gómez-Román et al., 2021; Setiyawan et al., 2021). Additionally, the perception of urgency to participate showed stagnant progress, underscoring the need for further efforts to motivate public engagement (Gómez-Román et al., 2021). These trends emphasize the critical role of aligning program preferences with audience needs, as program preference emerged as the most impactful factor influencing outcomes. While information retention followed closely, underscoring the need for ensuring that audiences retain the information provided, the marginal improvements from increasing program frequency suggest the potential for saturation. Furthermore, word-of-mouth, though valuable, was less effective than public campaigns, highlighting the greater impact of organized, wide-reaching efforts.

### IV.8 Implementation of research results

To implement research results, more specifically in a governmental context, careful and strategic planning is essential, particularly when dealing with technologies like DEWATS. The first stage involves conducting thorough pilot projects. These pilots should simulate sludge collection and other operational aspects both before and after public socialization efforts. This approach allows for the collection of valuable data, ensuring that any potential risks, such as premature operation or low adoption rates, are identified early. Such risks, if not managed, could lead to insufficient sludge collection, undermining system sustainability, and increasing per capita costs.

The next stage is to analyze the pilot data to refine strategies for broader implementation. This involves assessing the effectiveness of communication strategies and public engagement efforts, identifying areas where public perception or policy adherence may be lagging. The insights gained from the pilot stage will guide the development of targeted outreach and education programs, tailored to address specific challenges and optimize adoption rates. The government should then roll out the implementation in phases, starting with regions that have shown the highest readiness or interest based on the pilot data. This phased approach allows for adjustments based on real-time feedback and helps build momentum through early successes.

Finally, ongoing monitoring and evaluation are crucial. This stage involves continuously assessing the system's performance, public participation levels, and compliance with local policies. By maintaining this feedback loop, the government can ensure the long-term functionality, economic viability, and sustainability of the DEWATS technology. Additionally, these stages highlight the importance of building trust within communities and addressing any "not in my backyard" mentality, which is essential for sustaining public support and ensuring the success of such initiatives.

The recommendations for implementing the simulation results is represented in Figure IV.4.

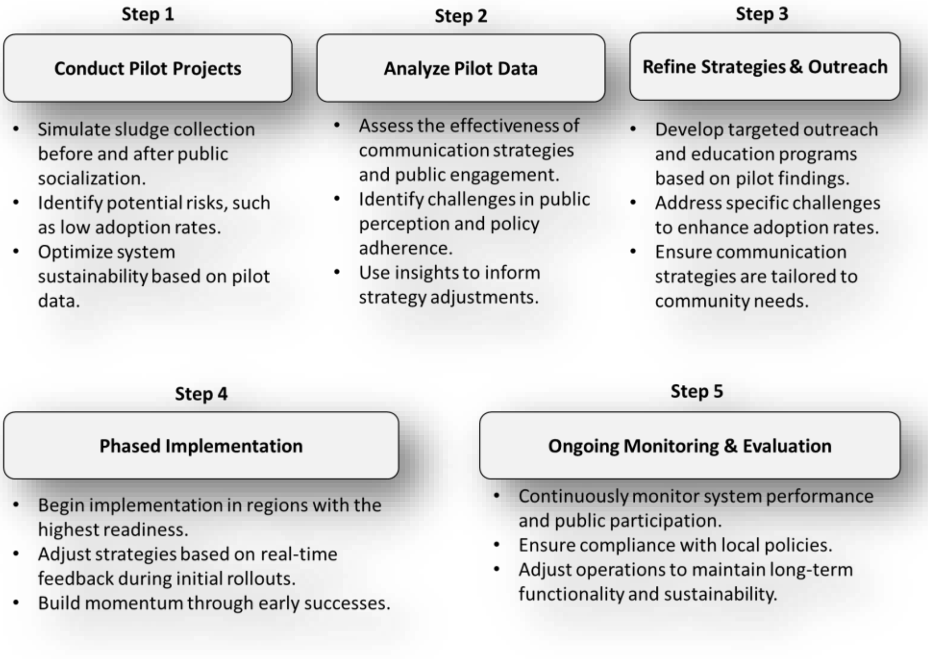


*Figure IV.14 Implementation recommendations*

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# Chapter V Summary and Conclusion

## V.1 Conclusion

This study has explored the theoretical and practical aspects of DEWATS technology acceptance, utilizing PLS-PM, fuzzy clustering, and ABM methodologies. Key findings highlight the importance of well-defined constructs in PLS-PM for model validity, with strong reliability observed in Benefit (LV1) and Concern (LV2). Practical implications indicate that effective communication strategies emphasizing the benefits of DEWATS, combined with addressing technical and social concerns, are crucial for fostering public acceptance. The diverse cluster profiles—The Enthusiasts, The Ambivalent, and The Conflicted—suggest that tailored engagement strategies are necessary to address the unique perceptions and concerns of each group**.**

The analysis simulations results provide significant insights into public perceptions and the adoption of Decentralized Wastewater Treatment Systems (DEWATS) in East Bandung City. The study highlights the importance of accurately defining and measuring constructs, as evidenced by the reliability of variables like Benefit and Concern. The practical implications emphasize the need for outreach policies that highlight DEWATS' benefits, particularly regarding health, environment, and community welfare, while addressing concerns and technical issues. The findings suggest that public socialization and exhibitions are effective in rapidly fostering positive perceptions and overcoming barriers, whereas focus group discussions require more time to achieve full adoption. The study concludes that tailored communication strategies that consider community dynamics and preferences are crucial for building trust, ensuring compliance with local policies, and sustaining public engagement. These strategies should focus not only on disseminating technical benefits but also on educating the public about the regulatory framework, ultimately enhancing the overall acceptance and implementation of DEWATS.

## V.2 Practical Recommendations

To enhance the acceptance and implementation of DEWATS technology, several practical recommendations emerge from the study's findings, particularly regarding tailored strategies for different community clusters. For "The Enthusiasts," maintaining their positive engagement is crucial; this can be achieved by providing regular updates on the project's progress and promptly addressing any concerns they may have. For "The Ambivalent," the focus should be on showcasing successful case studies and involving community members in planning and implementation to build confidence in the technology. Meanwhile, "The Conflicted" group requires a more direct approach—addressing their concerns head-on while consistently reinforcing the benefits of DEWATS. Additionally, implementing robust initial engagement methods, such as public socialization and exhibitions, has proven effective in fostering early enthusiasm and reducing resistance. Incorporating Focus Group Discussions (FGDs) can further help target specific concerns and build trust within the community. To capitalize on the growing support for Faecal Sludge Treatment Plants (FSTPs), it is essential to build trust and actively work to minimize the "not in my backyard" mentality.

The implementation of these strategies should follow a structured approach to ensure their effectiveness and sustainability. The first step involves conducting simulations of sludge collection in pilot projects, both before and after public socialization, to test and refine these strategies. The use of Agent-Based Modeling (ABM) can further enhance these simulations, allowing for a deeper understanding of community dynamics and potential challenges. Once the pilot data has been analyzed, strategies can be refined to better address the needs of each community cluster. Phased implementation should then be rolled out, starting with regions that demonstrate the highest readiness and engagement. This phased approach allows for real-time adjustments based on feedback, ensuring that the strategies remain responsive to community needs. Continuous monitoring and evaluation are essential throughout the implementation process, ensuring long-term functionality, compliance with local policies, and sustained community support. By following this structured approach, DEWATS technology can be effectively promoted and maintained, ensuring its successful adoption and operation in the long term.

## V.3 Research Contributions

This research contributes to the theoretical understanding of DEWATS technology acceptance by validating the importance of well-defined constructs within PLS-PM and highlighting areas for theoretical refinement. The practical contributions include insights into effective communication strategies and engagement approaches tailored to diverse public perceptions. The use of fuzzy clustering and ABM provided a comprehensive understanding of how different variables influence public acceptance and adoption rates, offering valuable guidance for policymakers and practitioners aiming to implement DEWATS technology effectively.

## V.4 Limitations and Future Research

### V.4.1 Research limitations

This study presents several methodological constraints that must be acknowledged. Partial Least Squares Path Modeling (PLS-PM) has limitations, such as sensitivity to sample size and potential multicollinearity among indicators. Additionally, fuzzy clustering may produce overlapping clusters, complicating the interpretation of results and the identification of distinct group characteristics. Agent-Based Modeling (ABM) also has its limitations, relying on assumptions about agent behavior and interactions, which may not fully capture the complexity of real-world scenarios. Furthermore, ABM simulation results are sensitive to initial conditions and parameter settings, which can affect the accuracy and reliability of the findings.

Regarding external validity, the findings of this study may be specific to the particular context and time period in which the study was conducted, limiting their applicability to other settings or time frames. Additionally, the dynamic nature of the study variables means that certain relationships examined might change over time, making the findings less applicable in different temporal contexts. These limitations highlight the need for cautious interpretation and application of the study's results in other contexts.

The theoretical and practical implications of this study also face certain limitations. The theoretical framework used to guide the study might have inherent limitations that affect the interpretation of the findings, particularly regarding theories of public perception of DEWATS with word-of-mouth (WOM) and socialization mechanisms. Practical recommendations based on the findings might face challenges in implementation due to contextual or situational constraints not addressed in the study. These challenges necessitate further research to refine the theoretical framework and explore practical implementation strategies.

### V.4.2 Future Research Recommendations

To enhance the understanding and implementation of DEWATS technology, several key directions for future research are recommended based on the findings and limitations of this study. Firstly, expanding the scope by increasing the sample size and geographic coverage in future studies is essential. A larger sample size will improve the statistical power of the analysis, making the findings more reliable and generalizable. Additionally, extending the geographic scope to include diverse regions will provide a broader perspective on the acceptance and challenges of DEWATS technology across different cultural, social, and economic contexts. This expansion is crucial for identifying region-specific factors that influence acceptance and for tailoring strategies to better meet local needs and conditions.

In terms of methodology, integrating qualitative and quantitative approaches is highly recommended to provide a more comprehensive understanding of the research problem. By combining methods such as PLS-PM with other statistical techniques, or employing mixed-method approaches, researchers can gain deeper insights into the nuanced factors affecting public perception and acceptance of DEWATS. Moreover, enhancing the modeling aspect of the research is critical. This includes making the agent-based model (ABM) more dynamic by improving the algorithm and transitioning from "spot agents" to direct agent-to-agent interactions, which will yield more accurate simulations. Additionally, incorporating a control group within the modeling process is essential for comparing outcomes and validating the model's effectiveness, especially when considering the socio-economic statuses of the agents.

In the realm of action and collaboration, it is recommended that ABM be applied in the implementation plans for DEWATS through close collaboration with government authorities. This collaboration is vital to ensure that the models and insights derived from the research are effectively translated into real-world practices, leading to the successful adoption and implementation of DEWATS technology. These combined efforts in expanding scope, refining methodology, enhancing modeling, and fostering action and collaboration will make the research findings not only theoretically robust but also practically applicable.

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# APPENDIX A

*Questionnaire instrument (in Indonesian)*

Instrumen penelitian

Pertanyaan dalam Survey

*Bagian 1*

| Code | Response | | |
|---|---|---|---|
| **Data Demografis**<br><br>Nama | | | |
| Status di Kartu Keluarga | ☐ Kepala Keluarga<br>☐ Istri<br>☐ Anak<br>☐ Lainnya | | |
| Umur | | | |
| Jenis Kelamin | ☐ Perempuan<br>☐ Laki-laki | | |
| Pekerjaan | | | |
| Pendidikan | ☐ SD<br>☐ SMP<br>☐ SMA<br>☐ S1 | ☐ S2<br>☐ S3<br>☐ Lainnya……… | |
| Alamat | Kecamatan:<br><br>☐ Kecamatan Gedebage,<br>☐ Kecamatan Panyileukan<br>☐ Kecamatan Rancasari | Kelurahan : | |
| Status Kepemilikan Rumah | ☐ Hak Milik Sendiri | : Memiliki hak penuh atas rumah | |
| | ☐ Hak Guna | : Memiliki hak untuk memanfaatkan bangunan atau Tamah untuk jangka waktu tertentu sesuai dengan perjanjian dengan pemilik | |
| | ☐ Hak Sewa | : Membayar sejumlah uang kepada pemilik rumah atau tanah untuk menggunakan properti tersebut selama periode waktu tertentu. | |

| | | | |
|---|---|---|---|
| | □ | Koperasi Perumahan | : Bergabung dalam sebuah koperasi untuk membangun atau membeli properti, dan kemudian setiap anggota memiliki hak kepemilikan atas bagian mereka dalam properti tersebut |
| | □ | Rumah susun (Apartemen) | : Memiliki unit di sebuah gedung apartemen |
| Sudah berapa lama tinggal dikediaman saat ini? | □ | 0 – 5 tahun<br>□ 5 – 10 tahun<br>□ 10 – 20 tahun<br>□ Lebih dari 20 tahun | |
| Pendapatan (per keluarga) | □ | < Rp. 2.500.000<br>□ Rp 2.500.000 – Rp 4.999.999<br>□ Rp 5.000.000 – Rp 9.999.999<br>□ Rp 10.000.000 – Rp 14.999.999<br>□ Rp 15.000.000 – Rp 19.999.999<br>□ ≥ Rp 20.000.000 | |
| Sarana sanitasi/penanganan air limbah apa yang rumah Anda miliki? | □ | Tangki septik individu<br>□ Sarana Komunal<br>□ Tidak Tahu | |
| Seberapa sering Anda memakai jasa penyedotan WC? | □ | < 2 tahun<br>□ 2 – 5 tahun<br>□ > 5 tahun<br>□ Tidak Pernah | |
| Apakah Anda familiar dengan pelayanan pengelolaan air limbah? | □ | Ya<br>□ Tidak<br>□ Sedikit tahu | |
| Dalam keluarga Anda, siapa yang sering mengerjakan pekerjaan rumah? | □ | Suami<br>□ Istri<br>□ Anak/Lainnya | |

*Bagian 2*

Informasi mengenai pengolahan air limbah setempat dan sanitasi

Berikut adalah penjelasan singkat mengenai proses sanitasi (pengolahan air limbah rumah tangga) dengan sistem setempat.

*Bagian 3*

| Kode | Item | Respon |
|---|---|---|
| **Pandangan Saudara terhadap pelayanan pengelolaan air limbah rumah dan sanitasi** | | |
| **Pandangan terhadap Kebermanfaatan** | | |
| B1 | Melakukan pemeliharaan mandiri terhadap fasilitas pribadi (tangki septik) dan berpartisipasi dalam layanan lumpur tinja terjadwal tidak memberatkan bagi saya | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B2 | Pengelolaan air limbah setempat penting untuk menjaga kesehatan masyarakat dan keamanan lingkungan tempat tinggal | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B3 | Pengadaan pengelolaan limbah setempat penting untuk diadakan demi terjaganya lingkungan dari polusi akibat air limbah | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B4 | Saya bersedia membayar jumlah retribusi pelayanan air limbah sesuai jumlah yang ditetapkan | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B5 | Pelayanan pengelolaan air limbah domestik akan meningkatkan kesejahteraan masyarakat di lingkungan tempat saya tinggal | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B6 | Saya ingin mendaftarkan diri pada pelayanan pengelolaan air limbah setempat | Skala Likert 6 poin (sangat setuju hingga sangat tidak setuju) |
| B7 | Saya mendukung terbangunnya Instalasi Pengolahan Lumpur Tinja (IPLT) di daerah kediaman saya | Skala Likert 6 poin |

| | | |
|---|---|---|
| | | (sangat setuju hingga sangat tidak setuju) |
| **Pandangan terhadap Kekhawatiran** | | |
| C1 | Pemeliharaan mandiri terhadap fasilitas pribadi (tangki septik) dan berpartisipasi dalam layanan lumpur tinja terjadwal memberatkan | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C2 | Fasilitas air limbah setempat dapat menimbulkan dampak buruk bagi kesehatan masyarakat dan keamanan lingkungan tempat saya tinggal | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C3 | Fasilitas air limbah setempat dapat mengganggu kenyamanan dan menimbulkan kerusakan bagi tempat saya tinggal | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C4 | Membayar retribusi memberatkan bagi saya | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C5 | Saya khawatir pihak berwenang tidak dapat mengelola fasilitas dengan baik dan menimbulkan keresahan diantara masyarakat | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C6 | Saya bisa mengolah air limbah sendiri tanpa bergabung dengan layanan pemerintah | Skala Likert 6 poin<br>(sangat setuju hingga sangat tidak setuju) |
| C7 | Saya mendukung pembangunan Instalasi Pengolahan Lumpur Tinja (IPLT) di daerah yang jauh dengan kediaman saya | Skala Likert 6 poin |

| | | |
|---|---|---|
| | | (sangat setuju hingga sangat tidak setuju) |

*Bagian 4*

| **Preferensi Saudara terhadap metode sosialisasi masyarakat** | | |
|---|---|---|
| Berikut adalah beberapa bentuk metode sosialisasi public publik.<br>Urutkan sesuai dengan preferensi Anda dalam mendapatkan informasi seputar layanan sanitasi. Berikan nomer 1-7 disamping opsi. | | |
| M1 | ☐ | Sosialisasi dengan ahli dan pemerintah di ruang publik |
| M2 | ☐ | Group diskusi terfokus (FGD) dengan ahli, pemerintah, dan anggota Masyarakat |
| M3 | ☐ | Sosialisasi Masyarakat secara individu dari pintu ke pintu |
| M4 | ☐ | Kunjungan ke contoh fasilitas pengolahan air limbah |
| M5 | ☐ | Pameran mengenai komponen dan system pengolahan air limbah domestic |
| M6 | ☐ | Selebaran dan pamphlet yang didistribusikan ke setiap rumah |
| M7 | ☐ | Informasi yang bisa dilihat secara online maupun ditempat publik |

| **Kebiasaan komunikasi dengan lingkungan** | | |
|---|---|---|
| K1 | Seberapa religiuskah Anda menilai diri Anda sendiri? | Skala Likert 6 poin<br>(sangat religius hingga sangat tidak religious) |
| K2 | Seberapa sering Anda mengobrol dengan orang yang sangat religious? | Skala Likert 6 poin<br>(sangat jarang hingga sangat sering) |
| K3 | Seberapa sering Anda mengobrol dengan orang yang sangat tidak religious? | Skala Likert 6 poin<br>(sangat jarang hingga sangat sering) |