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Digital Opportunity or a Threat? Adoption of Internet of Things (IoT) Monitoring Systems for Natural Resources in Germany

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Abstract: In Germany, modern digital technologies like Internet of Things (IoT) have been increasingly promoted for better environmental and natural resources management through "smart" monitoring and real-time data. However, adopting such advanced technologies is complex and brings a wide array of risks and challenges, and it remains unclear whether local actors are in fact willing and sufficiently equipped to adopt them. Using the Motivations and Abilities (MOTA) framework, and quantitative data collection and analysis methods, this study explores the motivations and abilities of German local (governmental) actors by focusing on the adoption of IoT-based forest and water monitoring systems. The findings reveal an early-stage adoption of IoT environmental monitoring, with limited awareness and no plans for adoption. The lack of willingness, however, is not attributed to a lack of motivation; it is, rather, influenced by perceived insufficient financial and technical capacities and resources. This study provides novel insights for understanding the complex relationship between actors' behavior and the adoption of advanced digital technologies in the realm of environmental and natural resources management. The results provide a robust foundation for future research, and inform policy and practice aimed at facilitating digitalized natural resources management.

Keywords: IoT environmental monitoring; technology adoption; MOTA framework; Germany

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1. Introduction

The sustainable management and conservation of natural resources—encompassing forests, land, soils, water, energy, and biodiversity—is high on the political agenda for both the European Union (EU) and Germany alike [1]. Accurate and timely information on the state and condition of natural resources is essential for tracking changes, evaluating the progress and effectiveness of natural resources policies, and guiding adaptive management strategies. In Germany, with the advances in the Internet of Things (IoT) and the development of modern sensors, considerable effort and resources have been invested in the past years to expand and improve data collection and analysis on the state and condition of natural resources. Numerous companies, start-ups, research institutes, and initiatives have emerged developing various IoT-based environmental monitoring systems as a promise of more effective and efficient protection measures [2]. The IoT monitoring, also known as "smart" or "intelligent" technology, is based on the use of wireless sensor networks, which are relatively affordable and allow the remote and real-time measurement of multiple environmental parameters (e.g., humidity, water levels, leaks, temperature, and other physical properties) with minimal human intervention [3–5]. Smart, connected devices with embedded communication modules can then process this information using computing technology and quickly send the data to the cloud or a data center for further actions or analyses. This enables managers, decision-makers, and scientists to monitor changes on the state and condition of natural resources in real time and more precisely, with an optimal control of pollution and other undesirable effects [6]. IoT environmental monitoring, thereby, facilitates proactive and faster responses to natural disasters and pollution threats, enables the development of more efficient and sustainable policies and management strategies, and fosters collaboration to address numerous environmental challenges [7,8].

However, the adoption of modern digital technologies (such as the IoT environmental monitoring systems) by local (government) actors in Germany is not always feasible, as revealed by recent studies in the field of digital transformation [9–11]. It is a part of a complex digital transformation process [10,12] which is often confronted with different obstacles, such as regulations, infrastructural limitations, technological and usability constraints (i.e., lack of qualified staff and know-how), as well as financial constraints. Additional bottlenecks are due to weak leadership and management skills regarding reform implementation, change management, and process re-engineering [9,10]. In the field of natural resources management and the environment, a growing number of publications reveal similar constraints and challenges in the adoption of new digital technologies [1–9]. For example, a recent report from the German Environment Agency [13] revealed that major risks and challenges in digitizing natural resources management might encompass concerns that relate mainly to digital infrastructure and security, data governance and compliance, data standardization and integration, knowledge and technical expertise, as well as potential environmental and societal impacts. Similar (potential) risks and challenges have been revealed in the field of water management [13–15], nature conservation [14], as well as forest management [15,16], land management, and agriculture [17,18]. The wide array of (potential) hurdles and challenges leads to the question of whether local actors are in fact willing and sufficiently equipped to adopt new digital tools in the field of natural resources management.

Yet, still little is known about the motivations and abilities of German local actors to adopt advanced digital tools, particularly in the field of natural resources management and IoT environmental monitoring. To date, most recent studies proceed from a techno-engineering perspective and focus on the technical aspects of advanced digital tools and their potential for increasing information capabilities. For example, Liesch et al. (2020) developed a comprehensive system that combined IoT and AI processes with methods from environmental informatics and the water domain in particular to monitor groundwater pollution [19]. Similarly, Kenebel et al. (2022) designed and tested a bark beetle early-warning system with modern sensors and AI-based data analysis [20], while Bolte et al. (2021) examined the potential of IoT in national forest monitoring [21], and Heller and Teschenmacher (2018) investigated whether IoT technology lived up to its promise by implementing the technologies in a practical case of hydrological research for direct flow measurements [22].

While these studies have made notable strides from a technological and engineering perspective, predominantly focusing on the technical intricacies of advanced digital tools and their potential to enhance information capabilities, a significant research gap persists in comprehending the motivations and abilities of local actors.

The main objective of this empirical study is to fill in the research gap. By applying a social science perspective, we aim to explore the motivations and abilities of German local actors to adopt IoT environmental systems in the field of natural resources management. More specifically, we focus on the adoption and use of IoT systems for monitoring the state and conditions of forest and water resources. The selection of forest and water monitoring as our empirical focus was determined by the practicality and feasibility for data collection within a broader research project on forest and water management in Germany (see Section 2.2), along with heuristic considerations. In particular, the latter played an important role, as our study aims to provide initial insights and develop further research ideas rather than definitive conclusions and generalizations about the findings. Theoretically, by employing the Motivation and Ability (MOTA) framework [23], we investigate actors' motivations and abilities and identify their correlations (influence) to the adoption of IoT environmental monitoring systems. Empirically, we focus on the motivations and abilities of mainly local governmental actors (public authorities and organizations) involved in forest and water management and/or monitoring activities (see Section 2.2). For this, we leverage quantitative data collection and analysis methods. Through this investigation, our study does not only enhance the understanding of the motivations and abilities of local actors to adopt and utilize IoT environmental monitoring systems, it also sheds light on the complex interplay between technology adoption and actors' behavior, paves the way for future research, and assists decision-makers and other relevant actors in setting the interventions and actions necessary to address technological adoption challenges.

We proceed as follows: Section 2 presents the conceptual and methodological considerations, including the MOTA framework and its elements, data collection, and analysis methods. The empirical results are presented in Section 3. Finally, the discussion is presented in Section 4.

2. Conceptual and Methodological Considerations

There are many social science theories that set out to explain technology adoption. However, most models, with few exceptions, make use of predictors that are exclusively cognitive, relating the adoption of a new technology to actors' attitudes, beliefs, and perceptions, and do not sufficiently consider external variables, such as their abilities, resources, and capacities [24]. In the pursuit of a more holistic approach, we opted to apply the Motivations and Abilities (MOTA) framework [23], which, despite its recent development, has so far proven to render successful results in exploring the motivations and abilities of actors [25]. Although it has been mainly developed and applied in the context of water resources management to assess the adoption of projects, policies, and plans, we recognize and explore its potential applicability in the context of technology adoption and environmental monitoring. This would provide an opportunity to identify its adaptability and limitations, and thus contribute to its further development. The MOTA framework and its elements are presented in the sections below, as well as the corresponding data collection and analysis methods.

2.1. Motivations and Abilities (MOTA) Framework

Rooted in social science, the MOTA framework [23] interlinks existing actor analysis methods and behavioral models to provide a structure for exploring behavioral action, which happens when motivations, abilities, and triggers act together [25]. In other words, what actors do (e.g., adopting IoT) is based on their perception of some causative factor (trigger), their preference and level of commitment (motivation), and their capacity to act in a given manner (ability) [26]. In this realm, there are several distinctive elements in the MOTA framework, namely: *action*, *trigger*, *motivation*, *ability*, and *outcome*. The *action* is defined as the target behavior of actors regarding a specific project or plan. In our study, the *action* refers to the adoption of IoT environmental monitoring systems by relevant local actors (see Section 2.2). Adoption is here understood as the planning/development stage and use of IoT environmental monitoring systems. The *outcome* is the visible result of an action, which happens when motivation and ability act together. In our study, the outcome relates to digitalized natural resources management; yet, it falls beyond the scope of this study and is not considered in the analysis. In the sections below, we operationalize the MOTA elements relevant to our analysis in the context of technology adoption, i.e., motivations, abilities, and triggers, and summarize them in Figure 1.

2.1.1. Motivation

Motivation refers to the factors that drive an actor to engage in a particular action, i.e., the adoption of IoT monitoring systems. Following Phi et al. (2015) [23], we define motivation as the function of perceived opportunities ("benefits") and threats ("challenges"). By reviewing the academic literature on the advantages and challenges of the digitalization and adoption of advanced digital tools, not only within the field of natural resources management but also in broader contexts, both within Germany and globally, we identified a list of opportunities and threats that could potentially increase or undermine the motivation of German local actors to adopt IoT monitoring systems. The most prominent opportunities encompass enhanced risk assessment and the early detection of natural disasters [13,27–29], and improved decision support and strategy development [14,30]. IoT technologies have also been advocated to facilitate access to real-time information, and hence public participation, as well as information exchange and cooperation among local actors [7]. IoT systems contribute to enhanced transparency, legitimacy, and trust of local public authorities [31,32]. Yet, the adoption of IoT has been related to various challenges and risks as well. So far, data security and privacy are outlined as one of the biggest challenges to the adoption of modern digital tools, both within natural resources management and beyond [14,28,31–34]. Furthermore, increased information exchange and accessibility increases the risk of data misuse and misinterpretation [32,35], potentially leading to false environmental assessments and conflicts among stakeholders [36]. Concerns also arise over the loss of legitimation and public trust, as real-time data may reveal the underperformance of actors involved in natural resources management [37,38]. The adoption of IoT systems may also trigger organizational changes, from job eliminations to modified work routines [7,32].

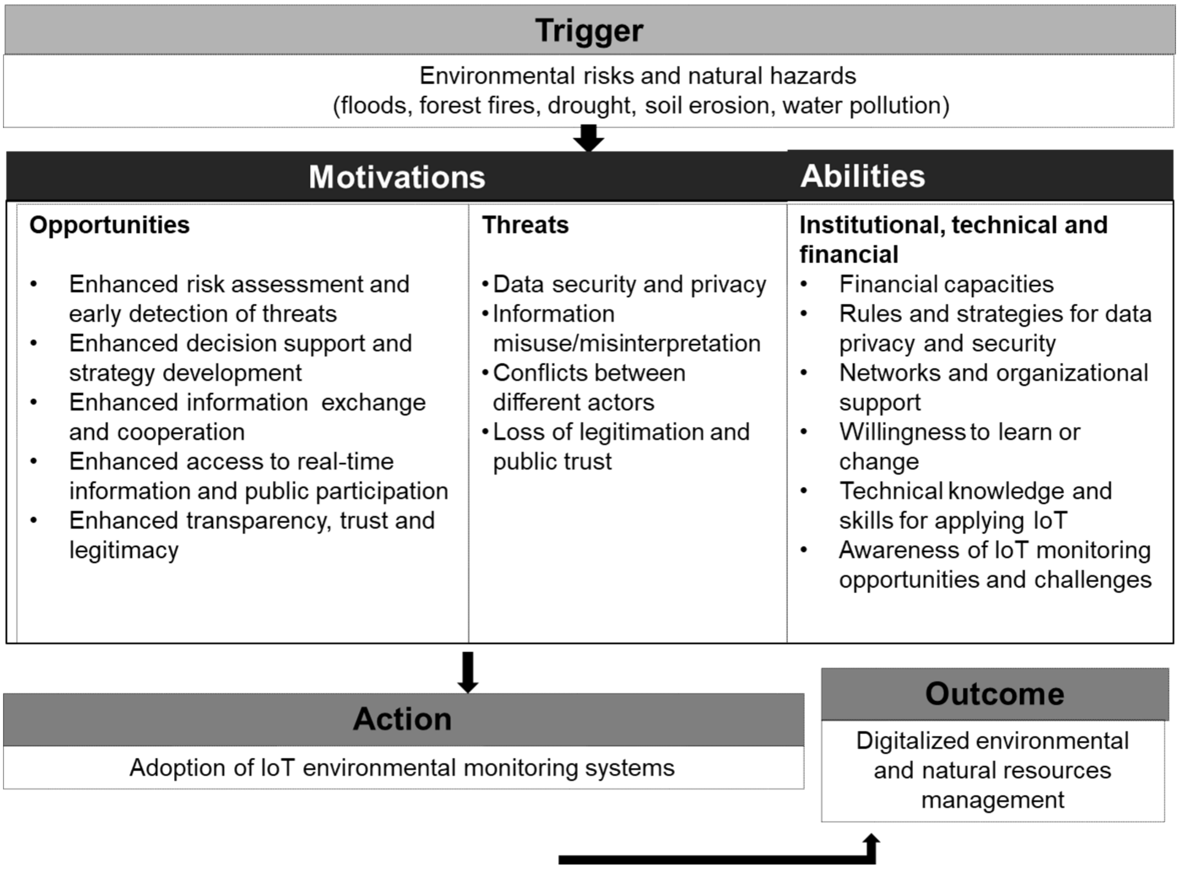

Figure 1. MOTA framework for adoption of IoT environmental monitoring (adapted from Sadik et al., 2021) [26].

2.1.2. Abilities

While actors' motivations shape what they are willing and interested to do, their abilities determine if they can do it [23]. In the MOTA framework, abilities are defined as the financial, institutional and technical skills, resources, and capacities of the actors. Following these three categories, and by reviewing the relevant literature, we identified six major categories of abilities that are relevant for local actors to effectively adopt modern digital tools. Financial and technical resources is key for local actors adopting new technologies, as their adoption often involves significant initial investments in infrastructure, skilled staff, training, and ongoing maintenance [7,9,29]. Technical know-how and knowledge of digital benefits are also crucial assets [9,15,29,32]. Robust digital data strategies and regulations form the basis for successful digital transformation [12]. Collaborative public–private partnerships, political support, and local networks also play pivotal roles in IoT adoption [9,39]. Moreover, the general actors´ attitudes toward digital technologies matter, as integrating modern digital tools can lead to concerns about job security and resistance from employees [9,10,13,32].

2.1.3. Triggers

In the MOTA framework, triggers are defined as events or external circumstances that can influence the perceived opportunities, but also the abilities of actors to adopt a certain plan or project. Triggers can be thought of as "prompts" that initiate a particular action. Since a trigger is a causative factor, the influence of a trigger would depend on the intensity of the trigger [40]. The triggers in our study refer to environmental risks and natural hazards, such as floods, droughts, forest fires, soil erosion, water pollution, pests and diseases, etc. Very often, these risks can serve as catalysts, prompting local actors to adopt IoT monitoring systems to enhance their capacity to respond to and mitigate these environmental issues more effectively.

2.1.4. Research Questions

Based on the above, the following empirical research questions emerge:

(1) How do environmental risks serve as triggers for adopting IoT monitoring systems?
(2) How do perceived opportunities and threats influence the adoption of IoT environmental monitoring systems?
(3) How do actors' perceived abilities (financial, technical, and institutional) influence the adoption process?

2.2. Data Collection

We utilized quantitative data collection, which is an effective tool in exploratory research to gain preliminary insights and provide the foundation for further research [41]. Empirical data on the motivations and abilities of German local actors were collected through an online survey, which was conducted between February and March 2022 as a part of a large-scale survey within the framework of a research project.

The MOTA part of the survey comprised of five sections including background information on IoT monitoring and questions about triggers, motivations, and abilities. The metrics used for each question followed the MOTA guidelines for assessing the triggers, motivations, and abilities of actors [42]. First, to ensure data validity, respondents rated their awareness of IoT forest and water monitoring systems on a Likert scale ranging from 1 (good) to 5 (never heard). The purpose of this metric was to quantify respondents' awareness of IoT forest and water monitoring systems, and it was measured through Likert scale responses that provided a structured and numerical representation of their awareness levels. Next, we explored whether forest- and water-related risks triggered the adoption of IoT monitoring systems. Respondents were asked to indicate if their organizations were planning or already using IoT monitoring for risks such as floods, water shortages, water quality, forest fires, insects/fungal decay, storms, forest drought, and soil erosion. The purpose of this question was to assess the relationship between specific environmental risks (forest- and water-related) and the adoption of IoT monitoring systems. Following the MOTA framework, the metric aimed to understand if these risks act as triggers for organizations to either plan or already use IoT monitoring systems. To gain insights into the motivations of relevant actors, we asked the respondents to evaluate potential opportunities and threats related to IoT technologies, as described in Section 2.1.1. They used a four-point Likert scale to express their agreement or disagreement with five statements about IoT monitoring opportunities and five statements about potential threats. At last, following the MOTA guidelines and to yield insights into actors' abilities, we asked the respondents to rate their abilities to adopt IoT monitoring, covering institutional, financial, and technical aspects (see Section 2.3) on a scale from 1 (low) to 3 (high).

While primarily quantitative, our survey also allowed respondents to supplement their Likert-type answers with comments. This gave them the chance to elaborate, provide examples, and express their perspectives openly. The survey questions were developed in German and underwent a pilot test with field experts. The feedback on question wording and clarity was invaluable in identifying and rectifying any potential issues related to understanding and ambiguity.

We distributed the survey to a wide range of relevant actors across all 401 administrative districts in Germany. These included mainly public authorities and organizations involved in forest and water management and/or monitoring activities, such as: (1) state administrations for forest, water, or environmental/nature conservation, (2) local water management authorities, and (3) research organizations. Yet, we also included forest owners and service providers who also conduct monitoring activities to improve their forest management practices. We did not include, however, environmental NGOs, as they are not as involved in monitoring activities, as they are in other aspects of forest and water management, such as advocacy and conservation efforts [43]. Although we considered actors from two different sectors, conducting a comparative analysis is beyond the scope of this study. Such a comparison, however, could be a valuable avenue for future research.

We informed the participants that survey participation was voluntary, and assured their anonymity and confidentiality. As part of the large-scale survey, we received a total of 154 responses, with the majority coming from the forest sector (86/154), followed by environmental/nature conservation (38/154), and water management (23/154). These respondents represented one or more of the actor groups outlined in Table 1. Yet, it may appear that the sum of responses across actor groups in Table 1 exceeds the total number of 154 responses. This is due to the nature of the survey design, allowing participants to associate themselves with multiple actor groups. Consequently, some responses are counted in more than one category, contributing to the individual counts within each group while maintaining the consistent total response number of 154.

Table 1. Actor groups and number of responses.

Actor Group	State Administration (Forest, Water, Nature Conservation)	Forest Owners and Service Providers	Water Management Authorities	Research Organizations	Others
Number of responses	100	28	34	2	19

Among the 154 respondents, a significant portion (43%, 67/154) reported they were unaware of IoT monitoring systems, and thus did not complete the related survey questions. The lack of awareness varied across the different actor groups, with 27 responses from water management authorities, 20 responses from forest owners and service providers, 7 responses from the state administration, 2 responses from research organizations, and 11 responses from other categories.

This resulted in a reduced dataset of 87 responses and introduced a self-selection bias, as organizations lacking awareness of IoT chose not to participate. Of course, this limits the generalizability and applicability of our findings beyond this specific context. Nevertheless, the study retains an exploratory nature, which allows the utilization of small-scale data collection and the use of results for heuristic purposes rather than seeking broad representativeness or generalizability [44].

2.3. Data Analysis

In our research, we employed descriptive statistical analysis as an initial step to gain insights into the triggers, motivations, and abilities of the relevant actors. Descriptive statistical analysis is a widely recognized method in empirical research within social sciences, well-suited for simplifying and summarizing complex datasets [41]. To be more specific, we began by calculating the frequency distribution of the various key independent variables, including forest and water risks, perceived opportunities and threats, as well as institutional, technical, and financial abilities. The resulting frequency distributions are visually presented in figures (Figures 2–7), offering a clear and structured overview of the prevalence and patterns associated with triggers, motivations, and abilities. These distributions served as a foundational step in our data analysis, assisting us in answering the empirical research questions. Subsequently, we conducted bivariate tests to explore the correlations between the independent variables and the dependent variable (i.e., the adoption of IoT monitoring), enabling us to obtain valuable insights into how motivations and abilities influence the adoption process. These tests were carried out using the SPSS 28.0.1 (Statistical Package for the Social Sciences) software program. Given that our data had ordinal and nominal scaling, and considering the relatively small sample size, we utilized cross-tables and the Chi-square test. This statistical approach allowed us to identify significant interrelationships between triggers, motivations, and abilities and the level of IoT adoption, with the significance determined by a p-value below 0.05. It is important to note that, while the Chi-square test assesses the relationship between one independent variable and the dependent variable at a time, it remains a valid method for exploring correlations between different variables [45]. However, we acknowledge that the influence of multiple independent variables may be at play, and these potential factors should be further investigated using multivariate tests to control for their effects.

3. Results

3.1. Environmental Risks as Triggers for Adopting IoT Monitoring Systems

In Germany, the adoption of IoT forest and water monitoring currently seems to be in a nascent stage (Figure 2). So far, IoT systems have been mostly adopted (in use, development, or projected) for monitoring water-related risks, such *floods* (50 %), *water shortage* (42%), and *water quality* (37%). In this context, many respondents referred to specific water conditions or events as triggers for adopting the new technology. Examples included the 2021 flood catastrophe, the decreasing levels of groundwater in the drought period 2018–2020, as well as the deterioration in the water quality. Similarly, more than half of the respondents (34%) reported the (planned) use of IoT technology for detecting and forecasting *forest fires* due to their increased intensity and frequency in the period 2018–2019. Furthermore, the results showed that forest damage caused by insects/fungal decay (e.g., bark beetle infestations) (28 %), *storms* (23%) or forest *drought*, e.g., tree mortality or canopy damage (19%), have also prompted some authorities and organizations to adopt IoT monitoring systems. Yet, although soil *erosion*, exacerbated by climate change, poses risks to forest soils and water quality in Germany [46], the results showed that, currently, IoT technologies for monitoring soil erosion are not being adopted. In summary, although forest and water risks may have prompted some local actors to consider the adoption and use of IoT monitoring, the majority stated that their organization or authority had no plans to adopt them. For deeper insights, we present the findings from the analysis on the motivations and abilities in the sections that follow.

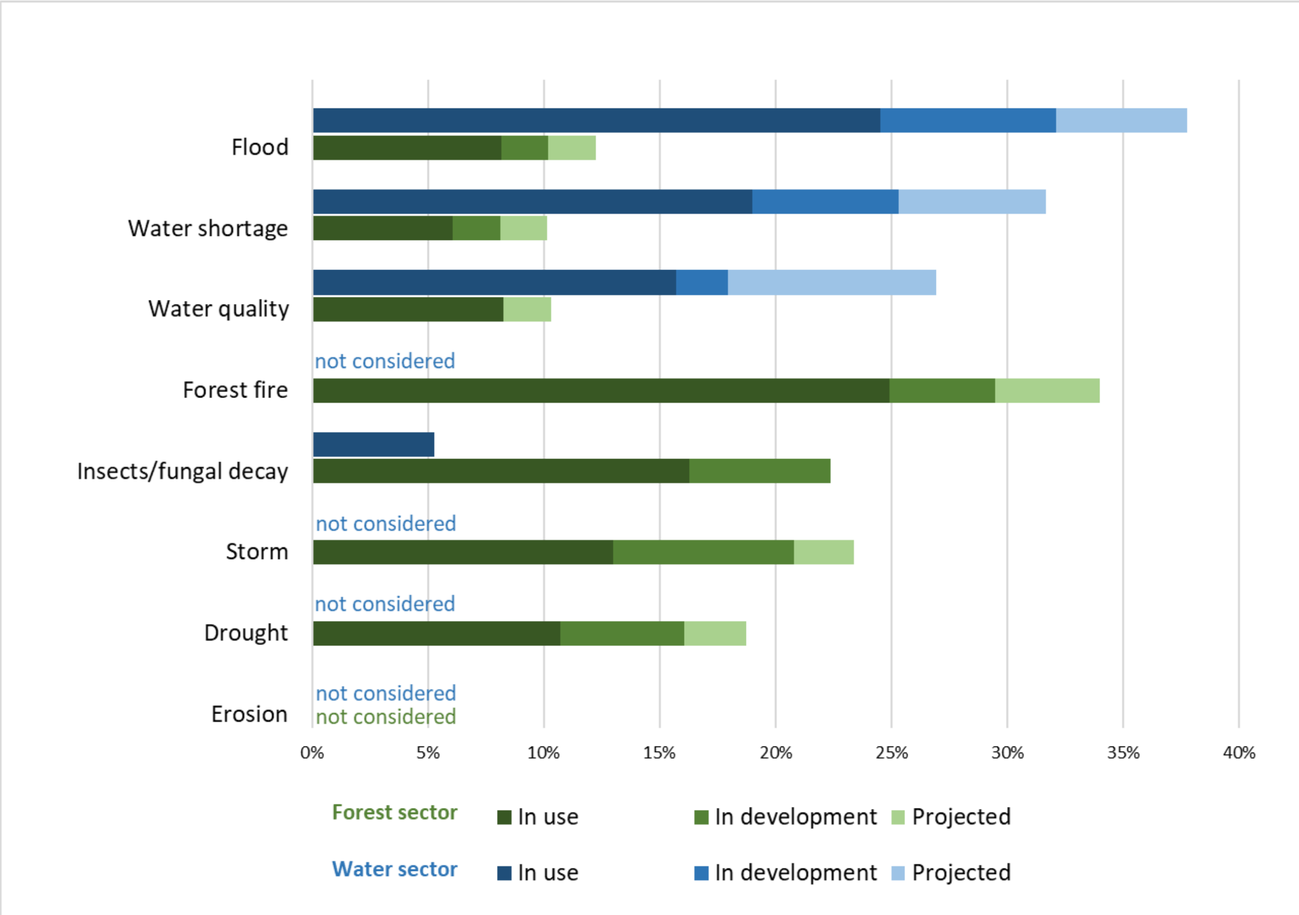

Figure 2. Adoption of IoT monitoring for forest and water risks, n = 87.

3.2. Perceived Opportunities and Threats, and Their Influence on Adoption of IoT Environmental Monitoring

The majority of the respondents appeared to have a positive perception and provided mostly affirmative responses in regards to the opportunities of IoT monitoring. Yet, there was some variation in the level of agreement. For example, as shown in Figure 3, more than 70% of respondents expressed agreement regarding the potential of IoT to improve *access to real-time information and public participation*, with 43% fully agreeing and 31% somewhat agreeing. Similarly, a substantial portion of participants agreed that IoT monitoring systems, due to their connectivity features, facilitate *information exchange and collaboration* among various sectors and administrative levels, with 39% in full agreement and 36% somewhat in agreement. This trend continued with the perceived ability of IoT monitoring systems to enhance *decision support and strategy development*, where 39% fully agreed and 36% somewhat agreed. Many respondents also saw the promise of IoT monitoring in advancing *risk assessment and early detection of natural hazards*, like floods and forest fires, with 37% fully agreeing and 31% somewhat agreeing. Furthermore, it was widely agreed that IoT monitoring, by increasing the availability and accessibility of real-time information, contributes to improved *transparency, trust, and legitimacy* of local authorities, with 32% fully agreeing and 38% somewhat agreeing.

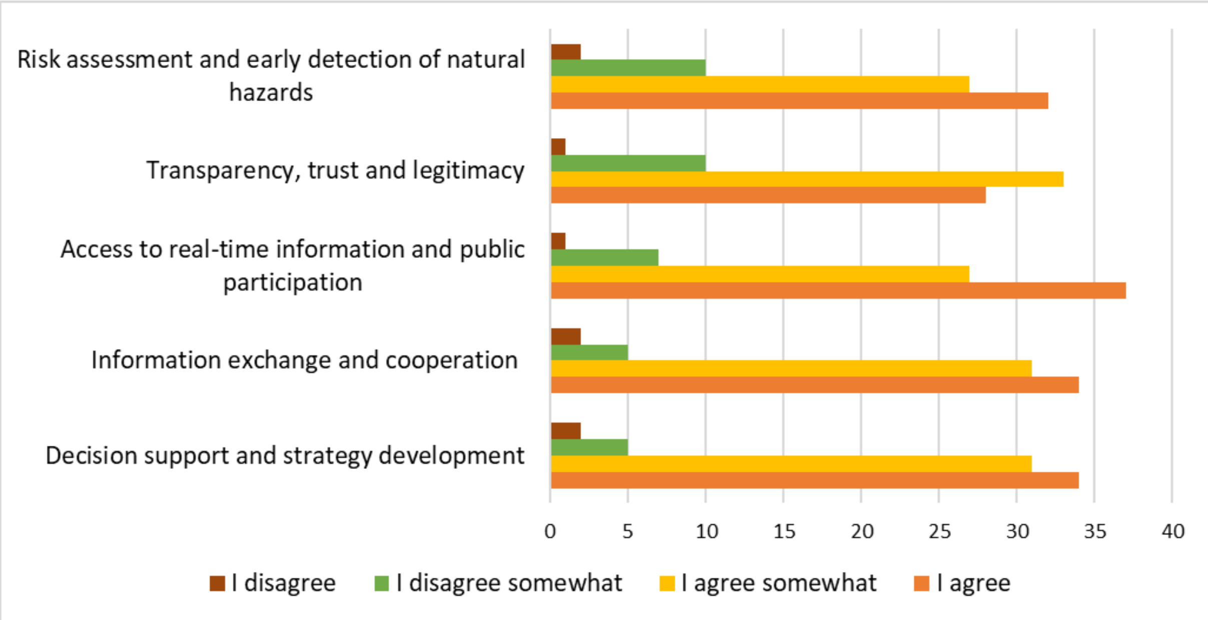

Figure 3. Perceived opportunities of IoT environmental monitoring (forests, water).

In summary, the results indicate that, while most respondents acknowledge the benefits of using IoT monitoring in forest and water management, it remains unclear how these perceptions influence actual IoT adoption. To explore this further, we examined the correlation between perceived opportunities and the current adoption of IoT systems for forest and water monitoring (Figure 4). Our findings reveal that, when respondents hold a *more optimistic* view (i.e., they agree or somewhat agree) regarding the utility of IoT monitoring systems, they are more inclined to adopt these technologies for monitoring three or more forest and water risks. Conversely, in organizations and authorities where skepticism prevails (i.e., *less optimistic*) regarding the potential benefits (i.e., respondents disagree or somewhat disagree), IoT monitoring systems tend to be limited to one or two specific forest or water risks.

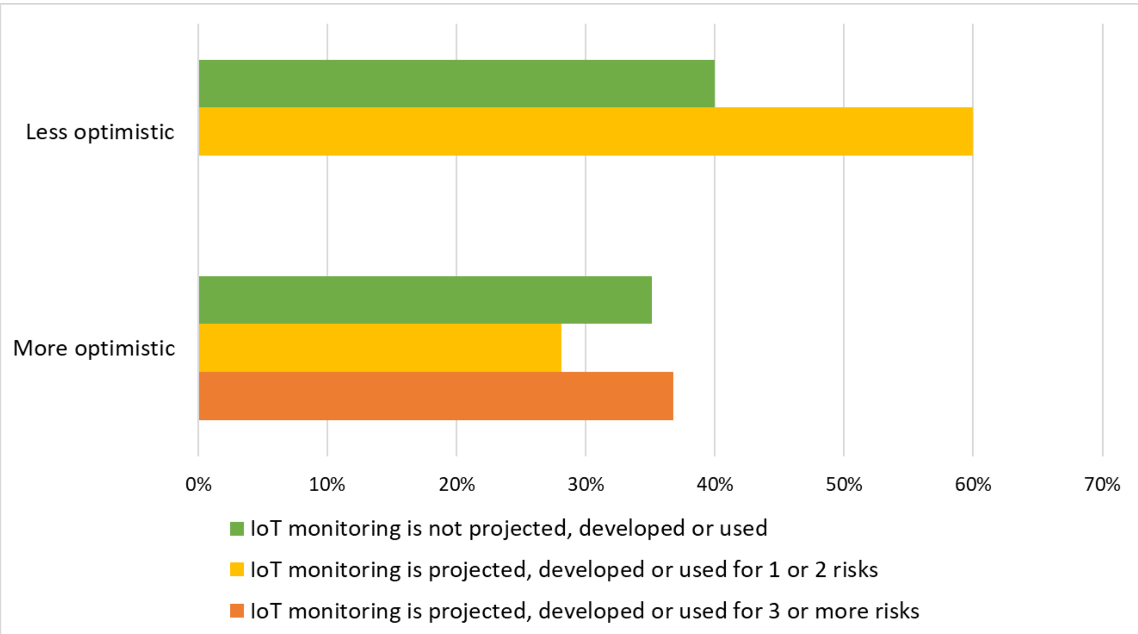

Figure 4. Correlation between perceived opportunities and IoT adoption.

Regarding the potential threats (Figure 5), nearly half of the respondents, accounting for 48%, identified *data privacy and security* as a substantial risk for their organization or authority, with 17% in complete agreement and 31% somewhat in agreement. Another significant risk, as perceived by approximately one-third of the respondents (36%), was the potential for *misuse/misinterpretation of information*, with 10% in complete agreement and 26% somewhat in agreement. Contrary to the widely recognized notion that fear of *organizational structure change* often acts as a significant barrier to IoT technology adoption, our study revealed that a majority of respondents (56%) did not view it as a major threat. In fact, 24% disagreed and 32% somewhat disagreed with the idea that organizational change posed a significant risk in our study. Similarly, the *risks of increasing conflicts between actors* (17% disagreed, 38% somewhat disagreed) and the *loss of legitimation and trust* (23% disagreed, 39% somewhat disagreed) were also not considered significant threats by the respondents. In the subsequent phase of our analysis, we conducted correlation tests to examine how perceived threats influence the adoption of IoT monitoring systems in the context of forest and water management. In contrast to the perceived opportunities, we found that perceived threats exerted minimal or no influence on the adoption of IoT monitoring for natural resources management.

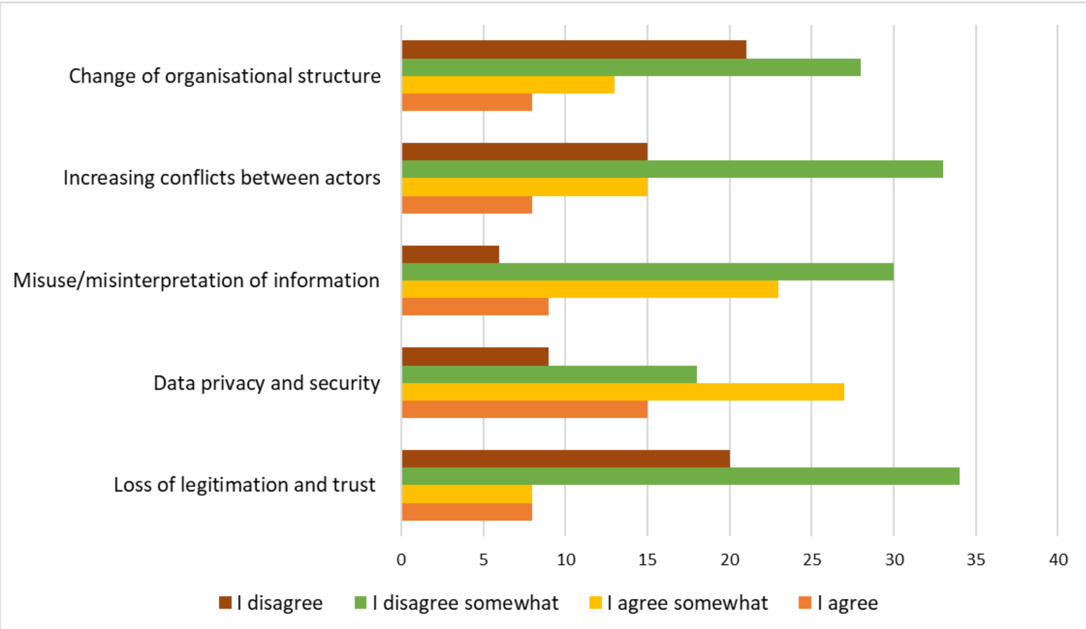

Figure 5. Perceived threats of IoT environmental monitoring (forest, water).

3.3. *Perceived Abilities (Financial, Technical, and Institutional), and Their Influence on Adoption of IoT Environmental Monitoring*

The findings indicate that most respondents perceive their organizations to have insufficient abilities for adopting IoT monitoring systems (Figure 6). Specifically, more than half of the respondents perceived their organization's *financial capacities for implementation and operations* low (51%), while nearly half regarded *technical know-how and IT competence* as low (38%), with a quarter rating it as average (25%). Additionally, respondents expressed dissatisfaction with the diversity of the professional *network* and the level of political *support* for adopting new technologies, as 36% considered it low and 27% considered it average. The findings also suggest the need for more tailored strategies for digital transformation, as 35% of respondents evaluated the presence of a *coherent strategy for technological innovation* as low and 29% as average. Similarly, *knowledge about IoT possibilities* was deemed low by 34% of respondents, with 26% rating it as average. Interestingly, almost half of the survey participants (48%), primarily from the forest sector, assessed their authority's general *attitude toward advanced technologies* as average (48%).

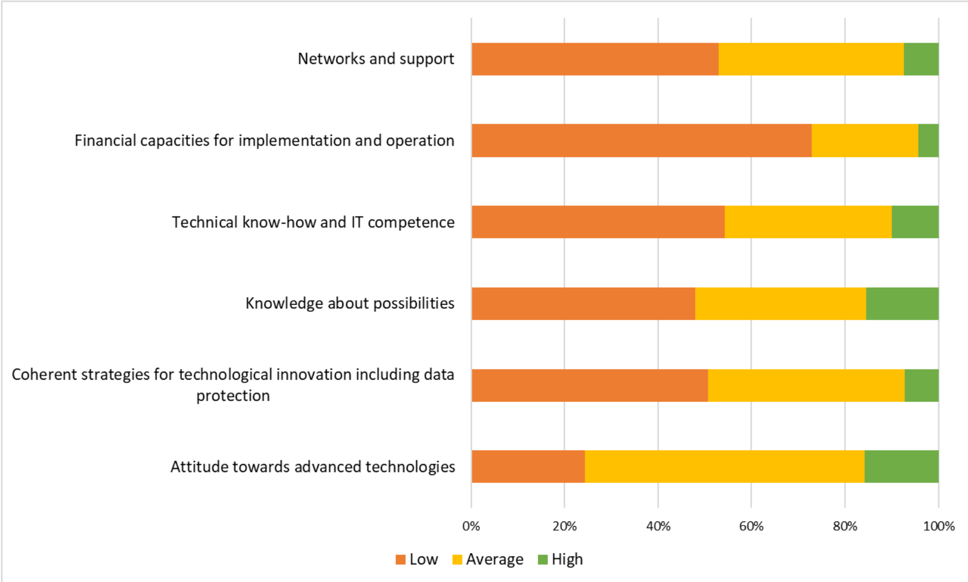

Figure 6. Perceived abilities to adopt IoT environmental monitoring (forests, water).

We also investigated the correlation between actors' perceived abilities and the adoption of IoT technology for forest and water monitoring. The ability index was computed as an average of all perceived abilities (Figure 7). The results reveal that organizations and authorities that perceive themselves as possessing *high* abilities in terms of financial resources, technology, and infrastructure are more inclined to embrace IoT technology for monitoring three or more forest- and water-related risks. Conversely, those that perceive their abilities as weak (low, *medium*) tend to adopt advanced monitoring systems for less risks, or do not have plans to adopt new technology at all. It is yet worth noting that, while this finding suggests that abilities may play a significant role in the adoption of new technologies, our study focused solely on the correlation between abilities and IoT technology adoption. It did not explore the relative importance of abilities compared to perceived threats and opportunities in influencing the adoption decision, a topic that merits a consideration in future research.

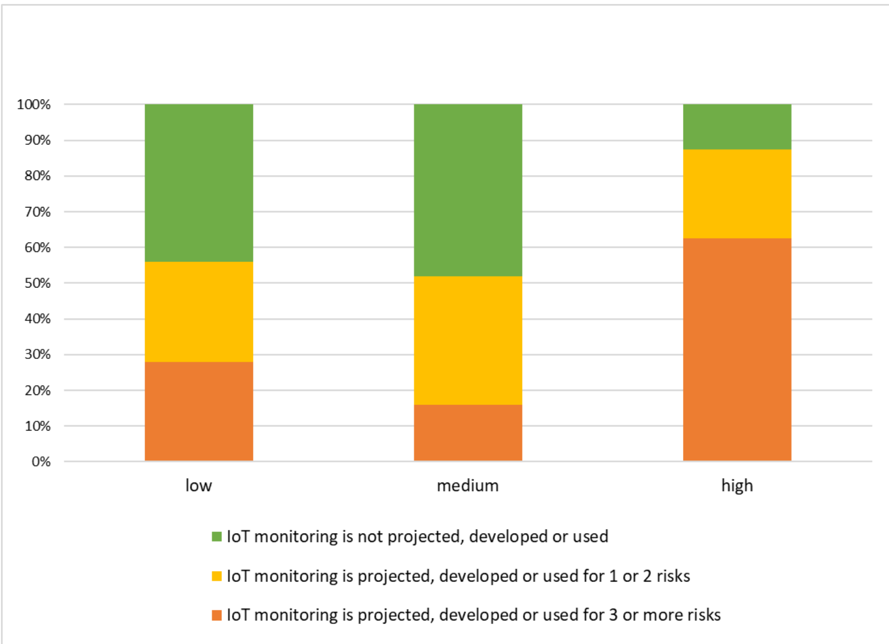

Figure 7. Correlation between perceived abilities and adoption of IoT monitoring.

4. Discussion

4.1. Adopting IoT Forest and Water Monitoring Systems in Germany—A Digital Opportunity or a Threat?

This empirical study aimed to provide initial insights into the motivations and abilities of German local actors to adopt IoT environmental monitoring systems. The MOTA framework was used here to explore actors' motivations and abilities, and their influence on the adoption of IoT forest and water monitoring systems in Germany. Although the overall aim of this analysis was solely explorative, and it was beyond the scope to make any theoretical contributions to the framework, we reflect on its application and offer suggestions for further improvement. The study relied on quantitative data collection and analysis methods, and the ensuing results are discussed in the sections below.

The first empirical research question of the study focused largely on exploring environmental risks acting as triggers for adopting IoT forest and water monitoring systems. As the results showed, IoT systems have been mostly adopted for monitoring water-related risks, such as floods, water shortage, and water quality, but also forest fires. The fact that numerous respondents referred to specific recent weather conditions and events as triggers for embracing the new technology could be attributed to the escalating impacts of climate change on forest and water systems in Germany in recent years [47]. Nevertheless, although forest and water risks may have prompted some local actors to consider the adoption and use of IoT monitoring, the analysis showed that the adoption of IoT monitoring for forest and water is still at a nascent stage, with many still even unaware of the emerging technologies. This is surprising considering the rapid development of IoT environmental systems and federal policy developments such as the Digital Agenda for the Environment [2]. While organizations may require more time and adaptability to stay current with new technologies [48], we argue that understanding the lack of awareness across different sectors and actor groups requires further research. In this realm, exploring the role of individual characteristics, like educational background, age, or gender [49], could provide valuable insights. Furthermore, understanding the influence of cultural and historical contexts might also shed light and explain the lack of awareness. For example, Germany's rich history in water and forest management, coupled with substantial expertise and infrastructure for risk evaluation, underscores the importance of historical context [50]. Established monitoring practices, proven over decades or even centuries, maintain a central role in natural resource management, deeply ingrained in institutional memory and practices. This reliance on traditional methods may lead authorities and organizations to overlook or remain "blind" to novel and innovative tools and approaches [51].

The second question of the study centered upon perceived opportunities and threats, and their correlation to the adoption of IoT environmental monitoring. Although many respondents declared no plans to adopt new monitoring systems, the lack of intention does not appear to stem from a lack of motivation. As indicated by the findings, a significant proportion of the respondents clearly acknowledge the numerous advantages offered by IoT monitoring systems. This suggests that IoT monitoring systems are generally regarded as a valuable opportunity for forest and water management and policy. Moreover, a more favorable perception of the effectiveness of IoT monitoring systems correlates with an increased propensity to adopt these technologies. Conversely, in instances where skepticism about potential benefits dominates, the adoption of IoT monitoring systems tends to be confined. Aligned with previous research [52], this underscores the connection between positive perceptions of effectiveness and the extent of technology adoption. Conversely, although major concerns such as data privacy, security, and misuse have been largely acknowledged, the analysis revealed that perceived threats or risks do not influence the willingness of actors to adopt IoT technology. This contradicts the prevailing consensus among most studies and scholars in the field, which often argue that perceived threats and risks can act as major impediments to the adoption of IoT technology [32,53]. In this context, it becomes imperative to critically examine how such concerns are being framed and whether they reflect genuine risks or are used strategically to resist technological change, as our study did not reveal a correlation between perceived threats and IoT adoption.

Considering that the lack of intention to adopt new IoT monitoring systems is not rooted in the lack of motivation, we can infer that the major factors contributing to this lack of intention are actors´ abilities. The third empirical question focused on exploring perceived institutional, financial, and technical abilities, and their relationship to the adoption of IoT environmental monitoring. As the results clearly demonstrate, financial and technical capacities and resources were viewed as insufficient for effectively adopting IoT monitoring technologies. In fact, this aligns with previous research on digital transformation in Germany, revealing that a lack of technical competence and funding are among the major barriers hampering the adoption of new digital technologies at the local level [9,10]. The results also revealed that the willingness to adopt IoT technology for monitoring various forest and water risks is closely linked to the perceived level of resources and capabilities within the organizations and authorities. Organizations with a positive perception of their financial, technological, and infrastructural capacities are more inclined to embrace IoT solutions. On the other hand, those who perceive their abilities as inadequate are less likely to consider adopting this technology. The results highlight the importance of organizational readiness and resources in shaping the adoption decisions of IoT technology for environmental monitoring in the context of forest and water management. This, however, gives rise to a number of critical questions about the political and normative dimension in which technology adoption is embedded. For instance, it would be interesting to explore how new digital technologies gain political support and legitimacy at the local level, and who determines, and how, whether there will be any funding available for the adoption of new digital solutions, particularly in public authorities. In this context, an exploration of the political and strategic interests that may advocate for or against specific digital technologies also becomes essential [54,55].

4.2. Methodological Reflection and Limitations

This study provides valuable initial insights into the complex interplay between actors' behavior and technology adoption, particularly in the context of emerging new monitoring technologies and natural resources management. Its findings provide guidance for decision-makers and practitioners aiming to leverage IoT monitoring for the more efficient sustainable management of natural resources, and lay a robust foundation for further scholarly inquiry and discussions. In this regard, the MOTA framework, although mainly developed and used in the context of water resources management and policy, proved useful and applicable as a heuristic research tool for scrutinizing actors´ motivations and abilities, and investigating their correlation to technology adoption. However, as already discussed in a recent study [56], there is a notable gap in the MOTA framework regarding its treatment of the institutional dimension. The MOTA framework presently lacks the specific and precise concepts and relationships necessary for a comprehensive integration of the institutional dimension, which can be delineated as a distinct category influencing not only actors' perceptions, but also their capabilities [57]. Furthermore, considering the study´s limitations (see Sections 2.2 and 2.3), we acknowledge that our findings and suggested avenues for future research may not encompass all perspectives on IoT monitoring in the field of natural resources management. Therefore, we recommend further comparative analysis and case studies to validate the applicability of our findings in broader contexts.

5. Conclusions

In summary, this study provides valuable empirical insights into the complex interplay between actors' behavior and technology adoption for natural resources management. It also lays a robust foundation for further scholarly inquiry and discussions in the field of social science and digital transformation within the context of natural resources management. In this context, we argue that technology adoption does not exist in a vacuum.

Instead, it is embedded within a multifaceted web of intricate political, normative, historical, and sociocultural contexts that profoundly influence the adoption process and actors' behavior. Understanding these influences would add an important layer to the critical understanding of actors' behavior and technology adoption in the context of natural resources management.

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