# Introducing environmentally friendly soap-based firefighting agent for extinguishing forest and peatland fire in Central Kalimantan, Indonesia

## Technology Acceptance Model

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### Abstract

Central Kalimantan experienced the highest rates of burning and the most repeated fire incidents. Water is the most common means of extinguishing forest fires in Indonesia. However, it is less efficient at wetting and penetrating hydrophobic surfaces during the extinction of peatland fires. Firefighting agents with high penetration capabilities are added to improve the performance in fire extinguishing forest fire. Introducing an environmentally friendly soap-based firefighting agent (SFA) for extinguishing forest fire require a socio-technological transition process. This paper aims provides comprehensive information on the process of introducing technology, quantifying multiple benefits and interview survey to evaluate the perceived acceptance of technology of firefighting agents. There is no gap of expectation on what the potential user can get and cannot get from the technology. We also confirm the technology acceptance model of SFA in Central Kalimantan. Technology-inclusive system transitions supported by appropriate enabling conditions, including effective multi-level governance and institutional capacity, policy design, and implementation can generate benefits across different sectors at a local and national level.

## Introduction

Kalimantan experienced the highest rates of burning and the most repeated fire incidents, indicating a shift from extensive to recurrent fires (UNDRR, 2023). The peat fires severely degraded air quality in the cities of Kalimantan and Sumatra, with air pollution levels rapidly reaching very unhealthy levels due to the increased hotspot counts. The pervasive air pollution from wildfires and peatland fires in 2019 led to school closures, depriving children of learning opportunities and other health issues (Lohberger, 2018). The impact of forest fires and haze is particularly significant for vulnerable communities, especially those with chronic risk factors. The fire directly impacts and destroys biomass, organic matter, plant composition, and diversity. The fires in 2015 alone resulted in the loss of over 760,000 hectares of Indonesian forests (UNDRR, 2023). The largest recent fire in Indonesia, in 2015, burned approximately 4.6 Mha, releasing 0.89 Gt of carbon dioxide equivalent (Subekti et al., 2016) and causing economic losses for US$28 billion (Kiely, et al, 2021).

The Indonesian government continues its efforts to limit forest and peatland fire, and Indonesia's regulatory interventions have been more effective in reducing forest fire incidents. These regulations generally fall into four main categories: fire management, forest exploitation and management, disaster management, and decentralization. The government also supports multilevel operations, facilitates fire care community groups, provides technical training, and conducts public awareness campaigns on forest fires and prevention (UNDRR, 2023). Water is the most common means of extinguishing large-scale forest and peatland fires in Indonesia. However, it is less efficient at wetting and penetrating hydrophobic surfaces during the extinction of peat fires (Rakowska et al., 2017). Firefighting agents with high penetration capabilities are added to improve the performance in fire extinguishing peat fire (Kanyama, 2025). Adding surfactants to water enhances the extinguishing performance by lowering the water's surface tension and significantly increasing its ability to penetrate burning materials (Mizuki et al., 2007; Santoso et al., 2021). The existing studies reported that the application of an environmentally friendly firefighting agent is effective in reducing the amount of time and water required to extinguish the fire compared to the use of water alone (Subekti et al., 2017; Kanyama et al., 2025) and cost saving (Samejima, 2025). Society and technology intertwine and coevolve, culture and social structures shape the design and use of technology, and technology, in turn,influences cultural and social experience (Cerezo & Verdadero, 2003). Although the use of chemical based synthetic foam was more effective during the extinguished forest and peatland fire in 2015 (VOA, 2015); 2019 (Katadata, 2019); and 2023 (Ditjen PPI, 2023; Matakalteng, 2023), however, chemical firefighting agent was invasive; toxic and irritate to human skin (Damkar, 2020; Yilmaz-Atay,2022). Certain technologies are accepted (to varying degrees) while many, though not apparent, are rejected. Rejection of technology may be expressed as a phenomenon wherein society, ranging from individual users, community groups, through states (nations), capable of availing the services of a particular technology, deliberately choose to refrain from its use, in full of part. The technology acceptance model explains how society accepts and uses a technology through a process of introducing a new technology and ends up tusing the technology (Davis, 1989). An understanding of the complex relationship between users and technology is important from sociology and technology points of view.

Introducing an environmentally friendly soap-based firefighting agent (SFA) for extinguishing forest and peat fire requires a socio-technological transition process. The process includes knowledge transfer of new technology to improve the perceived evaluation of usefulness and perceived ease-of-use, diffusion of technology, and uptake at the local level in Central Kalimantan (Ozili, 2024). While the role of SFA in firefighting to extinguish forest and peat fire is recognized as an important approach for combatting forest and peatland fire in Indonesia, the enabling conditions for the transfer, diffusion, and uptake of those technologies are not well understood or documented (UNEPCCC, 2023). The information related to those processes is ad hoc, spread across many sources, and not well documented. This paper aims to fulfil the knowledge gap through analysis of the interaction between users and the introduction of environmentally friendly SFA for extinguishing forest fire in Central Kalimantan, Indonesia. It is expected to contribute as a practical tool to inform stakeholders (government, academia, and industry) on improving the transfer, diffusion, and uptake of technologies, which are expected to play a leading role in countries meeting disaster risk reduction on forest and peatland fire. The article will be organized through the following sections: (a) the next section will discuss theliterature review and methodology; (b) following by an empirical analysis and (c) discussion and conclusion.

## Literature review and methodology

Introducing an environmentally friendly SFA for extinguishing forest and peat fire is not only about the supply of new technology across international frontiers but also the complex process of sharing knowledge and adapting technology to meet local conditions along with the demand management (Connick, 2015). A sociotechnical system comprises technology, regulation, user practices and markets, cultural meaning and dictum, infrastructure, maintenance network, and supply network. Scholars try to describe interventions that may influence the progress of introducing a new technology into the marketplace and approach the issue on a systemic level (Hekkert et al., 2007; Sagar et al., 2009). It has to be a fit between the incumbent socio-technical system for a new technology to diffuse, or an opening needs to be created or formed (by intervention or a coincidental combination of circumstances) to provide an opportunity for a technology to emerge (Geels, 2005). The transitions begin by altering technologies; competencies, skills, and knowledge; and meanings and common understanding of the use of SFA for extinguishing forest and peatland fire. They can then work through at least three diffusion paths through which they bring about larger changes: (a) Embedding: a process of combining and adapting technologies and integrating them into existing structures, as well as giving these technologies meaning (Wirth et al.,2018); (b) Translation: a horizontal diffusion, where there is replication and reproduction elsewhere (in different communities, organizations or institutional contexts, or across sectors (firefighting division, disaster resilience team, environment and forestry, etc); (c) Scaling: the internal development and growth of niche experiments (Liedtke et al., 2015).

The transitions process emphasizes purposive experimentation as a powerful driver of change because it facilitates a learning process where technologies and new social relations can forge new sustainable socio-technical systems (L. Fuenfschilling, Frantzeskaki, and Coenen,2018). The experiments on utilizing soap-based firefighting foam consist of two sets of activities: (1) small initiatives for the earliest stages of learning take place in local level; and (2) the emergence of networks of key stakeholders with knowledge, capabilities and resources, cooperating in a process of mutual learning (Bai, et al 2010; Berkhout et al., 2010). The experiments are expected to be able to respond the basic questions of operation and the reconciliation of classic business considerations (e.g., cost reductions) and sustainability orientations (maximizing benefit for local environment) at a time of climate disaster emergency (Meelen, 2023). The efficiency, environmental, and economic gains can be enablers for adoption technology. The role of emotions was also identified as an emerging topic in the adoption of new technology. Researchers find a positive effect of "technophilia" on the perceived ease of using new technology (Wolff and Madlener 2019). While these adoption models can help to identify factors that might stimulate or hamper innovation embedding, they also have shortcomings in the context of socio-technical transitions (Geel and Johnson, 2018). To overcome those challenging issues, a related quandary is that complexity necessitates combining evidence-based decision-making with experiential knowledge to ensure a new technology is forward-looking as well as context-appropriate (Friend et al., 2014). The article provides comprehensive information on the process of introducing technology, quantifying multiple benefits, and evaluating perceived acceptance of technology of firefighting agents based on empirical field experiments and verification survey. It was part of the project on the business verification survey of Japanese technologies to extinguish forest and peatland fire using environmentally friendly SFA in Central Kalimantan, Indonesia, from 2023 to 2025, funded by Japan International Cooperation Agency (JICA) in collaboration with the University of Palangkaraya.

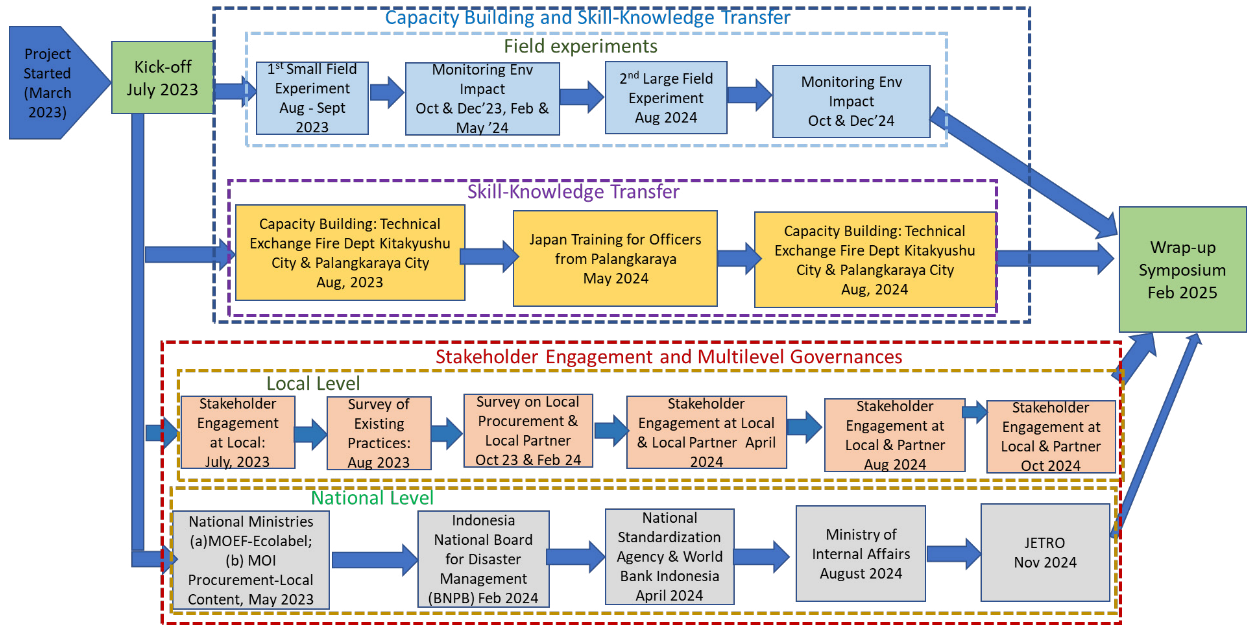


**Figure 1:** Progress of introducing soap-based firefighting agent in Central Kalimantan

## Introducing an environmentally friendly soap-based firefighting agent solution at local level

The project on the business verification survey of Japanese technologies to extinguish forest and peatland fire using environmentally friendly SFA in Central Kalimantan, Indonesia, was begun in 2023 (figure 1). The project duration is two years, funded by the Japan International Cooperation Agency (JICA). There are three main activities under the project as follows: (a) field experiment; (b) skill & knowledge transfer and (c) policy studies; stakeholder engagement and multi-level governance. The field experiment focuses on the verification of SFA's performance and its multiple benefits on environments and economic benefits. Skill and knowledge transfers aim to introduce know-how technology and compliment it with technical training on how to use and maximize the benefits. Skill and knowledge transfer were conducted mostly by main actors of firefighting under the cooperation in between Kitakyushu City fire department and relevant agencies in Palangkaraya and Central Kalimantan such as fire department, disaster and rescue team of central Kalimantan and Palangkaraya city. The policy studies focus on these following aspects: (a) public procurement involving government agencies; (b) incentive of local product of technology in the electronic purchasing system; (c) standardization and labelling of product to enter market. While conducting the policy study, we also conduct stakeholder engagement for information sharing on the technology and market research simultaneously at the local and national level in collaboration with partners and collaborators.

## Field experiments for knowledge transfer of know-how technology

The field experiments were carried out within the University of Palangkaraya campus, Central Kalimantan. The experiments on utilizing SFA consist of two sets of activities: (1) initiatives for the earliest stages of learning take place about the technology and attributes; and (2) the emergence of networks of key stakeholders in Palangkaraya city and surrounding cities with knowledge, capabilities and resources, cooperating in a process of mutual learning. The field experiment aims to do these following activities: (a) assess the safety of the soap-based fire-fighting agent against human body and environment using the Globally Harmonized System (GHS), which is used as the national standard by the Government of Japan and the Government of Indonesia; (b) to collect basic data on the performance of soap-based technology compared with the common practice using water only; (c) analyse the impact to the environment by using the indicator of the regeneration of plants on the land after the basic experiment.

The basic experiment was conducted two times (figure 1) with small boxes in the first year and was enlarged to a real forest with the size of 25 x 20 metres to have a more real simulation in the second year. Both experiments were done within the university areas, as shown in figure 2. The first small-scale experiment was conducted from September 15 to 23, 2023. It was done at dried peat soil packed in 1.5m x 1.5m, which was burned for 24 hours. Water or 1% Soap-based firefighting agent (SFA) was sprayed using a backpack-type water tank until the peat surface temperature was below 50°C. Additional firefighting activities were conducted if the peats were reignited. The amount of water and time required for firefighting activities were measured to evaluate the actual performance of the

2a. Small Scale Experiment – Small Boxes

2b. Large-scale demonstration & techno show - August 2024

**Figure 2:** Small-scale and large-scale demonstrations in Palangkaraya

soap. The large demonstration onsite was conducted at the area of 20m x 25 m. The peat soil was burned for about 30 minutes, and soap was sprayed using pumps and hoses and also using a back-pack type water tank. A large demonstration was conducted on August 2024. The large experiments also aim to provide an opportunity for stakeholders to have an experience of the technology. The experience is important as it may determine technology acceptance and intention to use it (Murthy & Mani, 2013).

## Measuring multiple benefits of soap-based firefighting agent (SFA)

Besides experiment to introduce the usefulness and ease-of-use of the technology and, measurement actual performance of soap is important to provide an evidence-based analysis. The team conducts monitoring the multiple benefits of soap on environment and economic aspects.

### Monitoring environmental benefits

Introducing environmentally friendly soap-based firefighting agents to extinguish forest fire show high economic feasibility and large potential to reduce greenhouse gas emissions and other environmental benefits (Kitso, 2025). Environmental benefits were monitored through field experiments on the water and SFAS usage at the dried peat boxes, toxicity test, and effects on ferns test.

A. Water conservation (water saving)

Water saving was monitored through an experiment with the dried peat boxes. It was conducted through a comparison analysis of the fire extinguishing using water only as the business as usual (BAU) and soap-based firefighting agent solution (SFAS). The intervention of technology reduced water consumption by 75%, as shown in Figure 3.

B. Effects on vegetation

A toxicity test was conducted at the laboratory, while effect on the fern test was conducted for the actual fern plant. It was complimented with field monitoring of tree component in the ecosystem at both dried peat soil packed and the location of large-scale demonstration in 2024 (figure 4).

### Quantifying economic benefits

A. Time saving and human resource saving

In parallel with the water saving, time used was also monitored through an

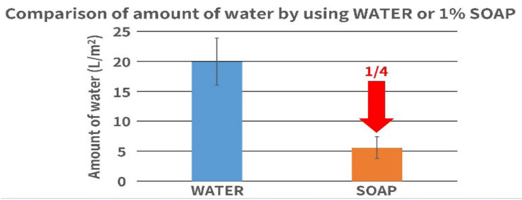


**Figure 3:** Environmental benefit on water saving (Source: Kanyama, 2025)

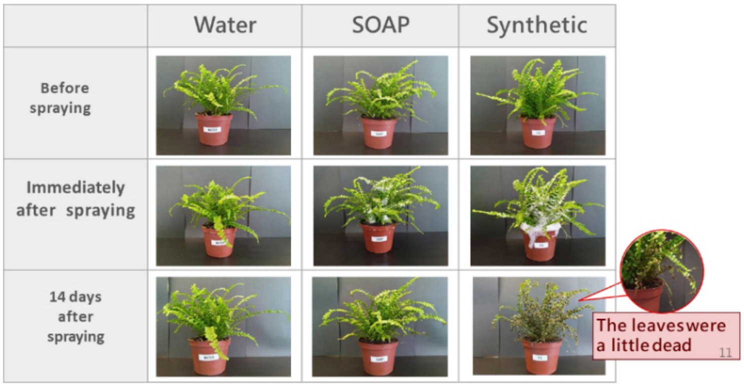


**Figure 4:** Effects on Fern Test (Source: Kitso, 2025)

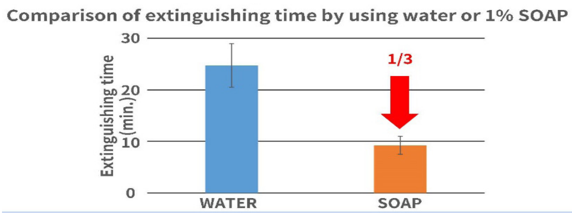


**Figure 5:** Economic Benefits – Time Saving (Source: Kanyama, 2025)

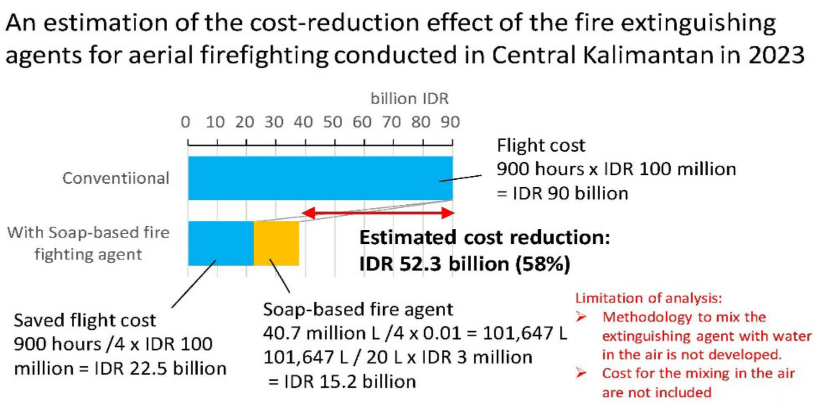


**Figure 6:** Economic benefits (Source: Samejima, 2025)

experiment with the dried peat boxes. Through a comparison analysis of the fire extinguishing using water only as the business as usual (BAU) and soap-based firefighting agent solution (SFAS), we found the intervention of technology reduces extinguishing time by almost 67%, as shown in figure 5.

B. Cost saving

Due to the availability of robust data, the team conducts a comparison analysis Aerial bombing with water as business as usual versus intervention with additional of innovation technology of a soap-based fire-fighting agent into the water used for aerial bombing. The scenario for using soap are as follows: (a) retail price of soap around 3 million rupiah per gallon; (b) dilution ratio 1%; (c) efficiency of water use 400%. The reference cost for aerial fire-fighting is about 100 million rupiah per hour (Samejima, 2025). It is estimated that the cost saving of about 52.3% or equal to 58% compared to business as usual. The results are shown in figure 6. However, the calculation doesn't include the cost for mixing of water with soap because of the undetermined methodology for mixing the soap and water. The simulation shows the cost-effectiveness of technology intervention. However, it is not a one solution fit for all situations. The interventions show more efficiency and effective for aerial bombing, extinguishing deep peat fires to prevent repeating peatland fires after finishing extinguishing at the surface level. It is important to explore and analysts the best practices for utilizing soap-based fire-fighting agent for extinguishing forest and peat land fire.

## Discussion

Perceived evaluation was conducted to evaluate the progress of the interaction between users and the introduction of technology on environmentally friendly SFA for extinguishing forest fire in Central Kalimantan, Indonesia. It was conducted through an interview survey (online) to the stakeholders who joined the large-scale experiments in August 2024. In total, 47 person from respective organisations and NGO participated in large-scale onsite experiment. About 44.7% out of 47 attendants participated in the interview survey. Most of the respondents are working related to the firefighting around 66.7%. They come from government related agency around 71.4%; academia/NGO, around 19% from academia/NGOs, and the remaining 9.5% from private sector/companies.

### Technology acceptance model of SFA in Central Kalimantan

The interview survey of multiple responses to the main challenging issues on firefighting to extinguish forest and peat fire. The top mind of the respondents answering about the availability of water (located far away) is on top of the main challenging issues, around 57.1%. The availability of water during firefighting to extinguish forest fires was already identified (Alfaro et al., 2024), and several countermeasures have already been implemented to overcome this issue in Indonesia (Pustandpi, 2024). However, facing the scarcity in dry season and future trends, the introduction of SFA may contribute to a better solution to solve limited water availability on the field. Insufficient equipment (infrastructure) comes as the second concern at around 47.6 %. We didn't further explore the detailed information about this aspect in our survey, however, another study confirms this finding (Pustandpi, 2023). About 42.9% respondent also concerned about the reignite problem of peatland fire, and limited human resources is the lowest, around 33.3%. The limited capacity and human resources are challenging factors in implementing forest management units (FMUs) in Central Kalimantan (Budiningsih, 2022). Time saving of SFA could contribute to overcoming the issue on the number of personnel in each FMU. By reducing time-use by 67% compared to business as usual approach, implementing fire extinguishing using SFA would improve time allocation for human resources efficiently. The implementation of firefighting to extinguish forest and peat fire is a complex and multidimensional issues that require synergy and collaborative efforts among stakeholders, technology intervention could improve the overall performance. Looking at the current performance based on local experiments in Central Kalimantan, it provides evidence on the advantage of SFA for extinguishing forest and peatland fire due to its advantages on small water consumption and shortened time-use compare to the business as usual practice of using water only.

Through the process of introducing the technology, capacity building and training and also dissemination of the product and research activities during the project period had elevated stakeholders' understanding of SFA. The highest response was about "no impact on natural environment," around 52.4%. Having experiences of repeated forest fires and the recovery process are influential on the individual expectation about the environmentally friendly technology. The second consideration is the performance on the ability to have a depth penetration to soil to prevent reignition of peat fire and less water consumption at around 47.6%. The penetration below the surface reduce the chance of reignition after several days, especially peat fire. The impact to the human is 42.9%, it is least priority of respondent. These findings confirm that the respondents understanding and knowledge about SFA is at a high level. There is no gap between the presence of a technology and the expectation from the society. The education during the project activities increases users' knowledge of what they can get and cannot get from the technology (Ozili, 2024).

Those above individual perceptions of the technology and perceived evaluation on the SFA's performance influence the acceptance of technology from potential users of SFA in central Kalimantan. It was observed through the high response on the interest and willingness to implement real tests about the performance of SFA at around 66.7% of respondents. The respondents also had the confidence to conduct performance tests by themselves, representing the ease-of-use of the technology. This finding explains how an individual accepts and uses a technology, starting by an introduction of technology and ending with stakeholders acceptance and willingness to use it (Davis, 1989). Through the questionnaire survey, we couldn't find the partial rejection or expression of "not interested in the SFA".

### Enabling environment for socio-technological transitions

Moving forward from the perceived evaluation about the multiple benefits of technology and intention to use, respondents were asked to respond on a question related to the dissemination of SFA for diffusion and local uptake by policymakers in Central Kalimantan. The top priority is the price of the product, around 52.4%. Information about retail price is important in order to convince the decision makers. During the interview survey, we didn't provide information about retail price of product and its potential cost-saving compare to aerial bombing (figure 6). From the perspective of respondents, price is sensitive issue. Providing additional information on cost and time saving potentials which led to the quantification of economic benefits may help to provide evidence-based for the decision-making process at local level. The efforts to increase cost performance and reduce retail price will increase the diffusion rate and uptake at local level.

A second important aspect is registration to the national portal for the electric catalogue (e-Katalog) around 38.1%. The e-Katalog is an Indonesian-language online procurement platform managed by the Government of Indonesia (GOI) Goods and Services Procurement Policy Agency (LKPP), which allows public organizations and government institutions to purchase required technology, including soap-based firefighting agents. The government implemented a firefighting agent procurement process based on an electronic catalogue (e-catalogue) through the mechanism of e-purchasing. It was established to increase transparency and prevent corruption in public procurement. Manufacturer or their local agents can set their product prices in the sectoral e-Katalog. Under the new policy, price control to the manufacturer and market-based. Having the product listed in the e-katalog as the main entry point for e-procurement transaction means increasing probability of SFA to be accessed and purchased under the public procurement process. It removes barriers to organizational or institutional policies on the decision-making processes on purchasing SFA by government organizations or agencies (Muhammed et al., 2020). The implementation of this system will affect the uptake of technology at the local level. Combining the effort to produce SFA locally will increase the share of local content, which will increase the rank of technology. The national government already set a clear policy about products over the threshold of local content of technology will be highly recommended for the government procurement. It will increase the diffusion rate and uptake not only in central Kalimantan but across the country.

The third important aspect is additional information such as water saving and time saving, around 33.3 % respondents. During the interview survey, the questionnaire was distributed in parallel to the ongoing process of the onsite experiment in August 2024. Thus, it makes it difficult to provide additional supporting evidence on the performance of SFA and other environmental performance indicators to support an evidence-based policy process. It is consistent with previous indicators on the expectation of stakeholders on the minimum or no impact of SFA on the environment. The other two factors are supporting equipment 28.6% which is associated with the fact about limited capacity and infrastructure at the local level. The labelling national standard of Indonesian products will ensure the quality of product, however, it is least important from the viewpoint of respondents.

## Conclusion

Introducing an environmentally friendly soap-based firefighting agent (SFA) for extinguishing forest and peat fire requires a socio-technological transition process at a local level. The process includes knowledge transfer of new technology to improve the perceived evaluation of usefulness and perceived ease-of-use, diffusion of technology, and uptake in Central Kalimantan. Perceived evaluation was conducted to evaluate the interaction between potential users and the introduction of technology on environmentally friendly SFA for extinguishing forest fire in Central Kalimantan, Indonesia. Through the process of introducing the technology, capacity building and training and also dissemination of the product and research activities during the project period has elevated

stakeholder's understanding of SFA. There is no gap of expectation on what they can get and cannot get from the technology. The study also confirms the technology acceptance model of SFA for extinguishing forest and peatland fire in Central Kalimantan.

Socio-technological transitions need an enabling environment for diffusion and uptake at a local level. Although economic benefit is clear and quantitative, however, price scheme is sensitive and cost performance of product should be improved. One option is a localized product, manufacturing the soap within Indonesia. It will increase the local content of the product, which is useful to leverage the rank of technology in E-Katalog. It will increase adoption rate and uptake not only locally but also at a country level and ensure transparency of transaction process involving public procurement process. Finally, it helps to remove the barrier of local government agencies in decision-making process for procurement. Technology-inclusive system transitions supported by appropriate enabling conditions, including effective multi-level governance and institutional capacity, policy design, and implementation could generate benefits across different sectors at a local and national level.

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