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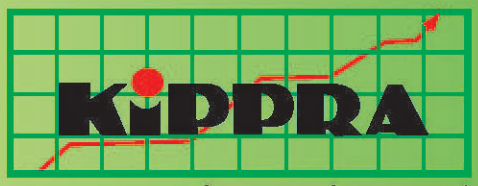

The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

Upscaling the Integration of Internet of Things in Tea Factories in Kenya

Eva Chebet Tangus and Kelins Randiek

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THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

YOUNG PROFESSIONALS (YPs) TRAINING PROGRAMME

Upscaling the Integration of Internet of Things in Tea Factories in Kenya

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Kenya Institute for Public Policy
Research and Analysis

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This paper is produced under the KIPPRA Young Professionals (YPs) programme. The programme targets young scholars from the public and private sector, who undertake an intensive one-year course on public policy research and analysis, and during which they write a research paper on a selected public policy issue, with supervision from senior researchers at the Institute.

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Abstract

The study envisions a future tea factory where every leaf is harvested at its peak for optimal freshness and flavour. By 2040, IoT integration in tea factories will revolutionize the process from plucking to packaging. Real-time data and automated machines will optimize harvest timing and maintain leaf traceability and freshness. IoT-enabled machinery will ensure precise processing conditions, enhancing flavour and consistency. Smart sorting and grading systems will boost efficiency, while IoT-equipped tasting panels and tracking systems will ensure quality and authenticity. This study explores these futures and assesses challenges and opportunities in each plausible future using the Foresight methodology.

The findings of the study show that consumer preferences and political relationships are pivotal drivers of the adoption of IoT in tea factories, fuelling the demand for smarter tea processing methods. Further, the modernization of tea production processes is amplified by awareness and economic trends, which emphasize the importance of tea quality, safety, and sustainability in tea processing. Awareness of the benefits and costs are guiding IoT integration in deciding on tea processes within tea factories. Lastly, connectivity to IoT infrastructure and social expectations influence the feasibility and adoption of IoT technology in tea processing. Understanding the interconnectedness of the drivers of change is crucial in IoT implementation.

To drive future innovation and growth in the tea industry, the government can enact tailored strategies based on scenarios and the key drivers of change. To start with, the government can enhance diplomatic ties to expand trade opportunities and regulatory support at the same time improve infrastructure to ensure seamless IoT operations. Further, the government can establish clear and comprehensive regulations and initiate pilot projects to provide practical insights for broader adoption. Public awareness campaigns are also crucial to foster stakeholder acceptance and demand for tech-integrated tea products. Collectively, these measures will enhance the industry's competitiveness, sustainability, and economic growth benefiting all stakeholders.

Abbreviations and Acronyms

IoT Internet of Things
RFID Radio Frequency Identification
ROI Return on Investment
KTDA Kenya Tea Development Agency

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1. Introduction

The term “Internet of Things” was coined by Kevin Ashton, a British technology pioneer, in 1999 while working at Procter and Gamble. Ashton envisioned a system where everyday objects could be connected to the Internet, enabling them to communicate and share information (Ashton, 2009). The evolution of the Internet of Things (IoT) in manufacturing has rapidly progressed over the years, witnessing a notable transformation in industrial processes (Wang et al., 2021). The key potency of the IoT concept is the strong effect it would have on numerous diverse sides of daily life and future users’ behaviour (Al Shahrani et al., 2023) . Another aspect of the revolution of the IoT is interconnecting humans at any time or from any place and enabling them to communicate with objects through communication networks. This is the underlying vision of the IoT. Figure 1.1 illustrates the features of the IoT. The advent of the Internet of Things (IoT) marks a pivotal moment in the evolution of manufacturing, laying the groundwork for a transformative era in operational processes (World Economic Forum - WEF, 2020,).

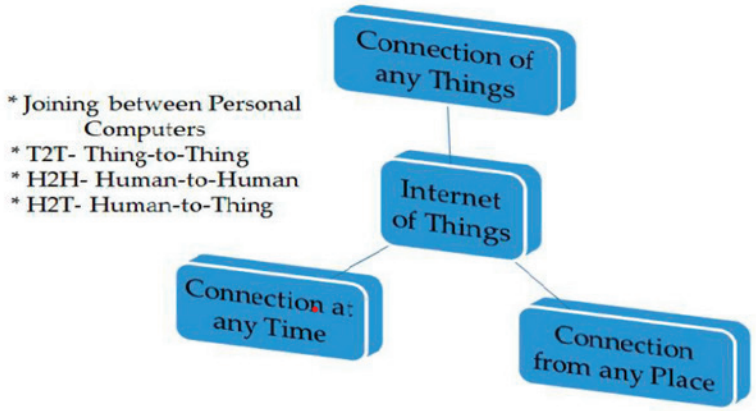
Positioned at the forefront of technological innovation, IoT seamlessly integrates the physical and digital realms, crafting an intelligent industrial landscape that goes beyond mere connectivity to revolutionize the tea factory by improving efficiency, reducing costs, and increasing productivity (Morchid, El Alami, Raezah, and Sabbar, 2023). Purpose-built for industries, IoT orchestrates a network of interconnected devices, sensors, and machines, all imbued with cutting-edge technologies (Soori et al., 2023). In tea factories, operational efficiency emerges as a central theme justifying the role of IoT in processing. Embracing IoT integration in tea processing from plucking to packaging heralds a new era of efficiency, quality, and innovation. Automated plucking machines, synchronized with real-time data on atmospheric pressure, temperature, and humidity, times the harvest yielding a bounty of premium leaves. These leaves are tracked by smart devices from field to factory, ensuring freshness and traceability. Within processing stages, smart machinery orchestrates each step with precision, meticulously adhering to optimal temperature and humidity ranges: 20°C to 25°C and 60 per cent to 70 per cent during rolling, 25°C to 30°C and 70per cent to 80per cent during fermentation, and 35°C to 40°C and 50per cent to 60per cent during drying (Dhanaraju et al., 2022). This ensures quality and flavour development.

Real-time data analysis and predictive maintenance algorithms work tirelessly, minimizing downtime and safeguarding quality standards. In sorting and grading, IoT sensors, keenly attuned to leaf attributes, ensure accuracy, while automated sorting machines, guided by predetermined quality criteria, enhance efficiency and consistency (Kimutai et al., 2021). Smart tasting panels, equipped with IoT devices, discern nuances of flavour and aroma, utilizing data insights to adapt processing techniques to evolving market demands and consumer preferences. Throughout the supply chain, IoT-enabled tracking systems vigilantly monitor tea shipments, while smart packaging adorned with RFID tags provides end-to-end traceability, ensuring authenticity and quality control. Workers too when

armed with wearable IoT devices, receive real-time feedback, fostering a culture of connectivity and empowerment (Kimutai et al., 2021)

As industries embark on the adoption of IoT applications, the foresight studies gain significance in comprehending the broader impact on business outcomes and so do tea factories. The synergy between theoretical research and practical applications becomes evident, emphasizing the substantial influence of IoT on tea processing and the broader business landscape. Engaging in foresight studies becomes imperative for businesses aiming to remain agile, competitive, and responsive to the demands of the evolving digital age (Lu, Wang, and Liu, 2017). By analyzing drivers of change, businesses can strategically plan their operations, investments, and innovations to capitalize on opportunities and mitigate risks. Moreover, foresight studies enable companies to develop robust strategies that are adaptable to various future scenarios, helping them navigate uncertainty with confidence (Tully, n.d.).

Figure 1.1: Features of IoT



Source: (Salih et al., 2022)

The primary research problem lies in the fundamental challenge of traditional industrial systems operating in isolated and non-interconnected silos. The absence of seamless communication and integration among various components of tea industrial processes hampers overall efficiency and limits the potential for advanced data-driven decision-making. This fragmentation of systems obstructs the realization of the transformative benefits promised by the Industrial IoT. The inefficiency in the existing industrial landscape hinders the effective integration of IoT technologies. Addressing this root cause is essential for unlocking the full potential of IoT in the implementation of smart tea industries, necessitating a comprehensive understanding of the importance of bridging communication gaps and integrating disparate components into a cohesive, interconnected industrial ecosystem.

Examining the foresight of IoT integration in smart tea industries provides valuable insights into future trends and potential opportunities. Empirical studies

employing foresight methodologies, such as scenario planning and trend analysis, shed light on the anticipated trajectory of IoT adoption in tea manufacturing. These studies forecast advancements in IoT-enabled crop monitoring, predictive maintenance, and supply chain optimization, leading to increased efficiency, sustainability, and competitiveness in the smart tea factories (Kim et al., 2020; Samadi and Tavakkoli-Moghaddam, n.d.). By examining foresight scenarios, researchers can provide evidence-based recommendations for policymakers and industry stakeholders to navigate the evolving landscape of IoT integration in tea factories.

Despite the valuable insights provided by empirical research into the foresight of IoT integration in smart tea industries, there remains a notable gap in the literature. Specifically, there is a need for comprehensive and focused studies that examine the intricacies of IoT adoption and its implications within the unique context of tea manufacturing. By addressing this gap, this study can offer tailored recommendations and solutions to overcome the challenges identified in specific scenarios, thereby facilitating the successful implementation of IoT technologies in tea factories. Conducting a foresight study on the integration of IoT in tea factories is justified to navigate the rapidly evolving technological landscape and strategically position the industry for future success. It also helps tea manufacturers assess the economic feasibility of IoT adoption, anticipate regulatory changes, and prepare the workforce for technological shifts. A foresight study on IoT in tea manufacturing is essential for informed decision-making, ensuring that the industry remains innovative, resilient, and responsive to the demands of a smart and interconnected future.

Further, IoT integration in smart tea factories significantly aids compliance with various regulations. For data privacy and security, IoT devices implement advanced encryption methods and secure data transmission protocols, ensuring adherence to the General Data Protection Regulation (GDPR) by protecting data both in transit and at rest from unauthorized access. In terms of food safety standards, IoT sensors provide real-time monitoring of critical control points, ensuring compliance with Hazard Analysis and Critical Control Points (HACCP) and Good Manufacturing Practices (GMP) standards. For instance, temperature and humidity sensors maintain optimal conditions during tea processing, reducing contamination risks and ensuring product integrity. Environmental regulations are addressed through IoT systems that optimize resource management by monitoring energy consumption and waste production. These smart devices can adjust processes automatically to minimize emissions and waste, aligning with environmental protocols aimed at reducing ecological footprints.

Compliance with labour laws is facilitated by wearable IoT devices that monitor working hours and conditions, ensuring adherence to occupational safety regulations by tracking worker health and safety metrics and alerting management to potential violations. Intellectual property rights are safeguarded as IoT systems continuously monitor and control access to proprietary technologies, ensuring that only authorized personnel handle critical data and processes, thus protecting innovations and maintaining competitive advantage. Additionally, IoT-enabled traceability systems track tea leaves from the field to the final product, providing

detailed records that ensure compliance with quality and safety standards. This transparency is crucial for audits and regulatory checks, demonstrating adherence to established guidelines. By integrating IoT technologies, smart tea factories not only enhance operational efficiency but also ensure strict compliance with a wide range of regulatory requirements, safeguarding both the business and its consumers.

The study examined the plausible future of IoT integration in tea factories and the challenges and opportunities in each plausible future regarding IoT integration in tea factories. Further, the study aims to develop comprehensive policy recommendations that address the regulatory, infrastructural, and economic considerations necessary for successful IoT adoption, ensuring that the tea industry can sustainably advance in a technology-driven era. These objectives are driven by the need to strategically position the tea. industry to navigate the rapidly evolving technological landscape and leverage the full potential of IoT for enhancing operational efficiency, product quality, and sustainability.

Following this introduction, the next section will delve into the current developments of IoT integration in tea factories in Kenya. This section will provide a detailed review of the ongoing initiatives, technological advancements, and the impact these integrations have had on the tea industry in Kenya. Through this exploration, the study aims to provide a comprehensive understanding of the present state of IoT adoption and its implications for the future of tea manufacturing in Kenya.

2. Development of IoT Integration in Smart Tea Factories in Kenya

The integration of the IoT in tea factories in Kenya is an emerging trend that promises to revolutionize the industry. Although still in its early stages, the partial adoption of IoT is gaining momentum as more factories begin to recognize its benefits. Awareness among tea factory managers and stakeholders is increasing, spurred by a prototype project that was done in the Sisibo Tea Factory. Furthering the progress in IoT integration, a notable IoT innovation in the tea fermentation process has been introduced, which represents a significant advancement in precision agriculture and smart factory operations (Kimutai et al., 2021). The IoT model for the fermentation process leverages a network of sensors strategically placed within fermentation units. These sensors continuously monitor critical parameters such as temperature, humidity, and oxygen levels, which are essential for achieving the desired quality of tea. The data collected by these sensors is transmitted in real-time to a centralized cloud-based platform, where it is analyzed using advanced algorithms and machine learning techniques.

IoT is currently used in pilot projects in regions such as Kericho and Nandi Hills. Multinational tea companies such as Unilever Tea Kenya Ltd are utilizing IoT for irrigation management, and monitoring pests and diseases to ensure quality control. Additionally, they integrate IoT technology during the fermentation stage of tea processing. It only participates in Private-public partnerships with KTDA in training smallholder farmers in sustainable tea cultivation.

whose output encourages wider adoption of IoT in tea farming. These projects demonstrate tangible benefits such as improved yield, quality consistency, and operational efficiency. However, there are still barriers to widespread adoption, including high initial investment costs and the need for skilled personnel to manage IoT systems. Data security and privacy concerns also need to be addressed with robust cybersecurity measures.

Looking ahead, advancements in IoT technology and decreasing costs of devices are expected to accelerate adoption in Kenyan tea factories. Prospects include more integrated and sophisticated IoT ecosystems that leverage artificial intelligence and machine learning for advanced data analytics and decision-making. As IoT integration continues to progress, it is set to transform the Kenyan tea factory, making it more efficient, sustainable, and competitive on a global scale.

In Kenya, the introduction of IoT is supported by various frameworks including the ICT policy framework of 2019. These efforts aim to harness IoT for sectors such as agriculture, healthcare, and logistics, promising enhanced efficiency and innovation. However, significant gaps remain, including infrastructure challenges in rural areas affecting device connectivity and power supply reliability. Regulatory frameworks need further development to address standards for data privacy, security, and interoperability specific to IoT. There is also a crucial need for more skilled professionals, increased awareness, and adequate funding to foster widespread adoption and mitigate cybersecurity risks.

3. Literature Review

3.1 Theoretical Framework

The study utilized systems theory. System theory, initiated in the mid-20th century, particularly by Ludwig von Bertalanffy, emphasizes the interconnectedness and interdependence of elements within complex systems (Salih et al., 2022). It posits that systems, whether biological, social, or organizational, are composed of interconnected components that interact with each other and their environment. Key concepts such as emergence, feedback, hierarchy, and openness are central to system theory, highlighting the holistic view of systems and their dynamic nature (Sterman, 2014) Applying Systems Theory to the study of the IoT in Kenya's smart industries provides a comprehensive framework for grasping interconnected dynamics. IoT integration, viewed through the Systems Theory lens, emphasizes component interdependence in the industrial ecosystem. Ludwig von Bertalanffy 1968 highlighted system interrelatedness wherein changes in one part affect the entire system.

Just as system theory emphasizes the interconnectedness and interdependence of elements within a system, IoT integration in smart tea factories involves the integration of various interconnected components such as sensors, actuators, data analytics systems, and control mechanisms to optimize tea production processes (Zhou et al., 2021). System theory highlights the importance of viewing the smart tea factory as a holistic system, where each component interacts with others and contributes to the overall functioning and performance of the system.

Moreover, system theory underscores the dynamic nature of systems, where feedback loops play a crucial role in system adaptation and improvement. The relevance of feedback loops in Systems theory, championed by theorists like Gregory Bateson is crucial. Real-time data feedback enables continuous monitoring, identifying inefficiencies, and facilitating adaptive responses, enhancing tea factories' resilience to dynamic economic and environmental factors. In the context of tea factories, feedback mechanisms enabled by IoT technologies allow for continuous monitoring and adjustment of production processes based on real-time data (Sony and Naik, 2020). For instance, if sensor data indicates a deviation from desired conditions, automated control systems can trigger adjustments to maintain optimal parameters, thereby enhancing tea quality and productivity.

Furthermore, system theory highlights the importance of considering the broader context in which smart tea factories operate, including environmental factors, market dynamics, and regulatory requirements (Verdouw et al., 2016). By adopting a systems perspective, smart tea factories can holistically integrate IoT technologies, optimizing not only production processes but also resource utilization, environmental sustainability, and overall performance. Leveraging system theory in IoT integration enables smart tea factories to maximize efficiency, quality, and sustainability while navigating the complexities of modern tea production.

3.2 Empirical review

From the empirical review done by the authors, findings show some tea farmers have embraced IoT for aspects like crop monitoring and quality control. Notably, a prototype IoT application has been applied in tea processing in the Sisibo Tea Factory (Kimutai et al., 2021). This section reviews factors influencing the adoption of IoT: Social, technological, economic, environmental, and political factors. This review is to help derive the drivers of change which are key for the scenario planning approach.

3.2.1 Social factors

Consumer preferences have undergone a significant evolution, with a notable surge in demand for sustainable and tech-integrated products in recent years (Sänn, 2017). This transformation is fuelled by a heightened consciousness surrounding environmental concerns and a growing insistence on transparency within supply chains (Dangelico and Pontrandolfo, 2015). Today's consumers actively seek out products that not only demonstrate eco-friendly credentials but also boast advanced technological features (Lee and Shin, 2018). The increasing awareness of sustainability issues has led to a shift in consumer behaviour, with individuals now prioritizing products that align with their values and contribute positively to environmental conservation efforts. Moreover, the desire for transparency reflects a broader demand for accountability and ethical business practices, driving tea factories to adopt more sustainable and transparent approaches to production and distribution. This trend underscores a fundamental shift in consumer expectations, emphasizing the need for businesses to prioritize sustainability and innovation in product development to remain competitive in the market.

The growing interest in the health benefits associated with tea consumption represents a significant driver of change in the tea factory, particularly concerning the integration of IoT technology in tea factories. Research has extensively documented the potential health-promoting properties of tea, including its antioxidant, anti-inflammatory, and neuroprotective effects (Chacko et al., 2010). Regular tea consumption may contribute to reduced risk factors for chronic diseases such as cardiovascular disease, cancer, and neurodegenerative disorders (Grosso et al., 2017). Additionally, tea such as green tea has been linked to weight management and metabolic health improvements (van Baak and Mariman, 2019). As consumers become increasingly health-conscious and seek out functional beverages, there's a rising demand for teas that offer not only exceptional taste but also tangible health benefits. This growing interest in tea's health attributes presents an opportunity for tea factories to leverage IoT technology to enhance production processes and product quality. By integrating IoT devices for real-time monitoring of cultivation practices, quality control, and supply chain management, smart tea factories can ensure the production of teas that meet stringent health and safety standards while also meeting the evolving preferences of health-conscious consumers.

Social expectations regarding fair labour practices in tea processing are also significant drivers of change for the integration of IoT in tea factories. Over recent years, there has been mounting concern about labour conditions in tea-producing regions, including issues such as child labour, poor wages, and unsafe working conditions (Wringe et al., 2018). Consumers and advocacy groups increasingly demand transparency and accountability throughout the tea supply chain, insisting on fair treatment and decent working conditions for tea workers (Wang et al., 2021). This heightened awareness has placed pressure on tea factories to adopt sustainable and ethical practices, including the implementation of fair labour standards and certification programmes (Tea_HL_EN, n.d.). In response to these social expectations, tea factories are turning to IoT technology to monitor and ensure compliance with fair labour practices. IoT devices enable real-time tracking of labour conditions, including worker hours, wages, and workplace safety measures (Jagadeesan et al., 2021). By integrating IoT solutions into their operations, tea factories can demonstrate their commitment to fair labour practices, improve transparency, and enhance accountability throughout the supply chain.

Across various cultures worldwide, tea holds significant social, cultural, and ritualistic importance, shaping consumption patterns and preferences (Tong et al., 2021) Traditional tea ceremonies, such as the Japanese tea ceremony or Chinese Gongfu tea ceremony, exemplify the reverence and cultural significance attributed to tea consumption. Moreover, tea is deeply embedded in social interactions, serving as a symbol of hospitality, friendship, and cultural identity (Verma, 2013). Quality, craftsmanship, and traditional production methods are given priority by tea producers because of the shifting cultural perspectives that fuel a growing demand for authenticity and legacy in tea products (Bhargava et al., 2019). The integration of IoT technology in tea factories is in line with the cultural emphasis on authenticity and tradition, as it allows producers to preserve and improve traditional tea-making processes while guaranteeing consistency, quality, and traceability (Verma, 2013). By leveraging IoT devices for real-time monitoring of cultivation, processing, and packaging, tea factories can uphold cultural traditions while meeting modern consumer expectations for quality and authenticity in tea products. Thus, cultural perceptions and traditions related to tea consumption play a pivotal role in shaping the trajectory of IoT integration in smart tea factories, bridging heritage with innovation to meet the demands of culturally diverse and discerning consumers.

3.2.2 Technological factors

The agricultural sector has witnessed a surge in innovative technology applications aimed at optimizing farming practices, enhancing productivity, and ensuring sustainability (Thilakarathne et al., 2021). These advancements include sensor technologies, data analytics platforms, and automation systems that enable real-time monitoring and management of agricultural operations (Dibal et al., 2022). In the context of tea production, IoT technologies offer immense potential for improving processing techniques, resource management, and quality

control throughout the supply chain. Smart sensors deployed in tea plantations can monitor crucial parameters such as soil moisture, temperature, and humidity, allowing for precision irrigation and fertilization (Farooq et al., 2020). Additionally, IoT-enabled platforms facilitate predictive analytics and decision support systems, enabling tea producers to optimize harvest schedules, detect crop diseases early, and mitigate environmental risks (Durga Sai Prasad et al., 2023). As IoT technologies continue to evolve rapidly, tea factories can leverage these innovations to enhance operational efficiency, reduce costs, and ensure the production of high-quality teas that meet consumer expectations. Thus, the rapid developments in IoT technologies for production catalyze the integration of IoT in tea factories, paving the way for more sustainable, efficient, and technologically advanced tea production systems.

The availability and speed of connectivity infrastructure for IoT (Internet of Things) have emerged as crucial drivers of change in the integration of IoT in smart tea factories. In recent years, there has been a significant expansion in the availability of high-speed Internet connectivity, including broadband and 5G networks, particularly in rural areas where tea plantations are often located (Deng, 2023). This increased connectivity offers smart tea factories the opportunity to deploy IoT devices for real-time monitoring and control of various aspects of tea production, from crop health monitoring to machinery operation. With fast and reliable Internet access, tea producers can access and analyze data collected by IoT sensors instantaneously, enabling timely decision-making and optimization of production processes (Gubbi et al., n.d.). Furthermore, high-speed connectivity facilitates seamless integration between different IoT devices and systems, enhancing interoperability and data exchange within smart tea factories (Gubbi et al., 2013). As a result, tea producers can leverage IoT technology to improve efficiency, reduce operational costs, and ensure product quality while adapting to dynamic market demands. Therefore, the availability and speed of connectivity infrastructure for IoT play a pivotal role in driving the adoption and integration of IoT in tea factories, empowering tea processors to harness the full potential of digital technologies for sustainable and technologically advanced tea processing.

3.2.3 Economical factors

Economic trends influencing tea prices and market demand play a crucial role in driving the integration of IoT in tea factories. The global tea market is subject to various economic factors, including supply and demand dynamics, currency fluctuations, and changes in consumer preferences (Nunes and Bennett, 2019). Fluctuations in tea prices can significantly impact the profitability of tea producers and the viability of tea factories. Moreover, shifts in market demand, such as an increasing preference for premium quality or sustainably sourced teas, require tea producers to adapt their production processes accordingly. In response to these economic trends, tea factories are increasingly turning to IoT solutions to optimize production, improve efficiency, and enhance product quality. IoT-enabled sensors can monitor various aspects of tea production, from cultivation and harvesting to

processing and packaging, allowing for real-time data collection and analysis to optimize resource allocation and minimize costs (Gao et al., 2021). Additionally, IoT-based predictive analytics can help tea producers anticipate market trends and consumer preferences, enabling agile decision-making and strategic planning to meet changing market demands (Sun et al., 2021). By integrating IoT technology into their operations, smart tea factories can better navigate economic challenges, maintain competitiveness, and capitalize on growth opportunities in the dynamic tea industry.

The affordability and cost-effectiveness of integrating IoT technologies in tea factories are pivotal factors shaping the adoption of smart manufacturing practices (Shah et al., 2024).Tea factory owners weigh the initial investment costs against the expected benefits and ongoing operational expenses (Jones and Brown, 2019). They seek assurance that the implementation of IoT will deliver tangible returns in terms of improved productivity, quality control, energy efficiency, and waste reduction (Lee, 2018). Scalability and flexibility are also paramount, with preference given to solutions that allow for gradual expansion and adaptability to evolving needs (Johnson, 2021). Market competition and the availability of cost-effective IoT solutions further influence decision-making, as producers navigate toward solutions that strike a balance between affordability and functionality (Chen and Wang, 2020). Affordability plays a significant role in determining the pace and extent of IoT integration in tea factories, with solutions offering clear ROI and long-term value likely to drive broader adoption and propel the industry toward smart manufacturing environments (Gupta et al., 2019)

3.2.4 Environmental factors

Climate change impacts in Kenya can significantly influence the integration of IoT in tea factories. With weather variability posing challenges to tea cultivation and production, IoT technology becomes vital for monitoring and adjusting processing parameters in real-time (Shah et al., 2024). Water scarcity exacerbated by climate change necessitates IoT solutions to optimize water usage through monitoring and recycling systems. Additionally, the emergence of new pest and disease pressures demands IoT-based monitoring for early detection and targeted intervention. Energy efficiency measures, crucial for climate change mitigation, are facilitated by IoT applications that monitor and control equipment while integrating renewable energy sources. Moreover, climate change-related disruptions in the supply chain highlight the importance of IoT-enabled logistics and supply chain management systems for maintaining resilience and efficiency in tea processing operations. Therefore, the integration of IoT in tea factories in Kenya becomes not only a means of enhancing operational efficiency but also a critical strategy for adapting to and mitigating the impacts of climate change on the tea factories.

Sustainability is increasingly linked to that of a circular economy model which promotes reparability, durability, and recyclability. This aims to minimize waste through reuse, repair, refurbishment, and recycling of existing materials and products focusing on designs that last over time (Patwa et al., 2021). Incorporating

IoT for smart waste management systems in manufacturing will be able to identify waste materials before the separation process reducing costs related to the waste separation process from hazardous materials, and enhancing the efficient use of resources such as water and energy in tea processing. There has been a growing demand for environmental awareness to mitigate the rate of environmental degradation and ensure sustainable development of the tea sector to mitigate the rate of environmental degradation.

3.2.5 Political factors

Legislations and Regulations are key in IoT integration. IoT integration in smart tea factories may impact and enforce the legal framework of general agricultural policies as spelled out in the laws of Kenya, Agriculture Act Chapter 318. The laws governing tea are the Tea Act Chapter 343 and the Kenya Tea Development Authority Order to control and regulate smallholder tea. With policy reforms toward liberalized markets, some modifications have been made but they have not yet been done comprehensively. Compliance with local and international regulations in tea production aids in regulating the tea factories for effectiveness in compliance that will help address the challenges and maximize opportunities in the integration of IOT in tea factories. The Tea Board of Kenya should regulate the industry, as stipulated in the Tea Act (CAP 343), licensing growers, manufacturing, and marketing agencies should be done away with, thus allowing the board to deal only with registration, monitoring, and ensuring a level playing ground for all.

The relationship between political dynamics and international tea trade significantly influences the integration of IoT in tea factories. Political stability within tea-producing and consuming nations creates an environment conducive to technological innovation and investment (Islam et al., 2021). When countries maintain positive diplomatic ties and engage in mutually beneficial trade agreements, it fosters confidence among investors and industry stakeholders, encouraging them to explore and adopt advanced technologies like IoT in tea production and processing. Favourable political relations not only attract investments but also provide a supportive regulatory framework that facilitates the implementation of IoT solutions (Oes et al., 2023). For instance, governments may offer incentives or subsidies to promote the adoption of smart technologies in the agricultural sector, including tea farming and processing.

Table 3.1: Drivers of change from literature review

STEEP analysis	Drivers of change	Authors
Social	Changing preferences towards sustainable and tech-integrated products	Patwa et al., 2021
	Growing interest in health benefits associated with tea consumption	Chacko et al., 2010; Grosso et al., 2017; van Baak and Mariman, 2019
	Social expectations regarding fair labour practices in tea processing	Tea_HL_EN, n.d.; Wang et al., 2021
	Levels of awareness and education about IoT and its benefits in tea processing	Mohamad Nor et al., 2018
Technological	Rapid developments in IoT technologies	Durga Sai Prasad et al., 2023; Farooq et al., 2020
	Availability and speed of connectivity infrastructure for IoT	Deng, 2023; Gubbi et al., n.d.
Economic	Economic trends influencing tea prices and market demand	Bennett et al., 2013
	Affordability and cost-effectiveness of implementing IoT in tea factories	Shaik Mohamed Sayed et al., 2023; Shah et al., 2024
Environmental	Effects of climate change on tea cultivation and production	Shah et al., 2024
	Sustainable and environmentally friendly tea production	Patwa et al., 2021
Political	Political relationships affecting international tea trade	Islam et al., 2021; Oes et al., 2023
	Compliance with local and international regulations in tea production	Dhanaraju et al., 2022

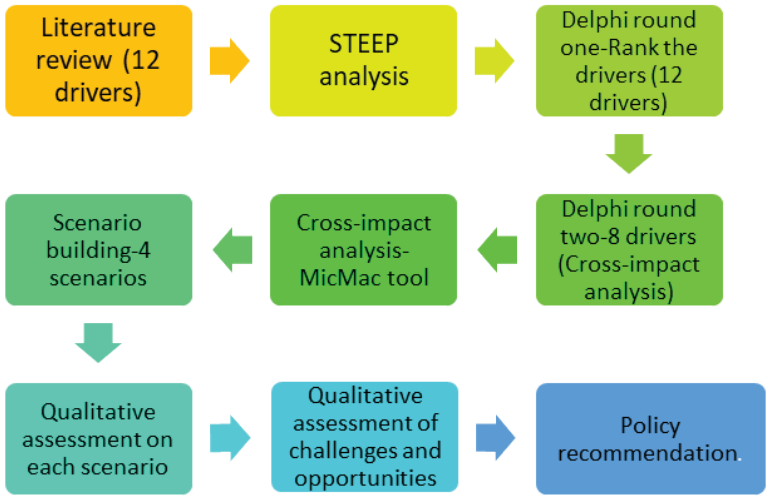
Sources: Authors' compilation

4. Methodology

The study utilized foresight capability methodology, integrating primary data (expert interviews) and secondary data (literature, reports) for comprehensive trend analysis and scenario planning, informing strategic recommendations. The sampling design employed in selecting the experts is a combination of purposive and snowball sampling. This approach allows for the strategic selection of experts who are best suited to provide relevant and rich information for the study, as well as the expansion of the sample through participant referrals. The study had three objectives. To answer the first objective, build future scenarios, the authors did a comprehensive literature review encompassing academic sources, industry reports and journals, focusing on IoT integration in manufacturing processes to identify factors influencing IoT integration, particularly tea production.

From the review, twelve drivers of change were identified from which the authors performed a STEEP analysis to group the drivers of change into Social, technological, economic, environmental, and political factors as shown in Figure 3.1. Subsequently, expert interviews were conducted with key stakeholders in the tea industry including tea manufacturers, tea farmers, consumers, IoT technology providers regulatory authorities, supply chain partners, and research/ policy makers, to rate the drivers of change that were identified through the literature review (Table 4.1). The responses obtained from the first round Delphi questionnaire were analyzed and the eight drivers that topped on their influence on IoT integration were picked as shown in figure 5.1. The Eight key drivers were then used to inform the second Delphi questionnaire for cross-impact analysis, which evaluates the impact of one driver on the other. Rounds one and two Delphi questionnaires were administered to 45 experts and responses are shown in Table 4.1. The process is presented in Figure 4.1.

Figure 4.1 Analytical framework



Source: Authors' compilation

Table 4.2: Respondent's distribution

Expert category	Pre-determined respondents	Round one respondents	Round two respondents
Tea manufacturer	7	5	5
IoT service provider	8	8	8
Tea farmer	5	4	4
Regulatory authority	5	3	3
Consumer	10	10	9
Supply chain partner	5	3	3
Researcher/policy maker	5	5	5
Total	**45**	**38**	**37**

Source: Authors' compilation

The cross-impact method was originally developed by Gordon and Helmer in 1966 and since then it has been widely. Cross-impact analysis serves as a valuable method for comprehensively evaluating the intricate relationships between variables within a system, facilitating a deeper understanding of their potential impacts on one another. By constructing a cross-impact matrix and systematically assessing the interactions between variables, decision-makers gain insights into the complex dynamics at play. This method enables the identification of critical factors, the exploration of various scenarios, and the development of robust strategies in the face of uncertainty. Kuru (2015) emphasized the significance of cross-impact analysis in strategic planning and risk management, highlighting its utility in anticipating future developments and informing proactive decision-making. Consequently, through its structured approach to analyzing interdependencies, cross-impact analysis offers a powerful tool for navigating complexity and enhancing organizational resilience (Kuru, 2015).

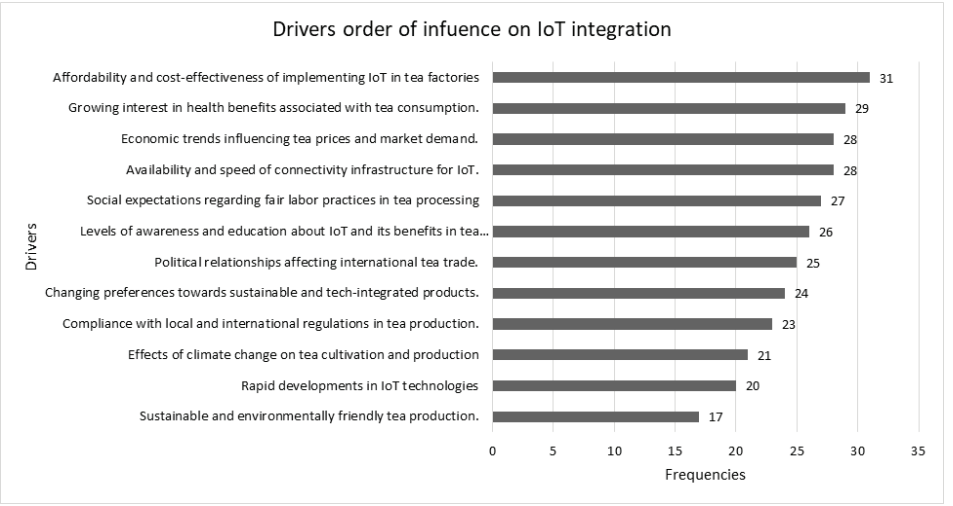
The results obtained from the second round Delphi questionnaire were analyzed and a cross-impact matrix resulted. This was subjected to cross-impact analysis using the MICMAC tool to map the variables in different quadrants to aid the identification of driving forces. These driving forces serve as the foundation for scenario development, which involves crafting four distinct narratives depicting potential futures for IoT integration in smart tea factories. Following this, a qualitative assessment of each scenario was used to answer the second objective. This uncovers a spectrum of challenges and opportunities associated with IoT integration in smart tea factories. The assessment aims to provide actionable insights for stakeholders and entrepreneurs, guiding them in making informed decisions regarding technology adoption and implementation strategies. Finally, the third objective of policy recommendation was based on the key drivers of change and the scenarios that were developed.

5. Results and Discussion

5.1 Futures of IoT Integration in Tea Factories

The study utilized a comprehensive approach called the foresight capability approach to explore the future of IoT integration in tea factories. Initially, the authors identified 12 significant drivers through a literature review which informed the round one Delphi questionnaire which was administered to 45 experts including the IoT providers, tea manufacturers, consumers, supply chain partners, regulatory authorities, researchers/policy makers, and tea farmers. 38 insightful responses were received. To refine our analysis, we conducted a frequency analysis of the responses, determining the order of influence for each driver as shown in Figure 5.1. Subsequently, we selected the top eight (8) drivers as shown in the second column of key drivers of change in Table 5.1.

Figure 5.1: Results of Delphi round one questionnaire



Source: Authors' compilation

Table 5.1: Drivers of change, key drivers of change, and driving forces

Drivers of change (12)	Key drivers of change (8)	Driving forces (2)
Social • Changing preferences towards sustainable and tech-integrated products. • Growing interest in health benefits associated with tea consumption. • Social expectations regarding fair labour practices in tea production • Levels of awareness and education about IoT and its benefits in tea production	• Changing preferences towards sustainable and tech-integrated products • Availability and speed of connectivity infrastructure for IoT • Social expectations regarding fair labour practices in tea production • Growing interest in health benefits associated with tea consumption • Levels of awareness and education about IoT and its benefits in tea production • Economic trends influencing tea prices and market demand. • Affordability and cost-effectiveness of implementing IoT in tea factories • Political relationships affecting international tea trade	Consumer Demand for Sustainable and Tech-Integrated Products (Consumer preference) Political relationships affecting international tea trade. (Political relationship)
Technological • Rapid developments in IoT • Availability and speed of connectivity infrastructure for IoT		
Economic • Economic trends influencing tea prices and market demand • Affordability and cost-effectiveness of implementing IoT in tea factories		
Environmental • Effects of climate change on tea cultivation and production • Importance of sustainable and environmentally friendly tea production		
Political • Compliance with local and international regulations in tea production • Political relationships affecting international tea trade		

Source: Authors' compilation

For further analysis, the key drivers of change were used to inform the round two Delphi questionnaire which is solely the impact of key drivers on the other key drivers. Once again, we engaged the same pool of experts, receiving 37 valuable responses. The responses from round two are summarized in Table 5.2. To unravel the complex web of interrelationships among these drivers, the study subjected the responses to the MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée à un Classement) tool. This analytical framework facilitated a deeper understanding of how each driver influences and is influenced by others within the system. The results of the cross-impact analysis allowed us to map the drivers onto a matrix, revealing their positioning in distinct quadrants based on their impact and dependence as shown in Figure 5.2.

Table 5.2: Cross-impact matrix

	Changing preference	Health benefits	Social expectation	Awareness level	Infrastructure connectivity	Cost implication	Economic trends	Political relationship	Active sum/influence
Changing preference		3	2	2	1	1	3	0	**12**
Health benefits	2		1	0	1	2	3	1	**10**
Social expectation	0	1		1	0	1	1	2	**6**
Awareness level	1	2	1		1	1	2	0	**8**
Infrastructure connectivity	1	1	1	2		2	1	0	**8**
Cost implication	0	0	2	1	1		1	1	**6**
Economic trends	2	1	0	2	2	2		1	**10**
Political relationships	2	3	0	2	1	1	2		**11**
Passive Sum/ dependence	**8**	**11**	7	**10**	7	**10**	**13**	**5**	71

Source: Author's compilation

Long label	Short label
Changing preferences towards sustainable and tech-integrated tea products	Changing Preference
Growing interest in health benefits associated with tea consumption	Health benefits
Social expectations regarding fair labour practices in tea production	Social expectation
Levels of awareness and education about IoT and its benefits in tea processing	Awareness level
Availability and speed of connectivity infrastructure for IoT	Infrastructure connectivity
The cost implication of IoT integration	Cost implication
Economic trends influencing tea prices and market demand	Economic trends
Political relationships affecting international tea trade	Political relationship

0 - No impact

1 - Low impact

2 - Moderate/slight impact

3 - Strong impact

No impact: A value of 0 indicates that there is no perceived interaction or dependence between the two drivers of change being compared.

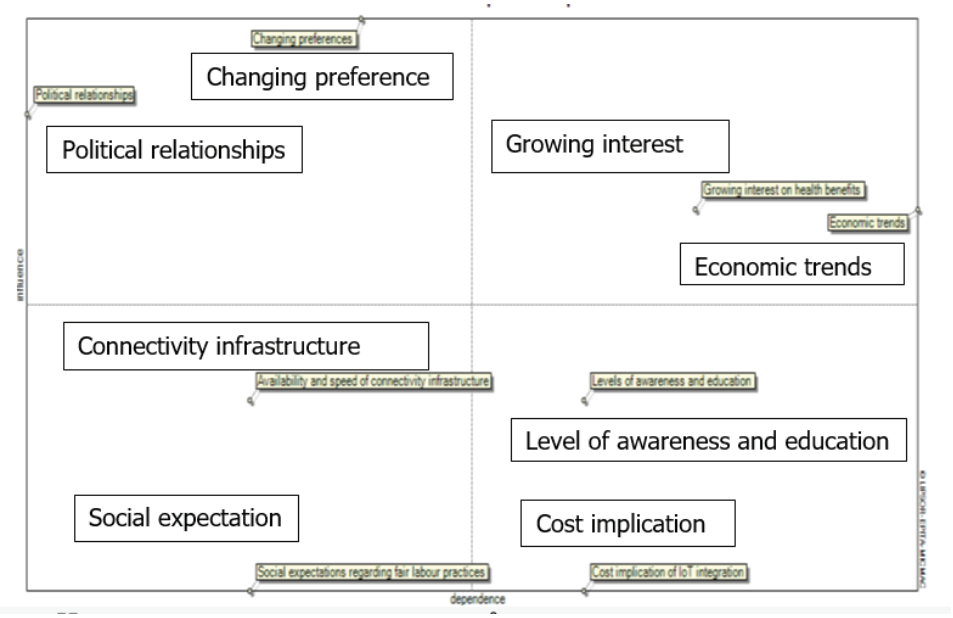
Low impact: A value of 1 suggests a dependent relationship between the drivers of change where changes in one trend may have some influence on the other, but it's relatively weak or indirect.

Slight impact: A value of 2 signifies a slight impact or moderate level of dependence between the drivers of change.

Strong impact: A value of 3 indicates a strong impact or high level of dependence between the drivers of change.

In Table 5.2, the row sum indicates the total impact that the element represented by that row has on all other elements. It indicates an idea of how influential that driver is on overall drivers. Column sum shows the total impact that all other elements have on the driver represented by that column. The results in the Table 5.2were then subjected to the MICMAC tool to derive the driving forces that are key in building scenarios. The outcome of the MicMac tool is the direct influence graph in Figure 5.2, which visually represents the relationships and influence between different factors or drivers affecting the integration of IoT in smart tea factories.

Figure 5.2: Matrix of direct influence/dependence map



Source: Author's compilation using MICMAC software

From the figure 5.4 relay factors (Quadrant 1) which includes growing interest in health benefits associated with tea consumption and economic trends influencing tea prices and market demand have high influence and high dependence in the smart tea factories. However, they are influenced by the driving forces in Quadrant 2 which include Political relationships affecting international tea trade, Changing preferences towards sustainable and tech-integrated tea products. Further, quadrant 3 are the autonomous factors which is social expectations regarding fair labour practices in tea production and availability and connectivity of IoT infrastructure. Lastly, quadrant 4 represents the results factors which is the outcome of the impact of the relay factor's influence in tea factories. From the map they include the Affordability and cost-effectiveness of implementing IoT in tea factories and levels of awareness and education about IoT and its benefits in tea processing. These factors have a direct impact on the integration of IoT in tea factories. For the tea factories to thrive, there needs to be a balanced consideration of these interconnected factors. Policies should focus on fostering international political relationships, encouraging sustainable and technology-driven consumer preferences, ensuring fair labour practices and enhanced IoT infrastructure. The outcome will drive the affordability and effectiveness of IoT integration in the tea industry, leading to more educated and aware stakeholders.

5.1.1 The interconnectedness between the variables in smart tea factories

Economic trends influencing tea prices and market demand

Influence by driving forces

Political relationships affecting economic trends through several channels. They dictate policy decisions such as trade agreements, tariffs, and diplomatic relations between tea-producing and consuming countries, which in turn shapes supply and demand dynamics, affecting economic IoT integration and even its trade volumes. These supports the finding by Arhin and Ishmael 2023. For example, trade restrictions or tariffs imposed by importing countries can impact the export volume and pricing of tea, thereby affecting overall IoT market demand and prices (Easterly et al., 1994). Further, it affects the currency exchange rates which in influence the IoT adoption rate.

Changing preferences towards tech-integrated tea products significantly impact economic trends by driving innovation and market expansion. This shift encourages tea companies to invest in R&D, leading to market differentiation and competitive advantages. IoT integration enhances productivity and efficiency in tea cultivation and processing through IoT and automation, reducing costs. It also shifts labour market demands towards more skilled workers. Consumer spending patterns favouring tech-enhanced products boost innovative sectors, while investments in supply chain and infrastructure influence economic trends. Environmentally, tech-integrated tea products promote sustainable practices, attracting eco-conscious consumers and driving the economy towards greener solutions involving IoT integration. Findings by Le and Vietsan 2021 suggest that this shift prompts regulatory and policy changes supporting technological adoption and consumer protection, shaping the broader economic landscape (Le et al., 2021). It's effect on market expansion for IoT drives the integration in tea factories.

Influence on result factors (cost implication and level of awareness and education)

Economic trends dynamics like inflation play a significant role in shaping the cost implications of implementing IoT in tea factories (Nistor and Zadobrischi, 2022).Economic trends affects IoT availability and the cost. High demand for IoT technologies can drive prices up due to intensified competition for limited resources. However, as more producers adopt IoT, economies of scale can kick in, leading to potential cost reductions as production volumes increase. Furthermore, economic incentives such as subsidies or favourable trade agreements can help alleviate financial barriers, making IoT adoption more accessible. Concurrently, economic trends influence the level of awareness and education about the benefits of IoT. In economies experiencing growth with robust market competition, companies are inclined to invest in marketing and educational campaigns to distinguish their products, thereby raising consumer awareness of IoT benefits and driving further demand and adoption. Additionally, collaborations between industry stakeholders, facilitated by favourable economic conditions, foster

shared knowledge and innovation, ultimately enriching overall awareness and understanding of IoT's potential benefits within the tea industry.

Growing interest in health benefits associated with tea consumption

Influence by driving forces

The political relationships affecting international tea trade and consumer preference towards tech-integrated tea products are significant driving forces that indirectly influence consumer interest in the health-related aspects of tea consumption. Political dynamics, including trade agreements and diplomatic relations, can impact the availability, pricing, and quality of tea products in the global market, thereby affecting consumer trust and confidence in the health attributes of tea. Further, Strong diplomatic ties often lead to cultural exchanges and joint public health initiatives that promote tea's health benefits. The growing interest in health benefits association with its consumption necessitates the tea factories to adopt IoT to cope with the demand. Concurrently, consumer preferences towards tech-integrated tea products contribute to IoT implementation that promotes accessibility of tea products that offer health benefits. IoT technological advancements in production techniques and quality control associated with these products can contribute to the preservation of tea's natural health attributes, aligning with consumer demand for health-conscious options. Together, these driving forces shape consumer perceptions and preferences regarding tea products with health-enhancing properties, influencing the overall interest in tea consumption for health-related reasons.

Influence on result factors

The growing interest in the health benefits of tea consumption significantly influences both the affordability and cost-effectiveness of implementing IoT in tea factories. As consumer demand for health-oriented tea products rises, tea companies are likely to prioritize investments in advanced quality control measures and production technologies, including IoT solutions, to ensure product integrity and compliance with regulatory standards. This heightened demand can lead to increased revenue, which in turn makes the implementation of IoT technologies more financially feasible. In addition, the consumer focus on health benefits can drive greater awareness and education about the importance of quality control and technological innovation in tea production. Tea companies may capitalize on this interest by promoting IoT adoption as a key component of their commitment to product quality, safety, and transparency. By aligning their technological advancements with consumer health trends, tea factories can enhance their market position while ensuring the cost-effectiveness of IoT implementation.

Result factors

Affordability and cost-effectiveness of implementing IoT in tea factories

The affordability and cost-effectiveness of implementing IoT (Internet of Things) technologies in tea factories is critical result factor shaping tea industry outcomes. IoT solutions offer benefits such as real-time monitoring, predictive maintenance, and automation, which can enhance operational efficiency, quality control,

and resource optimization in tea production. However, the initial investment costs, compatibility with existing infrastructure, and return on investment (ROI) considerations influence the adoption rate of IoT solutions among tea manufacturers. Companies that successfully demonstrate the tangible benefits and long-term cost savings of IoT implementation are likely to gain a competitive edge in the market.

Levels of awareness and education about IoT and its benefits in tea production

The levels of awareness and education about IoT and its benefits in tea production play a significant role in driving tea industry advancements. Many tea producers may be unaware of the potential applications and advantages of IoT technologies or may lack the technical expertise to implement them effectively. Therefore, initiatives aimed at raising awareness, providing training, and facilitating knowledge transfer regarding IoT solutions are crucial for accelerating adoption and fostering innovation in the tea industry. Collaborative efforts between industry stakeholders, technology providers, and educational institutions can help bridge the knowledge gap and empower tea producers to harness the full potential of IoT for sustainable growth.

Autonomous factors

Social expectations regarding fair labour practices

The factor is an autonomous factor, and it plays a pivotal role in shaping the dynamics of the tea industry. Stemming from broader societal values such as human rights, social justice, and sustainability, these expectations exert significant influence on the behaviour and decision-making of industry stakeholders, ranging from producers to consumers. Operating autonomously, they drive changes in tea factories practices and norms, irrespective of economic incentives or technological advancements. This translates into a heightened focus on transparency, accountability, and ethical sourcing throughout the supply chain. Failure to meet these expectations can result in reputational damage, consumer backlash, and regulatory scrutiny. Consequently, ethical labour practices have emerged as a competitive differentiator, with consumers increasingly favouring brands that demonstrate a commitment to fair treatment of workers and sustainable production methods.

Availability and speed of connectivity infrastructure

Infrastructure as an autonomous factor from MICMAC analysis indicates that the availability and speed of connectivity infrastructure are self-sufficient. They do not significantly depend on the other variables within the system of IoT integration in smart tea factories. The quality of connectivity infrastructure can either constrain or enable the effective deployment of IoT solutions in tea factories. High-speed, reliable Internet allows for real-time data collection, monitoring, and automation, enhancing operational efficiency and product quality. Conversely, inadequate infrastructure can limit the functionality and benefits of IoT systems.

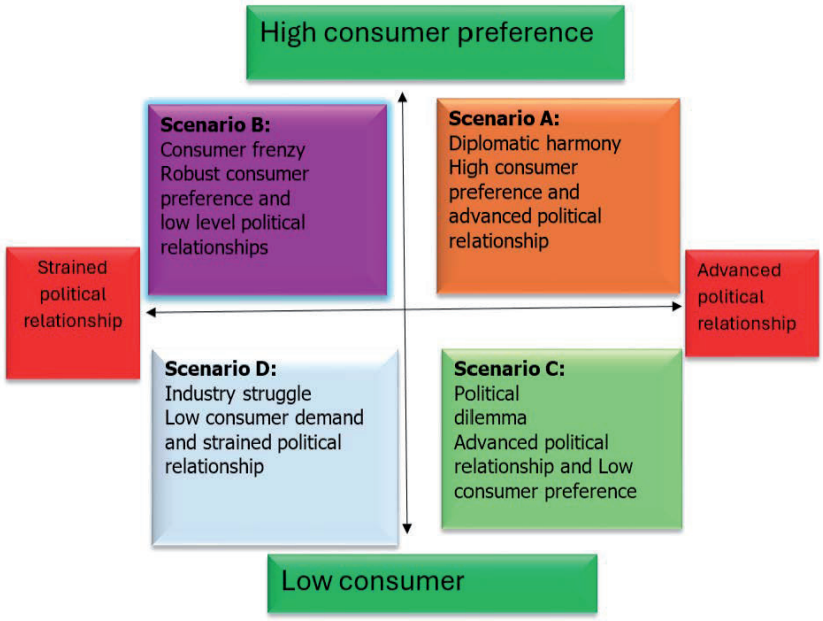
In a MICMAC analysis of outcome of the Delphi round two, the driving forces (consumer preferences and political relationships) initiate changes that are

amplified by relay factors (health benefits and economic trends). These, in turn, shape the result factors (awareness of IoT benefits and cost considerations), which determine the practical implementation of smart technologies. Autonomous factors (connectivity infrastructure and social expectations) independently influence the feasibility and acceptance of these changes within the tea factories. Understanding these relationships helps stakeholders strategically navigate the complexities of integrating technology and sustainability in tea production.

5.1.2 Scenario building

From the two driving forces obtained from MICMAC tool analysis, that is, political relationships affecting international tea trade and changing preferences towards sustainable and tech-integrated tea products (2nd quadrant) we can develop scenario cross summarized in Figure 5.3.

Figure 5.3: Scenario cross



Scenario one: High preference for sustainable and tech integrated tea products with strong political relationships

In this scenario, both consumer preferences and political relationships are favourable, creating an ideal environment for the tea industry to thrive. It represents a world of high consumer preference and stable diplomatic ties. For plausibility we can ask ourselves if we can envision such a world. Each scenario has the same probability of occurring in the future. There is an increased awareness

of tea's health benefits significantly boosting consumer demand for sustainable and tech-integrated tea products. Health-conscious consumers are more inclined to purchase tea that aligns with their lifestyle choices, driving producers to adopt practices that emphasize sustainability and technological integration. This heightened demand incentivizes producers to innovate and meet these evolving consumer preferences.

Strong social expectations and robust government regulations promote the widespread adoption of fair labour practices within the tea factory. Ethical production becomes a standard, enhancing the reputation of tea producers and meeting the growing consumer demand for socially responsible products. This alignment between social expectations and regulatory frameworks ensures that fair labour practices are not only adopted but also maintained and monitored effectively.

High levels of awareness and education about the benefits of IoT technology led to its rapid adoption in tea processing. Tea producers are well-informed about how IoT can optimize production processes, improve quality control, and enhance supply chain transparency. This knowledge empowers producers to integrate IoT technologies seamlessly into their operations, driving efficiencies and boosting productivity. Furthermore, excellent connectivity infrastructure, a result of strong political support for technological advancement and infrastructure development, supports this seamless IoT integration. This robust infrastructure allows tea producers to leverage real-time data for better decision-making and operational improvements.

While the initial costs of IoT integration are high, the long-term gains in efficiency and productivity make it economically viable. Government subsidies and financial incentives further mitigate the financial burden, encouraging more producers to invest in IoT technologies. These economic supports help to offset the initial investments, making it easier for producers to adopt modern technologies and improve their operations. Favourable economic trends and strong market demand for tea products enhance the profitability of adopting sustainable and tech-integrated practices. Consumers are willing to pay a premium for high-quality, sustainably produced tea, and market conditions support this trend. As a result, tea factories experience robust growth and enhanced competitiveness in the global market.

Tea producers thrive in this scenario by adopting sustainable and tech-integrated practices. Strong political relationships facilitate the implementation of favourable regulations, subsidies, and international trade agreements, further supporting the tea industry. The seamless integration of IoT technologies, supported by excellent connectivity infrastructure, leads to significant improvements in operational efficiency, cost savings and overall productivity. These advancements position the tea factories to meet growing consumer demand for health-conscious, ethically produced, and technologically advanced products. As a result, the industry experiences robust growth, enhanced competitiveness, and a strengthened reputation in the global market.

In this scenario, tea factories thrive with IoT integration due to strong consumer demand and robust political support. The high levels of awareness and education about IoT benefits lead to widespread adoption, supported by excellent connectivity infrastructure. Government incentives and subsidies further ease the financial burden of IoT implementation. As a result, tea producers experience significant improvements in efficiency, cost savings, and product quality. The industry sees enhanced competitiveness and profitability, positioning itself as a leader in sustainable and tech-integrated practices.

Scenario two: High preference for sustainable and tech-integrated tea products with weak political relationships

In scenario two, consumer preferences strongly favour sustainable and tech-integrated tea products, but political relationships are strained, creating a challenging environment for tea producers. Growing consumer interest in the health benefits of tea significantly drives demand for products that are both sustainable and tech integrated. Health-conscious consumers seek out tea that not only promotes wellbeing but is also produced in an environmentally friendly and technologically advanced manner. This high demand incentivizes tea producers to align their practices with these consumer preferences, pushing them toward sustainability and technological integration.

Despite the weak political support, strong social expectations compel companies to adopt fair labour practices independently. Consumers and advocacy groups exert considerable pressure on tea producers to ensure ethical production standards. In the absence of robust governmental regulations, tea factories take the initiative to implement fair labour practices, understanding that meeting these social expectations is critical to maintaining their market share and reputation. High levels of awareness and education about the benefits of IoT technology led to its voluntary adoption by proactive tea producers. These producers recognize the advantages of IoT in optimizing production processes, enhancing quality control, and improving supply chain transparency. However, the adoption is driven more by market forces and consumer demand than by political incentives or support. Connectivity infrastructure is patchy, with gaps in coverage that pose challenges for seamless IoT integration.

In response, private investments bridge some of these gaps, with companies investing in their own infrastructure to support IoT implementation. This results in a fragmented but gradually improving connectivity landscape. The high costs of IoT integration, coupled with a lack of political support, make widespread adoption challenging. Nevertheless, some tea producers absorb these costs to gain a competitive advantage in the market. They recognize that investing in IoT can differentiate their products and appeal to a growing segment of health-conscious, environmentally aware consumers. Mixed economic trends create uncertainty, but niche markets for high-quality, sustainable products remain robust. These markets provide a stable source of demand for producers who invest in sustainable and tech-integrated practices, allowing them to thrive despite broader economic challenges.

In conclusion, Tea factories in this scenario face a mixed outcome. While strong consumer demand drives some producers to adopt IoT technologies, the lack of political support creates IoT integration challenges. Connectivity infrastructure is inconsistent, requiring private investments to fill the gaps. High costs and the absence of governmental incentives make IoT integration difficult for many tea producers. However, proactive companies that absorb these costs gain a competitive edge, catering to niche markets that value sustainability and technology. Therefore, IoT adoption is gradual and uneven, with significant advancements seen primarily among the most innovative and resourceful tea producers.

Scenario three: Low preference for sustainable and tech-integrated tea products with strong political relationships

In this scenario, consumer preferences do not favour sustainable and tech-integrated tea products, but political relationships are strong, providing substantial support for these practices. Limited interest in the health benefits of tea reduces consumer demand for sustainable and tech-integrated products. Most consumers prioritize cost and taste over sustainability and technological integration, leading to a slower shift in market preferences. As a result, tea producers face less pressure from consumers to adopt IoT. Strong political relationships, however, play a crucial role in promoting sustainability and technological advancement within the tea industry. Government policies and regulations enforce fair labour practices and encourage ethical production standards. Despite the lack of consumer-driven demand, producers comply with these regulations to avoid penalties and benefit from potential subsidies or incentives offered by the government.

Low levels of awareness and education about IoT benefits result in slow adoption among tea producers. Without significant consumer demand or a clear understanding of the advantages, many producers are hesitant to invest in IoT technologies. However, strong political relationships ensure good connectivity infrastructure, laying the groundwork for potential future adoption. This infrastructure is established through government initiatives aimed at improving technological capabilities across industries, including tea production. Government subsidies and support reduce the financial burden of IoT integration, making it more accessible for tea producers. These economic supports encourage some level of IoT adoption, even if it is not driven by market demand. Favourable economic trends and strong political backing create a stable environment for tea producers, supporting traditional tea markets while gradually introducing sustainable and tech-integrated practices.

Basically, in this scenario political support ensures a favourable environment for IoT and fair labour practices, despite the low consumer demand for sustainable and tech-integrated products. Some tea producers adopt these practices due to regulatory compliance and financial incentives, but the overall tea factory transformation is slow. The groundwork laid by strong political relationships and infrastructure development positions the for future advancements, should consumer preferences eventually shift towards factory sustainability and technological integration.

Scenario four: Low preference for sustainable and tech-integrated tea products with weak political relationships

In this scenario, both consumer preferences and political relationships are unfavourable, creating a challenging environment for the tea factories. Minimal interest in the health benefits of tea results in low consumer demand for sustainable and tech-integrated products. Most consumers prioritize cost and convenience over health, sustainability, and technological integration. This lack of demand discourages tea producers from investing in sustainable practices and advanced technologies, as they see little market incentive to do so.

Weak political support exacerbates the situation, leading to inconsistent adoption of fair labour practices. Without strong governmental regulations and enforcement, many tea producers do not prioritize fair labour standards, resulting in a fragmented and often non-compliant industry landscape. This inconsistency undermines efforts to improve working conditions and erodes trust among socially conscious consumers who might otherwise support fair labour practices. Low levels of awareness and education about the benefits of IoT technology further hinder its adoption. Both producers and consumers lack understanding of how IoT can enhance production efficiency, quality control, and supply chain transparency. This knowledge gap makes it difficult for producers to justify the initial investment in IoT technologies, especially in the absence of clear economic or regulatory incentives.

Poor connectivity infrastructure, a result of weak political relationships, hampers IoT integration. Without reliable Internet and technological support, tea producers face significant barriers to implementing IoT solutions. This lack of infrastructure development stymies efforts to modernize tea processing and leverage data-driven insights, keeping the factories technologically stagnant. The high costs associated with IoT integration, combined with the lack of political support, make such investments economically unfeasible for most tea manufactures. Without subsidies, tax incentives, or other forms of financial assistance, the upfront expenses of adopting IoT technologies are prohibitively high. Producers, therefore, opt to continue with traditional methods that, while less efficient, require lower capital investment.

Unfavourable economic trends and low market demand further discourage investments in sustainability and technology. The tea industry faces declining profitability and market instability, making producers reluctant to take financial risks on new technologies and sustainable practices. Instead, they focus on short-term survival strategies, cutting costs wherever possible and avoiding significant changes to their operations. As a result, the tea factories struggle with inefficiencies and high costs due to the lack of both consumer demand and political support for sustainable and tech-integrated products. Adoption of IoT and fair labour practices remain minimal, leading to continued reliance on outdated and less efficient production methods. The industry faces significant challenges in maintaining competitiveness, as it lags other sectors that embrace IoT advancements and sustainability. This scenario highlights the critical need for coordinated efforts

between consumer advocacy, political support, and industry commitment to drive meaningful change and ensure the long-term viability of the tea factories.

In this scenario, the outcome for IoT integration in tea factories is the most challenging. Minimal consumer demand for sustainable and tech-integrated products, combined with weak political support, results in low adoption of IoT technologies. Poor connectivity infrastructure and high costs without subsidies make IoT integration economically unfeasible for most producers. The industry continues to struggle with inefficiencies and outdated production methods, leading to reduced competitiveness and profitability. Only a few forward-thinking manufactures may attempt IoT integration, but their efforts are hampered by broader systemic issues, resulting in minimal overall impact.

By examining these four scenarios, stakeholders can better understand the potential outcomes of different combinations of consumer preferences and political relationships with other key drivers of change allowing for more informed decision-making and strategic planning. This comprehensive analysis helps identify key areas for intervention and collaboration to promote a more sustainable and technologically advanced tea industry.

5.2 Assessing Future Challenges and Opportunities

To achieve the second objective, the authors used the scenarios developed from the two driving forces to do a qualitative assessment to identify the possible challenges and opportunities in each scenario and below are the discussions.

Scenario one: Diplomatic harmony (high consumer preference Vs advanced political relationship)

Challenges

i. Maintaining political stability: One of the primary challenges in the scenario amidst evolving geopolitical dynamics. Shifts in global power dynamics, geopolitical tensions, and diplomatic disputes can impact trade relations and market access, posing risks to the tea industry's stability and growth.
ii. Meeting consumer expectations: Another challenge is meeting the high expectations of consumers for quality and sustainable tea products. Consumers are increasingly prioritizing ethical sourcing, environmental sustainability, and product transparency. Meeting these expectations requires significant investments in sustainable farming practices, supply chain transparency, and quality assurance measures.

Opportunities

i. Negotiating favourable trade agreements: Strong diplomatic relationships present opportunities to negotiate favourable trade agreements and tariffs that benefit the tea industry. By leveraging diplomatic channels, tea-producing countries can secure preferential

trade terms, reduce export barriers, and expand market access for their products, thereby enhancing competitiveness and market penetration.

ii. Investing in innovation: Diplomatic harmony provides an opportunity for tea companies to invest in research and development to innovate and meet consumer demand for premium tea products. By investing in technology, product diversification, and value-added offerings, tea companies can differentiate their brands, capture higher market shares, and capitalize on emerging trends in the global tea market.

Strategic intervention

iii. Fostering diplomatic dialogue: To address the challenge of maintaining political stability, strategic interventions should focus on fostering diplomatic dialogue and cooperation among tea-producing and consuming nations. Engaging in multilateral forums, diplomatic summits, and bilateral negotiations can help build trust, resolve disputes, and mitigate geopolitical risks that may impact the tea industry.

iv. Implementing Sustainable Policies: To meet consumer expectations for quality and sustainable tea products, governments and industry stakeholders should implement policies that support sustainable tea production and promote environmental stewardship. This may include incentivizing adoption of sustainable farming practices, certification programmes for ethical sourcing, and regulations to ensure compliance with environmental standards.

v. Driving innovation through collaboration: Facilitating industry-government collaborations is essential for driving innovation and enhancing competitiveness in the global tea market. Governments can provide funding support, research grants, and incentives for tea industry stakeholders to collaborate on innovation projects, technology adoption, and market development initiatives. By fostering a collaborative ecosystem, the tea industry can harness collective expertise, resources, and networks to address common challenges and seize growth opportunities.

Scenario two: consumer frenzy (High Consumer preference Vs low political relationship)

Challenges

i. Expanding market access while overcoming trade barriers can be particularly challenging in the absence of strong diplomatic relationships. Trade agreements and tariffs heavily influence the flow of tea products across borders. Without favourable diplomatic ties, tea-producing countries may face challenges in negotiating advantageous trade

terms, which can hinder market access and limit export opportunities.

ii. Meeting growing consumer demand for tea products while maintaining sustainable production practices poses a significant challenge. The tea industry faces pressure to increase production to meet rising demand, but this must be balanced with environmental conservation efforts. Without sustainable practices, such as soil conservation, water management, and biodiversity preservation, tea production may degrade natural ecosystems and compromise the long-term viability of tea cultivation.

Opportunities

i. Harnessing consumer enthusiasm to drive market growth and industry expansion. Consumer interest in premium and specialty teas, as well as health and wellness trends, presents avenues for market differentiation and product innovation. By understanding and responding to consumer preferences, tea companies can carve out niche markets and cultivate brand loyalty.

ii. Investing in technology and infrastructure to enhance production efficiency and product quality. Automation, precision agriculture, and digitalization can optimize farming practices, reduce resource consumption, and improve yield consistency. Additionally, infrastructure improvements, such as transportation networks and processing facilities, can streamline supply chains and reduce post-harvest losses.

Strategic interventions

i. Focus on advocacy and engagement: Despite political constraints, there is need to put effort in advocating for the tea industry and engage consumers. This may involve lobbying policymakers to prioritize trade negotiations that benefit tea exporters, as well as educating consumers about the social, environmental, and economic benefits of supporting sustainable tea production. collaborating with industry associations, non-governmental organizations (NGOs), and consumer advocacy groups can amplify advocacy efforts and raise awareness about key issues facing the tea industry.

ii. Implement regulations and standards: Implementing regulations and standards is crucial to ensuring the sustainability and traceability of tea production. Governments can establish and enforce environmental regulations, such as water quality standards and land-use policies, to promote sustainable farming practices. Furthermore, certification programmes, such as Fair Trade and Rainforest Alliance, provide assurance to consumers that tea products meet ethical and environmental standards. By adhering to these standards, tea producers can enhance market access and consumer trust.

iii. Provide financial incentives and technical Assistance: Financial incentives and technical assistance can support tea processors in

adopting sustainable practices and improving production efficiency. Governments, international organizations, and development agencies can offer grants, subsidies, and loans to incentivize investments in renewable energy, waste management, and organic farming. Additionally, capacity-building programmes, training workshops, and knowledge-sharing platforms can equip tea producers with the skills and resources needed to implement sustainable production techniques effectively.

Scenario three: Political dilemma (advanced political relationship Vs low consumer preference)

Challenges

i. Stimulating consumer demand: Convincing consumers to choose tea despite low interest or apathy presents a significant challenge. Even with favourable political relationships, if consumers aren't interested in tea products, market demand remains stagnant, impacting sales and revenue.
ii. Maintaining profitability and sustainability: Limited market engagement can threaten the profitability and sustainability of tea businesses. Without sufficient consumer interest, tea producers may struggle to generate revenue, invest in sustainable practices, or expand their market presence, jeopardizing long-term viability.

Opportunities

i. Utilizing existing diplomatic channels: Despite low consumer preference, leveraging existing diplomatic channels can help advocate for the tea industry and raise awareness of its benefits. Engaging with diplomatic missions, trade delegations, and international forums allows tea stakeholders to highlight the economic, cultural, and health advantages of tea consumption, potentially influencing policy decisions and market perceptions.
ii. Diversifying product offerings: Diversifying product offerings provides an opportunity to cater to niche markets or emerging consumer trends. By introducing innovative tea blends, flavours, or packaging targeted towards specific consumer segments, such as health-conscious individuals or eco-friendly consumers, tea businesses can broaden their customer base and adapt to evolving preferences.

Strategic interventions

i. Develop targeted marketing campaigns: Creating targeted marketing campaigns that educate consumers about the health benefits and cultural significance of tea can help stimulate demand and enhance market engagement. Utilizing various marketing channels, storytelling techniques,

and experiential events, tea companies can effectively communicate the unique value propositions of tea products and differentiate them from competitors.

ii. Provide Incentives for industry innovation: Offering incentives for industry innovation and product development encourages tea producers to explore new ideas and cater to diverse consumer preferences. Grants, subsidies, or tax incentives for research and development initiatives incentivize experimentation and creativity, driving product innovation and market competitiveness.

iii. Collaborate with governments: collaborating with governments to implement policies supporting domestic consumption and export promotion is crucial for the growth and sustainability of the tea industry. Governments can introduce measures such as tax incentives, infrastructure development, or marketing support to stimulate domestic demand and facilitate international trade, creating a conducive environment for tea industry growth.

Scenario four: Industry struggle (low consumer preference Vs robust political relationship)

Challenges

i. Overcoming market stagnation: The primary challenge in this scenario is overcoming market stagnation and low demand, compounded by the absence of political and consumer support. Without government backing or consumer interest, the tea industry struggles to stimulate demand and expand market reach, leading to stagnant growth and reduced profitability.

ii. Addressing economic vulnerabilities: The tea industry faces economic vulnerabilities and market volatility without government assistance or trade partnerships. Economic shocks, currency fluctuations, and supply chain disruptions exacerbate financial instability, making it difficult for tea businesses to navigate uncertain market conditions and sustain operations.

Opportunities

i. Exploring alternative markets: Despite challenges, there are opportunities to explore alternative markets or distribution channels to diversify revenue streams and mitigate risk. Targeting niche markets, such as specialty tea shops, health food stores, or online platforms, enables tea businesses to reach untapped consumer segments and adapt to changing market dynamics.

ii. Investing in community development: Investing in community development initiatives presents an opportunity to strengthen local economies and foster resilience within tea-producing regions. Supporting smallholder farmers, promoting sustainable agricultural practices, and investing in infrastructure projects contribute to poverty alleviation, economic empowerment, and social cohesion, creating a more resilient tea industry ecosystem.

Strategic interventions

i. Forge strategic alliances: Tea businesses can forge strategic alliances with neighbouring countries or regional trade blocs to access new markets and enhance competitiveness. collaborating on trade agreements, market access initiatives, and promotional campaigns fosters regional integration, facilitates cross-border trade, and expands market opportunities for tea products.
ii. Implement industry restructuring: Implementing policies to support industry restructuring and modernization is essential for enhancing competitiveness and sustainability. Governments can offer investment incentives, tax breaks, and capacity-building programmes to encourage tea businesses to adopt modern technologies, improve efficiency, and upgrade infrastructure, ensuring long-term viability in a challenging market environment.
iii. Advocate for government support: Advocating for government support and international assistance is crucial for addressing systemic challenges and promoting tea industry sustainability. Engaging policymakers, tea industry associations, and international organizations to prioritize the needs of the tea industry, such as infrastructure development, access to finance, and market promotion, can help overcome barriers to growth and foster a supportive business environment.

6. Conclusion and Policy Recommendations

6.1 Conclusion

The findings indicate several interconnected scenarios, each with its own set of challenges and opportunities. Understanding these dynamics can aid in formulating effective policies that enhance both political and economic stability.

For instance, in political harmony scenario (advanced political stability and high consumer preference), tea factories expect robust adoption of IoT, which is crucial for fostering a conducive environment for economic growth. The opportunity here lies in meeting consumer expectations through negotiating favourable trade offerings and foster innovation by providing subsidies for IoT adoption. By leveraging sustainable political stability by enacting IoT regulatory framework, the government can secure beneficial trade deals that satisfy consumer demands and boost the economy.

Amidst a consumer frenzy scenario (strained political relationship and high consumer preference), tea factories face a challenging landscape. The policy makers can focus on addressing potential disruptions in the supply chain due to trade restrictions or tariffs on IoT components. Focus by policy makers includes promotion of domestic IoT production. Though there is a high demand for IoT, the cost of implementation may rise due to geopolitical tensions, making it an essential. offer incentives to support the process.

Stimulating consumer demand becomes a significant challenge while maintaining profitability and sustainability in political dilemma scenario (advanced political relationship and low consumer preference). The focus is catalyzing the demand for IoT implementation. Policy makers can support research and development efforts to create appealing tea products. To justify the investment in IoT there is a need to boost the market demand for the product.

Lastly, in the face of industry struggle (strained political relationship and low consumer preference, the focus should be on boosting both the diplomatic ties and consumer demand for IoT technology. The focus in this scenario is supporting local innovation and even local private-public partnerships. Exploring new markets and supporting community initiatives can drive demand and stabilize the tea industry in challenging times.

6.2 Policy Recommendations

The findings of this study have a bearing in any public policy geared towards setting the standard for regulating IoT integration in the future of smart tea industries. The policy recommendations below enhance the adoption of IoT integration in smart tea factories:

Enhancing political stability

i. Foster political relationships: The government can develop and maintain stable political relationships to enhance trade opportunities regarding IoT adoption. This will facilitate the adoption of IoT technologies in tea factories by ensuring favourable trade agreements and regulatory support.
ii. Stakeholder collaboration: Promote collaboration among government agencies, private sector entities, academia and industry associations to develop cohesive strategies and share best practices for IoT adoption in tea processing, driving innovation and coordinated action.

Expanding market access

Availability and connectivity infrastructure: the government can invest in high-speed Internet and reliable power infrastructure especially in rural and remote areas, to ensure seamless IoT integration in tea factories. This will enable efficient data collection and real-time monitoring.

Expanding consumer interest

i. Pilot projects: Implement pilot projects to demonstrate the practical benefits and feasibility of IoT technologies in tea processing, providing valuable insights and refining strategies for broader adoption.
ii. Public awareness campaigns: Launch public awareness campaigns to educate stakeholders on the advantages of IoT in tea processing and even the benefits associated with tea consumption fostering demand for tech-enabled tea products and building support for IoT adoption.
iii. Capacity building programmes: Develop and implement training programmes to equip farmers and factory workers with the necessary skills to operate and maintain IoT systems. This ensures a knowledgeable workforce for successful IoT integration.

Towards complying with fair labour practices

Clear and comprehensive regulation: The government can establish robust regulatory frameworks to ensure data security, privacy, and interoperability of IoT devices in tea processing. It also promotes a secure and standardized approach to technology adoption across the tea industry. Further it can streamline market operations, ensure fair practice, and foster an environment conducive to IoT adoption. This will address challenges across various scenarios effectively.

By Adopting the policy recommendations, it will drive significant transformation in the tea factories. Enhanced international political relationships will expand trade opportunities and regulatory support, while improved infrastructure will ensure seamless IoT operations, boosting efficiency and productivity. Clear regulations will establish secure and standardized practices, and pilot projects will provide practical insights for broader adoption. Public awareness campaigns will foster stakeholder acceptance and demand, and capacity-building programmes

will develop a skilled workforce. collaborative efforts among stakeholders will accelerate innovation and reduce implementation barriers. Collectively, these measures will enhance the industry's competitiveness, sustainability, and economic growth, benefiting all stakeholders involved.

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