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Industry Development and Demand on Air-quality Sensor Industry: A Case Study of Taiwan's Practices

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***Abstract*—Air pollution is a major topic of public discussion as researches has confirmed that air pollution will affect human health. Therefore, developing air-quality sensor industry is always a main focus of the government. However, there is a research gap in the development and demand of the air-quality sensor industry. This research focuses on evaluating the development and demand of the air-quality sensor industry form the aspects of the market, technology, and eco-system. By analyzing the case of Taiwan, this research seeks to understand the demand and the practice to promote air-quality sensor industry. This research interviews experts such as research institutes, manufacturers, distributors, and sensor deployers, reviewing the current industry outlook, major strengths and weaknesses, and potential challenges, as well as discussing solutions to create a complete and sustainable environment. Finally, this research proposes industrial strategy recommendations from the perspective of the government.**

***Keywords*—air-quality sensor, case study, technology policy, air monitoring**

I. Introduction

With the improvement in sensor technologies, sensors with computing function are embedded into items surrounding people's daily life. Air-quality sensor plays a critical role in smart cities, smart industrial parks, and smart buildings [1]. The global air quality monitoring system market is expected to grow from $5.05 billion in 2021 to $5.57 billion in 2022 at a compound annual growth rate (CAGR) of 10.2%. The market is expected to reach $7.63 billion in 2026 at a CAGR of 8.2% [2]. The application field of air-quality sensor can be divided into 7 segments, including (1) Consumer Electronics: embedded into smartphones, wearables such as smartwatches, personal computers, and other home products; (2) Heating, Ventilation, and Air Conditioning (HVAC): applied in building automations such as air purifier, ventilation control, visitor control, and energy saving and safety equipment [3]; (3) Air Comfort for Transportation: monitors air pollutant and employs ventilation system inside the car; (4) Powertrain Management: detects and manages air pollutant of engine systems; (5) Medical: used in gas detection of respiratory assist and oxygen transport systems; (6) Environment: monitors urban air quality in outdoor weather stations [4]; and (7) Defense and Industrial Safety: gas detection to ensure national defense and factory safety.

In the context of air-quality sensor technology development and current status of major international firms, this research interviews experts such as research institutes, manufacturers, distributors, and sensor deployers aiming to answer the two following questions: (1) How can Taiwanese firms accelerate the process of market penetration, explore business opportunities, and find potential business partners; and (2) how can Taiwanese firms enhance the technological advantage in the air-quality sensor field, at the same time developing promising new technologies. By answering the two questions, this research seeks to provide suggestions and recommendations to strengthen the air-quality sensor industry and develop a complete and sustainable environment for both firms and research institutes.

II. Literature Review

A. *Importance of Air-quality Sensor Technologies*

In recent years, many countries started to focus on the technology development of air-quality sensors. Southeast Asia countries, because of plans to expand manufacturing and factory production, have rapidly increasing demand for gas detection. For instance, Thailand had struggled to provide effective solutions to air pollution issues. Thailand government set a goal to reduce greenhouse gas emission by 20% before 2030. To reach such a goal, Thailand currently focuses on providing a detection system that combines gas sensors and drones with the purpose of monitoring gas leakage in certain areas and encouraging experts around the world to participate in gas detection using real-time visualized information and infrared pictures provided via drones and communication systems. Vietnam actively develops technologies such as high-speed mobile network, big data, artificial intelligence (AI), and internet of things (IoT), combining these with communication and gas detection technologies. Vietnam plans to implement in Ho Chi Minh City, Hanoi and Da Nang, and replicate to other cities using the three cities mentioned as role model. Vietnam suffered from its economic growth and policy management problems when promoting green growth planning. Vietnam government aggressively seeks foreign investments to solve the biggest obstacle – insufficient funding. Indonesia set the goal to reduce total greenhouse gas emission by 29-41% before 2030, the government stated the country may reach carbon neutral prior to 2060. The emission control of Indonesia focuses not only on monitoring air quality, but also on forcing factories, coal-fired power plants, and cars to filter and reduce the emissions.

Based on the aforementioned information, the air-quality sensor industry, combining with Information and Communication Technology (ICT) technology and IoT, is very promising, especially in emerging countries where the potential of industry development is strong. Thus, past literatures focused and made predictions on the development

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and technology applications of air-quality sensor industry in countries such as Thailand and Indonesia **Error! Reference source not found.**.

With the informatization and the development of IoT in recent years, Taiwan promotes Civil IoT Taiwan based on the ICT industry, and seeks to merge and innovate the sensor industry, especially in the field of air-quality sensor. The Civil IoT Taiwan is constructed by multi-functioned sensors achieving comprehensive perception via Internet, and use big data cloud computing to perform passive environment monitoring.

B. Future Development of Air-quality Sensor Technologies

The major application segments of air-quality sensor currently are the defense and industrial safety, however, the segments of consumer electronics and indoor air quality are expected to grow significantly, and thus the air-quality sensors will develop toward miniaturization, multi-functioned, and low-energy consumption. The sensor technologies progressed form large sizes in the past to the micro sensor era of now, moving forward using the Micro Electro Mechanical Systems (MEMS) technology to develop next generation intelligent air sensor **Error! Reference source not found.**. AI and IoT technologies, which quickly expanded into and deeply affecting people's life, is mainly based on widely implemented perception layer sensors. Thus, air-quality sensor will play an important role in smart cities, smart industrial parks, and smart buildings [1].

Micro air sensor can integrate ICT into one circuit board, even into a much smaller chip. With the demand of monitoring CO_2, CO, and VOC increasing, the new application lean toward the consumers, leading to the low-cost air-quality sensor becoming more popular, the trend of miniaturization and low-energy consumption is also responding to the demand of consumer electronics and transportations [7]. Researches pointed out that the market of air-quality sensors used inside the car will increase at a compound annual growth rate (CAGR) of 4% during 2021-2025 to 2.7 million [9], showing that the market of consumer applications is increasing in the near future.

III. Research Methods

A. Data Sources and Research Method

This research applies the mindset of business ecosystem to understand the current industry outlook and the demand of research institutes, manufacturers, distributors, and sensor deployers via interviews and meetings with experts, and to provide industrial strategy recommendations to Taiwanese firms and can help Taiwan government develop policies related to the development, international competition and cooperation, and promotion of the sensor industries. This research invited 5 manufacturers, 3 distributors, 4 deployers, and 10 experts from research institutes, with the total of 22 experts and firm representatives. Figure 1 presents the conceptual framework of this research.

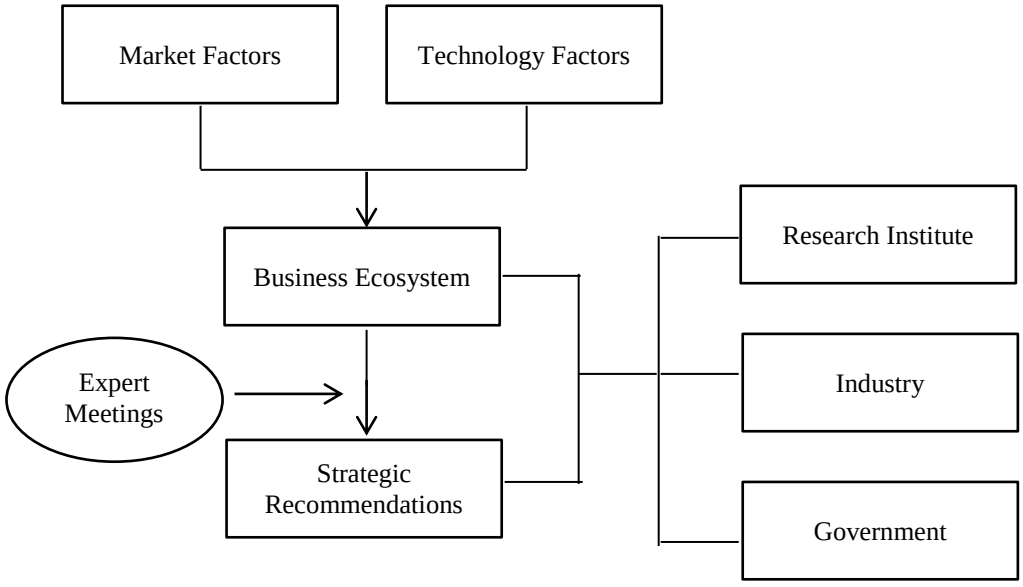

Figure 1. Conceptual Framework

B. Expert Meetings and Interviewees

Moore (1993) proposed the concept of business ecosystem，in which every organizations and individuals in the business activities, including the government, research institutes, manufacturers, distributors, and consumers, will generate interactions and form an economic association. Every player in the ecosystem has different function and relies on other players **Error! Reference source not found.**. Based on the concept of business ecosystem, this research interviews and holds

meetings with experts including research institutes, manufacturers, distributors, and sensor deployers, and provides strategy recommendations to researchers, firms, and government.

For research institutes, this research invites program leaders who participated in the Civil IoT Taiwan project; for

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firms, this research interviews companies that manufactures, distributes, or sales air-quality sensors, as well as the winning tenderer of the air-quality sensor implementation of the Environmental Protection Bureau.

IV. Result Analysis

A. *Research Institutes*

The prototypes developed by research institutes usually don't gain interests form firms due to too little productions. Research institutes and firms also have low willingness to get certifications for their products because the certification fee cost nearly half of the total research fund. The government, on the other hand, encourage research institutes to collect results in different environments and apply these results in different scenarios, such as industrial park air-quality control or embed air-quality sensor in home appliance, to accelerate the process of commodification.

B. *Manufacturers*

Until 2022, Taiwan has deployed over 10,000 air quality measuring stations. The Taiwanese firms have accumulated extensive deploying experience. Combining with back-end data alignment, interpretation, and application, theses firms have gained strong system integration ability. However, several firms exited due to the small domestic market size, therefore, expanding to international market or developing strategic alliance with foreign companies may help the firms find suitable environments, for instance, firms can promote smart agriculture in Southeast Asia countries and provide reference for farmers to make decisions.

C. *Distributors*

Since the Taiwanese sensors still haven't reach international market, the firms still face high costs because the firms are not enjoying economies of scale. To expand the market and reach economies of scale, the government can accelerate the development of domestic sensor industry and expand the scope of applications via regulations, requiring waste-discharging organizations such as factories, catering industries, stock farms, and hospitals to install sensors; and checked regularly by competent authorities.

D. *Deployers*

Taiwanese sensors have gotten many certifications and have certain level of accuracy. Currently, Taiwanese firms focus on domestic markets, meeting the deployment demand and at the same time providing consistent sensor data qualities. Because of the limited domestic market size, the initial development cost is high and firms have not reached economies of scale. Firms should expand the application scenarios, collect data under different contexts, and build experience databases. Firms can achieve the goal of "Taiwan can Help" by gradually building air quality detection models under different environments and promoting air-quality sensors to foreign countries with demand.

V. Conclusion and Recommendations

This research analyzes the current industry outlook and the demands for research institutes, manufacturers, distributors, and sensor deployers via expert meetings and interviews; and, based on the results, provides the following strategic recommendations for research institutes, the industry, and the government.

For research institutes, the application of IoT become more and more widespread, meanwhile, the public has increasing demand on daily life air quality information, leading to the sensor industry entering a new era of cooperation and competition. However, research institutes still face many challenges when developing air-quality sensor technologies, the major challenges include: (1) firms are not interested in the prototypes the institutes developed due to low productions; and (2) the certification fees are too high, affecting the willingness for institutes to get certifications for their products.

For the air-quality sensor firms, the current status is to increase the technology levels through the lead of government policies. The firms have accumulated extensive experience and have gained comprehensive system integration ability. Despite the quality and consistency of Taiwanese sensors, the lack of incentive mechanisms leads to the performance lower than expectations. Promoting a consistent localization policy in the future will help domestic sensor firms gain hands-on experiences and better performances overall.

Currently, Taiwanese firms have acquired key technologies for air-quality sensing elements. However, the limited domestic market size has forced several firms to exit. The firms cannot enjoy the benefit of economies of scale because the sensors have not yet reached the international market, result in a higher cost. The recommendation is to actively expand to foreign markets, replicate the implementation experience in Taiwan to markets such as Southeast Asia. Preparing for future demands, accelerating the process of technology export, and increasing the visibility of Taiwan are the main focus for air-quality sensor industry in Taiwan in the near future.

For the government, Taiwanese sensors have gotten many certifications and have certain level of accuracy. The high cost of initial development and the limitation of domestic market have led to firms not reaching economies of scale. According to ResearchAndMarkets (2022), there is a lot of room to growth with the air-quality sensor market [2], and the market is trending toward miniaturization, multi-functioned, and low-energy consumption. Thus, how to combine the sensor industry with the power of Taiwanese semiconductor industry, develop chip-type gas sensors, and apply MEMS technology to catch up with the market trend will be a main focus in future policy developments.

This research uses country-level macro perspective to analyze the air-quality sensor industry, focusing on creating a complete and sustainable environment; and pointing out the major strengths and weaknesses, and potential challenges. The findings of this research can not only provide reference for firms in "develop domestic sensors"

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discussions, but also assist related government departments to promote industrial development policies related to air-quality sensors, potentially increasing the governance synergy in the technology department.

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