The Formulation of Public Policy Framework

Encouraging Effective Collaboration within the Electric Bus Research and Manufacturing Cluster to Accelerate the Adoption of Electric Buses in Thailand

By

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A thesis submitted for the degree of
Doctor of Philosophy

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2022

Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Date: 28 June 2023

Abstract

The automotive industry is considered one of the largest sources of revenue for Thailand. However, with the recent acceleration of electric vehicle's technological development around the world, the Thai government was concerned that the domestic automotive sector might be at risk of losing its competitive edge since the whole supply chain in the automotive industry is centred around products based on the research and manufacturing of internal combustion engine vehicles. Therefore, the Electric Vehicles Committee of Thailand was formed by the government to support and promote the transition of the automotive industry towards an electric vehicles economy. However, the complexity and sheer size of the Thai automotive industry; both in terms of the supply chain of physical products and the amount of information being exchanged among public and private stakeholders have made the adoption process of public policies extremely strenuous. This research aims to facilitate and quicken the process by designing a policy framework for the adoption of public policies within a smaller segment of the electric bus industry and use it as a possible model for the development of the Thai electric vehicles industry in the future. This framework consisted of integrated tools and concepts from engineering management perspective, combined with the data which was collected from the researchers, manufacturers, and stakeholders in Thailand. The main objective of the framework is to assist the initial stage of public policies initiation in electric bus research, manufacturing, and requisition, which will ultimately cultivate the development of the electric bus manufacturing industry in Thailand. Moreover, this policy framework could also be applied to other segments of public policy, or even in the formulation of operational strategy in both public and private organisations.

Acknowledgement

In this occasion, I would like to express my gratitude to many people who contributed to the completion of this thesis.

Firstly, I am most grateful to the Royal Thai Government, especially the former ministry of science, technology, and innovation (now restructured into the Ministry of Higher education, science, research, and innovation), and the Office of National Higher Education Science Research and Innovation Policy Council (NXPO) who offer me an invaluable opportunity to study abroad and employ me in a meaningful and fulfilling job placement in their organisation.

I want to specifically extend my appreciation to both of my supervisors, Dr. David Butler and Professor Jorn Mehnen who always give me valuable advice on how to proceed with my research and encourage me in my study as a Ph.D. student. In addition, I would like to give thanks to my first and former supervisor Dr. Abigail Hird, who accepted me as her student when I first submitted my application to the University of Strathclyde.

Thank you to all my lovely colleagues in Leonardo Suite and friends from the societies who made me feel at home during my time at the campus, especially my work desk's neighbours who always lighten my day and my fellow Thai students who shared similar struggle in our research. It was a shame that our time together was very limited due to unfortunate circumstance regarding the pandemic in 2020-2021, but please know that I will always remember our time together.

I have my utmost gratitude to several people that donate their precious time to participate in my data collection process and want to extend my thanks to them. I am especially thankful to Dr. Thanakarn Wongdeethai, who introduce me to several other informants and external contacts who have insightful perspectives that were very beneficial to the making of this thesis.

Lastly, I am eternally grateful to my beloved father and mother, Supakit and Panarach Preedakorn, who always support my academic pursuit and shaped me into a person who I am today.

The Author

Kantapich Preedakorn attained a bachelor’s degree in engineering from Chulalongkorn University in Thailand. He also attained a first-class honour master’s degree in business administration from National Institute of Development Administration (NIDA) in Thailand. Not long after that, he was offered a scholarship from the Royal Thai government to study in the field of development studies with the focus on innovation policy. This circumstance led to his attainment of another master’s degree in science, technology, and innovation studies from the University of Edinburgh before moving on to study a doctoral programme in design, manufacturing and engineering management at the University of Strathclyde.

During the time of his work and study, he specialised in combining systematic thinking aspects of engineering and practical concepts in management to solve real world problems. He also has special expertise in creatively conceptualised seemingly complex problem into a more trivial exposition. This skill stems from his work experience as a project manager in a software publishing company and a production line overseer in a chemical factory. Complementary to his skillset, this thesis attempts to design a preventive mechanism to mitigate several issues that could arise from the potential industrial disruption, which could negatively affect the performance of the whole system.

After he finished a PhD programme at the University of Strathclyde, he was obliged to work for the ministry of higher education, science, research, and innovation in Thailand. In fact, it could be stated that this thesis is a research output that could be immediately applied in the real work environment for the direct sponsor and future employer; Office of National Higher Education Science Research and Innovation Policy Council (NXPO). Therefore, it can be assumed that he will be assigned several tasks related to the development of industry cluster in Thailand, especially in the development of electric vehicles sector of Thai automotive industry.

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List of Abbreviation

NSTDA	National Science and Technology Development Agency
NXPO	The Office of National Higher Education, Science, Research, and Innovation Policy Council
STI	Science, technology, and innovation
BMTA	Bangkok Mass Transit Authority
IDEF	Integrated Computer Aided Manufacturing Definition for Function Modelling
UML	The Unified Modelling Language
ACT	Activity Diagram
RTO	Research and Technology Organisation
ROSIS	Regional Open Sectoral Innovation System
USA	The United States of America
UK	The United Kingdom
EV	Electric Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
BMU	Battery Management System
VCU	Vehicle Control Unit
SME	Small and medium-sized enterprises
OEM	Original Equipment Manufacturer
PMBOK	Project Management Body of Knowledge
BPMN	Business Process Model and Notation
KNIT	Knowledge, Innovation, and Technology
ICEV	Internal Combustion Engine Vehicle
ITI	Intermediate Technology Initiative (Scotland)
TIC	Technology & Innovation Centre (The University of Strathclyde)
NGV	Natural Gas Vehicle
ZEV	Zero-Emission Vehicle Programme
RFID	Radio-Frequency Identification
NPV	Net Present Value
KMUTT	King Mongkut's University of Technology Thonburi
KMITL	King Mongkut's Institute of Technology Ladkrabang

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Chapter 1 Introduction

1.1 Rationale of the Research

In recent years the accelerated development and adoption of electric vehicles has become a global trend as individuals, organisations, and countries look for alternative environmental-friendly forms of transportation. Nowhere has this been more widely felt than in the global automotive industry as many manufacturers prepare themselves for the inevitable change (Ajanovic, 2015). Many automobiles manufacturers around the world have been prepared towards the changes that might occur in the near future (Gnann *et al.*, 2015). In Thailand, the automotive industry is one of its largest contributors to the economy (Figure 1-1). The sector is primarily based around the internal combustion engine with manufacturing processes and technologies focused on the production of cars, buses, and trucks. With no major indigenous automotive brand, Thai manufacturers have heavily relied on the technology of Japanese car manufacturers since the late 1980s (Busser, 2008). As a result, most technologies that are currently utilised in the manufacturing process of an automobile are based on the internal combustion engine system. To maintain the presence in global competition and the stability of the national economy, a national agenda to proactively transform the domestic automotive industry towards the new economy of electric vehicle manufacturing was set by the Thai government. However, past attempts to initiate research and development projects in the electric vehicle industry have not been very successful due to the lack of technological capabilities and the knowledge regarding electric vehicles among Thai stakeholders, who are mostly familiar with the internal combustion engine system (Schröder, 2021). To counter this challenge, the Thai government has initiated a national policy consortium for the adoption of electric vehicles. This consortium was established based on the triple helix model (Etzkowitz, 2008), which encourages the interactions between the public sector, industrial enterprises, and research institutions. The purpose of these interactions is to intensify the rate of industrial innovation by fully utilising the strengths and capabilities within a selection of stakeholders in the automotive industry.

Theoretically, the collaboration between stakeholders within the cluster must be continuous, to drive the research and technological outputs from the established cluster into commercial applications. However, the effective operation of an industry cluster in a large-scale industry such as the automotive industry in Thailand is difficult to achieve. This led to another decision to create a sub-section of the electric vehicles policy consortium to facilitate the timeliness of policy adoption in the smaller segment of the EV industry. The supply chain of bus manufacturing was designated to be one of the leading sectors to initiate the transformation from internal combustion engine vehicles (ICEVs) to electric vehicles (EVs), since buses are the most widely used public transportation in Thailand (Satiennam, Fukuda and Oshima, 2006). In contrast to passenger cars, Thailand is less dependent on foreign corporations in the manufacturing process of buses. Additionally, in contrast to the supply chain of passenger cars, Thailand is less dependent on foreign corporations in the process of bus manufacturing. Therefore, there are more readiness for EV technologies because of less uncertainty in corporate decision-making and higher manufacturing capabilities of local stakeholders. Air pollution in urban areas such as the vicinity of Bangkok is an ongoing major concern for the government (ChooChuay *et al.*, 2020). Hence, the full adoption of electric buses in the transportation system is expected to have a large positive impact on the condition of air environment as well as the health and welfare of Thai citizens. This research aims to study the current state of the electric vehicles and electric bus industry and provide a comprehensive public policy framework that could effectively encourage meaningful inter-organisational interactions among the members within the electric bus research and manufacturing cluster in Thailand. It is anticipated that the increased flow of communication between actors in the industry would lead to the heightening of innovative opportunities within the cluster. Ultimately, this should lead to more productive electric bus research and manufacturing activities which will accelerate the transformation of the bus-based public transportation system in Thailand towards the usage of electric buses. Furthermore, this would be the turning point towards a long-term sustenance of the automotive manufacturing industry in Thailand, despite a looming threat of industrial and technological disruption that could occur from the global progress of electric vehicles technologies.

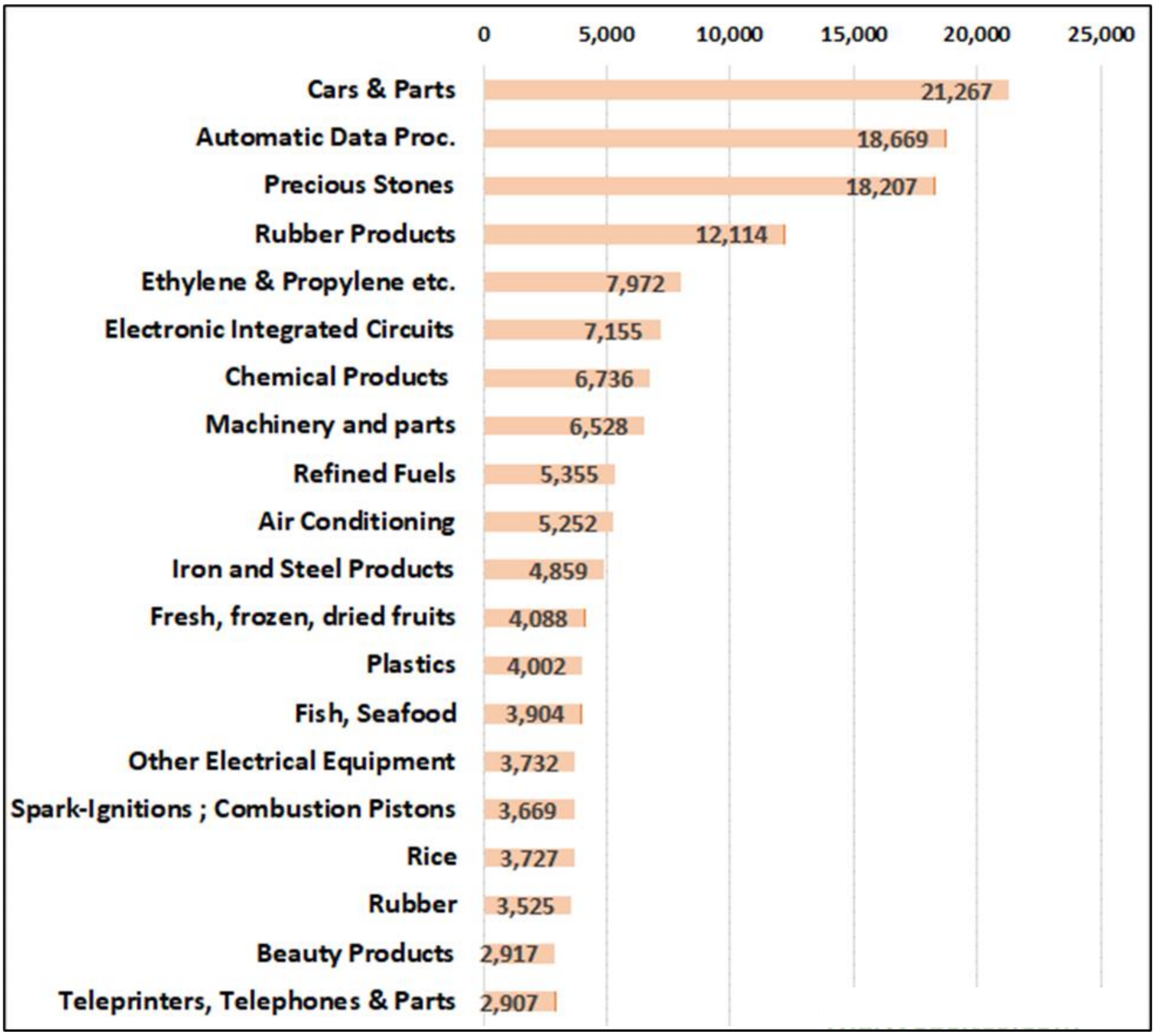

Figure 1-1 Thailand export products by value of million USD in the year 2020
(Source: Ministry of Commerce, Thailand, 2021)

1.2 Research Aims and Objectives

Despite the establishment of the electric vehicles policy consortium in Thailand, the process of transforming the Thai automotive industry towards electric vehicles is still not effectively implemented, evidently from multiple delays in policy implementation and unreached industry targets. To alleviate this problem, this research aims to formulate a public policy framework with the intention to facilitate the policy making process and intensify the collaboration between public and private stakeholders involved in the electric bus research and manufacturing cluster in Thailand. The novelty of this research will be the formulation of this framework because several frameworks for technological development found in the existing literature were usually fragmented and specific to a certain condition created by an objective of those research. Hence, they are not fully applicable to the research question posed by this thesis. On the contrary, the structure of this framework will be designed from the beginning by utilising the recent data collected from the Thai automotive industry which make them more suitable for this specific objective. The framework is represented by a collection of multiple components that are originated from management and engineering concepts.

Additionally, this framework would also contain a logical link between each component within the framework to clarify the rationality and connection behind each piece of information in the framework and improve the legibility toward laypeople and general audience who might not be an expert in the field of scientific management and policy making. The framework features analytical components that could be used in the facilitation of the policy making process for the planning, organising, implementing, and monitoring of an ongoing electric bus research and manufacturing cluster. It is designed based on the presumption that the collaborative network among stakeholders possess both socio-cultural and technical aspects. Therefore, several resulting designs within the framework is an attempt to straddle between these two aspects. Furthermore, the framework is designed in a flexible manner i.e., the policy plan resulting from this framework can be constantly modified based on additional inputs. As a result, this policy plan for the electric bus cluster can be further modified based on the updated information, even after the publication of this thesis.

In summary, a singular aim for this research is to investigate the governance and managerial issues, especially on the topic of inter-organizational collaboration within the Thai electric bus research and manufacturing cluster and propose a public policy-based approach to resolve or mitigate them. This aim can be distilled into three separated objectives:

1. *The determination of limitations within the application of innovation system which might be the cause of suboptimal operation in an innovation cluster* i.e., the deficiency of collaborative efforts among the members within the cluster. This research will explore both the theoretical concept of an innovation cluster in the literature review and the practical application of an innovation cluster in the electric bus industry in Thailand and propose a conceptual solution to mitigate these issues.
2. *The creation of structural guidelines to address policy inefficacy relating to the operation of innovation cluster via the formulation of public policy framework.* All components within the framework will be specifically designed to address contemporary industrial issues in the Thai electric bus research and manufacturing cluster, in addition to systemic issues within the concept of an innovation cluster. In addition, the formulated policy framework must be valid and suitable for an application in other segments of public policy.
3. *The identification of the specific gaps in the Thai electric vehicles and electric bus research and manufacturing cluster* which could potentially impede the upcoming adoption of electric buses in the transportation system. A public policy implementation plan that would be designed based on the structure of the formulated policy framework would likely solve both systemic issues within the cluster policy and industrial issues of the electric bus industry. Moreover, it will provide an insight towards the state of electric vehicles in Thailand, in which its situation might be in common with other developing countries.

Additionally, these objectives are further distilled into multiple sub-objectives based on the content of each chapter in this thesis:

1. Establish the linkage between the overarching notions of innovation system, complex system, and innovation cluster and extrapolate them into a single comprehensive study.
2. Explore and review managerial and engineering tools or approaches that will be used to formulate a public policy framework that would address all systemic issues of an innovation cluster.
3. Study the history and the current state of the global electric vehicles industry at the time of the research being conducted.
4. Assess the current situation of the Thai electric vehicles and electric bus industry and determine its gaps in comparison to the global electric vehicles industry.
5. Generate an organisational plan for the electric bus research and manufacturing cluster and the supply chain of electric bus manufacturing in Thailand.

6. Propose a public policy implementation plan which has the aim to encourage the manufacturing and adoption of electric buses in Thailand's transportation system.
7. Propose the evaluation schemes for the policy implementation plan and evaluate the public policy framework that was formulated in this thesis.

A continuing process of primary and secondary data collection while designing the policy framework is conducted, to design a relevant policy framework that can reflect the current development within the electric bus cluster. There are two main sources for this information: the primary data from in-depth interviews and conferences, and the secondary data from national databases and external studies. The interviews of the researchers and policy experts were conducted to determine the gaps in the electric vehicles and electric bus industry in Thailand. In addition, the interviews of several private stakeholders in electric bus cluster were conducted to gather practical aspects that could lead to the successful policy implementation within the cluster. The information was collectively analysed and utilised in the formulation of the framework, and subsequently a specific public policy implementation plan for the electric bus research and manufacturing cluster in Thailand.

1.3 Scope of the Research

At the initial stage of this thesis, it was planned that the study of a specific innovation cluster in Thai industry regarding the relationship between networking pattern and the degree of collaboration would be the main research topic. However, after several iterations of the literature review and the exchange of information between the researcher and the sponsor of this research project, the scope of this research was shifted to a less theoretical-oriented approach to increase its legibility among the possible audience. Nevertheless, the original intention to identify a single cluster within the Thai industry to perform a systematic study was not changed, regardless of the alteration in a former research question. In the final iteration of this research, the focus was equally divided between the design of a public policy framework and the formulation of a public policy plan to facilitate and accelerate the adoption of electric buses in Thailand. With this partition of the research focus, the results from this research will be beneficial to a larger group of the target audience which includes both policy makers and private stakeholders within the Thai automotive industry. Additionally, the thesis will also contribute to the existing body of academic knowledge by providing a clear explanation on practical limitations in an actual industrial setting of the current notion of innovation system and innovation cluster.

The segment of electric vehicles industry in Thai automotive sector is selected to be the subject of this research, based on the potential impact and the volatile situation of global industry which could introduce impactful changes towards the stability of Thailand's industrial economy. However, it was expected that the resulting policy framework would be overly generic and disjointed to be applied in an actual public policy setting of the Thai automotive industry. As a result, the scope of the research was narrowed down to only incorporate the sub-segment of electric bus research and manufacturing cluster. This focusing in of research scope has since proved to be beneficial to the rationality of the research outcome and the facilitation of a steady research progress throughout the period of a study. Even though the research scope was clearly indicated, it is reasonable to also study other extensive components within the supply chain of electric bus manufacturing industry. The significant extensions such as the operation of e-bus public transport services and the foreign trades of e-bus components will be crucial and contributory to the improvement of a formulated policy plan. However, a careful consideration must be taken to not overextend the boundary of the data collection process which could potentially dilute the clarity of the formulated policy framework.

The conduct of this research focused on the electric bus research and manufacturing cluster in Thailand. Nonetheless, the overseas case studies of best practices in the manufacturing and operation of electric buses also partially contributed to some contents within this thesis. The conduct of this research included the gathering of information from the government organisations, domestic and overseas component's manufacturers, domestic and overseas e-bus assemblers, public bus service operators, public and private research institutions, universities, and the general population in Bangkok. Starting from chapter 8 in this thesis, the research would focus on different potential scenarios for the development of the electric bus research and manufacturing cluster. The thesis will put less emphasis on the downstream segment of an electric bus manufacturing supply chain, which resulted in lesser differences among alternative policy implementation scenarios within a policy plan regarding the marketing, sales, and services of electric buses. In contrast, the designated policy implementation scenarios strongly differed in the acquisition of physical and intellectual resources for the research and manufacturing of electric buses.

1.4 Structure of the Thesis

This thesis is separated into ten chapters. The overall outline of this thesis is presented in Figure 1-2. The main topics for each chapter are summarised as follows.

Chapter 1 started with the introduction of the research topic, the formation of the research question, and the rationality behind the research question. The main aims and objectives of the research was thoroughly explained in this chapter. Furthermore, the intended research scope for the thesis was indicated to elaborate on the appropriate boundary of the research process. Lastly, the structure of this thesis is presented is this section to summarise the main ideas of all chapters in a concentrated manner.

Chapter 2 is the first literature review chapter, which will engage in the theoretical concepts of research and industrial collaboration. This chapter will explore the possibilities to augment the effectiveness of the collaboration among several organisations in the system. Several pre-existing examples and theories in the literature would be used to support this endeavour. The main topics of this chapter will include innovation systems, complex systems and complexity theory, and the formulation of innovation cluster. This chapter will set up the school of thought of this thesis and will provide the general outlook on how to design an encompassing framework for a topic which involves multitude of uncertainties that can originate from the synergies and conflicts of the actors within the system.

Chapter 3 will review a specific group of engineering and management tools and techniques that are set to be utilised in the formulation of the policy framework in this thesis. General considerations and issues in the creation of innovation cluster would also be reviewed. Both topics will be combined into a guideline to develop a compelling and interlocking framework structure that could serve as a template for the new inputs from any specific policy or business problems. In this thesis, the data from electric bus cluster in Thailand would be used as inputs to create a new policy implementation plan for the e-bus industry.

Chapter 4 is the literature review on the current progress and the development of electric vehicles industry and its relating technologies. The main contribution of this chapter would be in the later attempt to illustrate the gaps between the global industry and the Thai industry by colluding the facts from this review to the primary data collected in the Thai automotive industry. The main content of this chapter will include the general case studies in electric vehicles as an alternatives product to ICE vehicles, and the focused viewpoints in both supply and demand side of the electric vehicles industry. For the supply side, the review will focus on the research and development segment of this industry. In contrast, it will focus on the business model and the market for electric vehicles on the demand side.

Chapter 5 will provide the detailed information regarding the research methods that are used in this research. The collection of data can be separated into 3 main phases: the preliminary interview, the main data collection, and the feedback survey. The preliminary interview was conducted along with the process of literature review to find the optimal way to frame the expected outcomes of the research. The main data collection consisted of a series of interviews and conferences featuring the representatives from each group of stakeholders in the Thai electric bus industry. The feedback survey was designed to gauge the potency of this framework and its corresponding policy plan. Chapter 6 is the first part of the results and discussion section in this thesis. It will serve as the first building block in the formulation of the policy framework. This chapter will discuss the current situation in the Thai electric vehicles industry, and more specifically its electric bus research and manufacturing cluster. This would include the analysis of the current and potential stakeholders in the industry. Additionally, this chapter would also explain the urgency and the importance of electric buses adoption and conduct a cross-analysis with the literature which would showcase the current research and manufacturing gaps in the industry.

Chapter 7 is the goal setting part of the policy framework. It will consist of industry goals that were envisioned by Thai stakeholders and the elaboration of potential development pathways that could enable Thai industry to reach the goals. This section of the framework would contribute comprehensive ideas regarding the method to organise the current bus manufacturing supply chain towards the new economy of electric vehicles industry by considering essential technologies that should be acquired or developed. It would also include the possible changes in the business model of the industry, according to the cultivation of demand for electric buses by policy intervention.

Chapter 8 will develop the policy implementation plan for the vision and goals that were set by the previous chapter. This implementation plan will consist of three major components: the multiple scenarios design for e-bus cluster via IDEF0 diagrams, the segmentation of policy initiatives via strategic implementation plans, and the objective-based action plan via UML activity diagrams. These three steps would provide a tangible and flexible framework that could be replicated in any settings of public policy. This chapter will also include insights from overseas country regarding the manufacturing and operation of electric buses, to recreate their best practices into the policy initiatives that would be generated by this framework.

Chapter 9 will present a systematic method to monitor the degree of success in the implementation of a policy plan that can be generated by this policy framework. It will also present several sample metrics for the measurement of success of a policy plan regarding the adoption of e-bus. The evaluation process is designed by two different techniques which would be suitable for different management perspectives. The balanced scorecard would operate better for the policy maker because of its top-down perspective, while the work breakdown structure would perform better in the delegation of controlling process to smaller stakeholders within the cluster. This chapter would also contain the results from the feedback survey that was designed to measure the potency of the formulated public policy framework in this thesis.

Chapter 10 will conclude all research outputs that are generated in this thesis. This conclusion will consist of a summary of the policy framework, its limitations, and the key findings from the formulation process of a policy framework. It will also include the statement which detailing the novelty of the approach that was utilised throughout the process of the framework formulation and its contribution to academic knowledge within the related fields of study. Lastly, this chapter would end with the discussions regarding the implication from the results and findings of this research and the potential application that could be extended from the findings, including the suggestion for further research topics that could be based on this thesis.

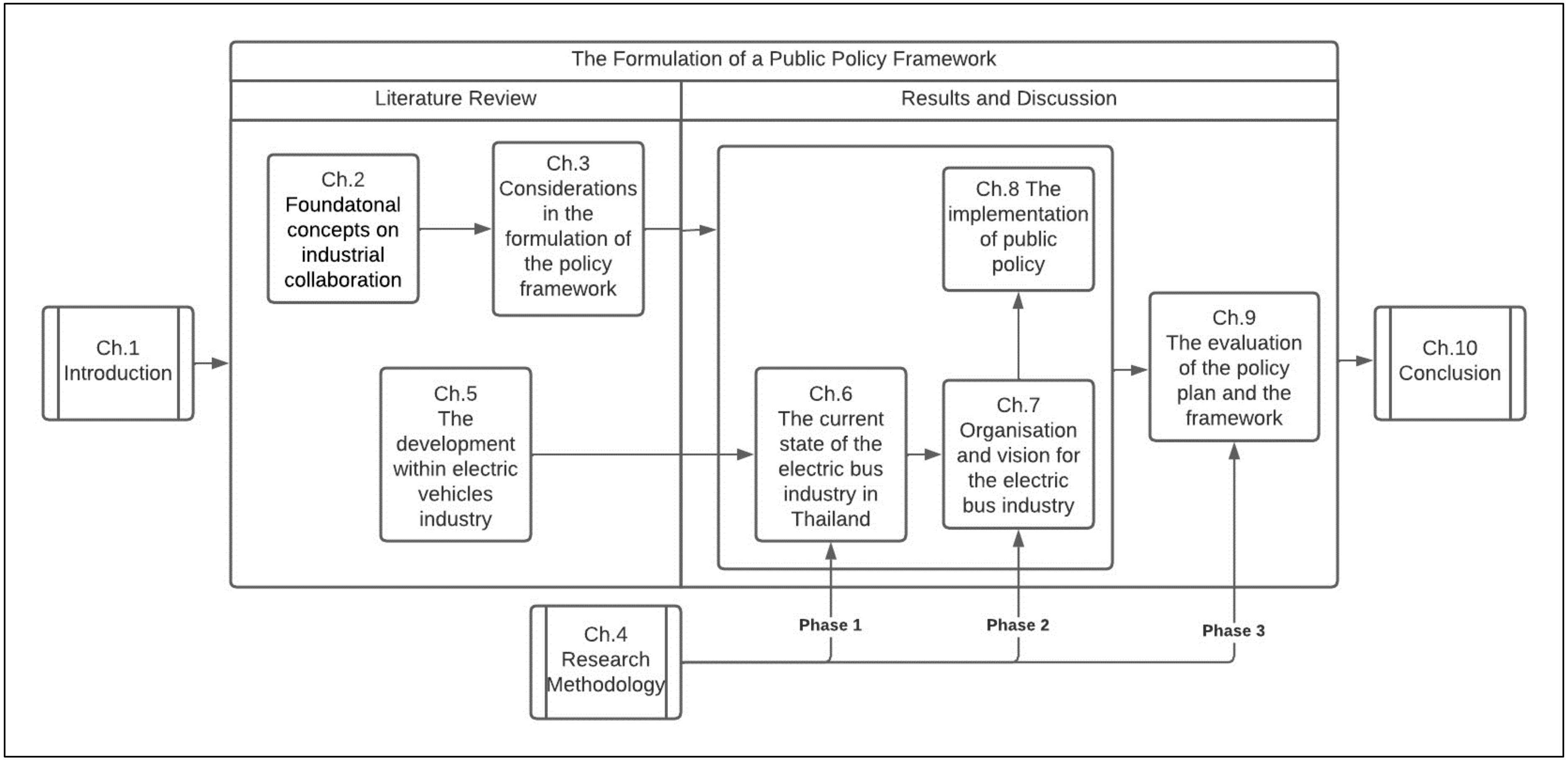

Figure 1-2 The overall outline of the thesis
(Source: Author)

Chapter 2 Foundational Concepts on Industrial Collaboration

2.1 Introduction

In this chapter, three different concepts are introduced: innovation system, cluster, and complex system. Despite the different origins between the three concepts, this thesis asserts that there are several commonalities between them. These commonalities would then be discussed and utilised as foundational knowledge for the formulation of a public policy framework which aim to promote the effectiveness of the operation within the existing innovation cluster of the electric bus research and manufacturing industry in Thailand. It is the intent of this thesis to preemptively study the similar features between these three concepts to encourage a robust and logical design of the policy framework. Furthermore, it is hoped that the common features within the three concepts could lead to a communal conclusion of the characteristic of cluster policies that could help transform the stagnant state of the industry cluster and promote them to involve or engage in more innovative activities that would potentially push the whole industry forward, in other words transforming them into an innovative-based cluster rather than industry cluster. In summary, the review of these three concepts is anticipated to be the crucial ingredients, in addition to the policy instruments, for the development of a domestic industry cluster i.e., policy implementation plan, which would be formed as the main deliverable of this thesis.

2.2 Background of the Concepts

2.2.1 Innovation System

System of innovation or innovation system is the concept that had gained popularity among policy makers and researchers during the past two decades. This concept was first introduced by B.-Å. Lundvall in his book chapter on national systems of innovation (Lundvall, 1985). Afterwards, the concept has constantly evolved alongside the development of innovation policy (Edler and Fagerberg, 2017). There have been many attempts to define 'innovation system', but none of the definitions were accepted among researchers as the definitive explanation (Chang and Chen, 2004). Nevertheless, the correlation between the amount of learning process that occurrs within the system and the scientific breakthrough or innovation was generally accepted as the central idea of the whole concept (Edquist, 2013). The approach to an innovation system in any iteration normally stresses the importance of information and knowledge exchange between actors within the system. These actors are either individuals or organisations within the system who contribute to the development of system's output. In other words, the positive or synergistic interactions between actors within the system are the key ingredients for the development of new ideas, processes, or products and services that are generated by the system in question. The system of innovation has been re-applied into many relating concepts.

Four of the most well-known sub-categories of the system of innovation are; 'national innovation system' (Lundvall, 1985) which had originated the concept, 'regional innovation system' (Cooke, Uranga and Etxebarria, 1997) which is very similar in its presumption compared to national innovation system, except that the system of interest would be geographically smaller in size, 'sectorial innovation system' (Breschi and Malerba, 1997) and 'technological innovation system' (Carlsson and Stankiewicz, 1991) which shift the boundary from geographical area to the type of industrial conglomeration, or the category of technology that is being developed by the system. This thesis would loosely utilise the concept of the innovation system as a foundation in an attempt to formulate appropriate public policy framework that would fit the current situation of the Thai automotive industry. Even though the input from each of the concepts would be considered, the sectoral innovation system will be emphasised in the literature review, followed by the regional innovation system because of the similarity of their scope, as compared to the current policy adoption plan in Thailand, which focuses on regional and industrial development.

The national innovation system concept is an approach that was developed in order to formulate the optimal path by orchestrating governmental and infrastructural policies within national geographical boundaries. It was established as an economically-driven framework to facilitate the growth of the country by the mean of innovativeness (Lundvall, 2007). This framework is very prominent in the field of science and technology policy. Several subsequent theories and approaches were developed based on the core ideas of the national innovation system. It has been a popular topic to be discussed, especially for developing countries (Kayal, 2008). Many nations are lured by its promise of increasing competitiveness, and the opportunity to catch up with the developed world. (Attia, 2015) However, it should be noted that the term 'innovation' is vague and usually subjected to misinterpretation by the general public. Many countries adopt the term without grasping its true meaning. Some critics interpret innovation as a 'buzz word' without any coherent meanings across several policy schemes (Intarakumnerd, Chairatana and Tangchitpiboon, 2002). This belies the proper utilization of the approach which could consequentially rendered it as an unconvincing topic in the point of view of some policy makers. There are also other major criticisms regarding the national innovation system approach aside from its vagueness and misrepresentation in many public settings, which will be explored further in later part of this chapter.

Regional innovation system was a concept that was directly inspired by the national innovation system. It was downscaled for the sake of better applicability towardss smaller sub-systems that are larger than a city, but smaller than a nation (Cooke, Uranga and Etxebarria, 1997). Even though Cooke was an advocate on utilizing the concept to improve United Kingdom regional innovation and industrial competitiveness, he also pointed out that a regional innovation system is not a total solution for regional development (Cooke, 2001). To be able to bring out the full extent and realise the benefits of this innovation-based policy, governments need to ensure that the system is decentralized and flexible enough to adapt itself according to the rapid and disruptive technological change (Asheim and Coenen, 2006). Due to this flexibility, the main advantage that has been emphasized for regional innovation systems is the opportunity for enterprises to enter an overseas cooperation with foreign companies, in contrast to national innovation system where the process of building up a network of collaboration is much slower. Nevertheless, a national innovation system is also crucial for its encompassing regulatory power that could be exerted, in order to make sure that the system of development works in accordance to the national policy. Hence, regional innovation system should always be regulated and used in conjunction with national policy, to ensure the effectiveness of regional development (Thomas, 2000). The advocate of regional innovation system also pointed out some of the most important factors to consider when creating regional innovation systems. Many of these factors are similar to what would be presented in the literature review regarding the formulation and operation of innovation cluster, which would be in the upcoming sections of this chapter.

Sectoral innovation system and technological innovation system are often bundled together as two of the smaller and less developed concepts of innovation system in many literature (Chung, 2012). Furthermore, they both focus on industrial boundary rather than geographical boundary akin to national or regional innovation systems. Despite the relatively lower volume of related work, they would be very substantial for the creation of the policy framework that is based on a certain artefact such as electric vehicles. A sectoral innovation system was described as a flexible tool to study the cultivation of innovation in a specified sector. A sector is broadly defined by network of actors that pursue the same objectives and possess interlinking, common form of knowledge (Malerba, 2002). The concept shared a lot of commonalities with the national innovation system. The major different is that a sectoral innovation system puts a lot of emphasis on the collective demand of institutions, which makes the concept more suitable in a smaller scope of corporate setting. The technological innovation system first originated as 'technology system' (Carlsson and Stankiewicz, 1991). It mostly shared the same characteristics with other concepts in system of innovation, which involve the importance of technological knowledge generation, diffusion, and utilization. However, many of the recent literature labelled it to be a system of innovation that focuses heavily on the deeper context of technology (Carlsson, 2007). This include the less aggregate application of the technology in question, and most often debased into a single application of the technology (Markard and Truffer, 2008). As a result, most scholars would apply the technological innovation system concept in a much more restrictive environment, in contrast to the open-endedness of the national innovation system and regional innovation system which mainly concerns macro scale development of the nation or a region.

It was asserted that the degree of sectoral specialization depends on how frequent the same group of knowledge is circulated within the region (Asheim and Coenen, 2005). Originally, regional innovation and sectoral innovation are mutually exclusive categories of an innovation system. As described before, a regional innovation system (RIS) was mainly based on geographical proximity, while a sectoral innovation system (SIS) was mainly based on industrial sectors. Porto Gómez, Otegi Olaso, and Zabala-Iturriagagoitia (2015) introduced the conceptual framework that integrated both concepts together as regional open sectoral innovation system (ROSIS). This study is similar to what would be the core principle of this thesis's policy framework for electric vehicles' innovation clusters. Therefore, the details on this article, especially its research method would be worthwhile to examine. Moreover, the core concepts of this study shared a lot of similarities to the idea of how proximity affects collaboration and innovative performance, which were set to be the main topic of discussion in this chapter. It should be noted that the analytical framework that was developed by this research only provides a snapshot for a specific moment in time (figure 2-1). Therefore, the framework would still have limitations on its inability to explain some evolutionary changes over time, which could occur during the lifecycle of an innovation cluster. However, the issues would be less detrimental if there is a robust framework that could readily utilise new information that is periodically collected. This consideration is one of the most prominent ideas behind the design of every components in the framework.

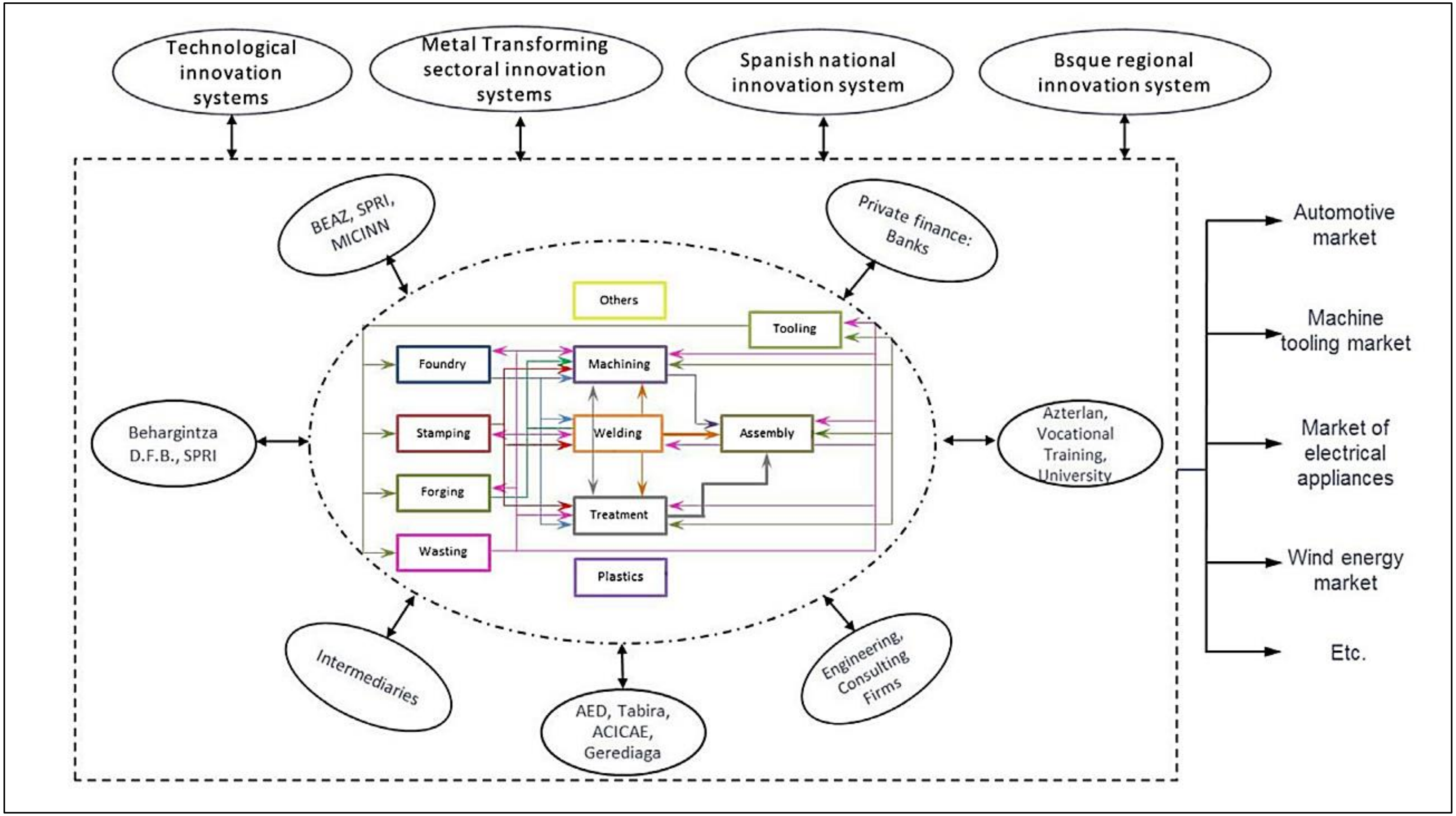

Figure 2-1 Characterizing a ROSIS in the Durango County.
(Source: (Porto Gómez, Otegi Olaso and Zabala-Iturriagagoitia, 2015)

2.2.2 Industry, Business, and Innovation Cluster

Industrial cluster, business cluster, or competitive cluster were described by Porter (1990) as a geographical location where resources and competencies are frequency exchanged between industrial actors. This definition shares significant similarities to the concept of an innovation system regarding the increasing importance of information flow and cooperative networks for industrial development (Pyke, 1992). According to the literatures that were presented in the previous section, collaborative efforts were proven to be strongly contributory for the attainment of innovation in any system. Likewise, innovation is the key aspect for any industry to maintain their competitiveness in the modern global arena with increasing technological complexity and a higher degree of market globalization (Farinha, Ferreira and Gouveia, 2014). There were some misconceptions among academia that the study of industry is the same as the study of industrial clusters. This is not true, because the study of a specific industry subconsciously ignores external linkages from that industry to other closely related industry (Chu, Zhang and Jin, 2010). This research aims to avoid this oversight and focus on an industrial cluster as a system of multiple actors linked together in complex multi-level collaborative relationships. Each of these actors would partially be doing their own share of contribution to the development of products or services within the cluster.

Another concept that has been increasingly researched due to the growth of virtual network technologies is innovation clusters (Feldman, 2002). An innovation cluster was defined as a virtual agglomeration of cooperation among multiple firms, in contrast to a science park which was defined as an agglomeration with geographical proximity (Salvador, Mariotti and Conicella, 2013). Similarly, the differences of an innovation cluster from a traditional industrial cluster were also emphasized in another paper. It was asserted that innovation clusters are more focused, based on technological and innovation knowledge, and more likely to utilize strengths and capabilities of a nation or a specific region than industrial clusters (Lee and Choi, 2013). In fact, both of these definitions could cause confusion because 'cluster of innovation' is another concept that was developed from the idea of industrial cluster, which also emphasised the important of physical proximity (Engel, 2015). It is believed that the innovation cluster could be a direct evolution from the industrial cluster. This evolution would require a highly creative population within the cluster, and the paradigm shift from production and efficiency based operation to research and innovation based operation. It is asserted that the process of transformation towards innovation clusters can be accelerated by the accumulative concentration of industry-academia linkage and knowledge sharing between parties within the cluster (Liao, Fei and Chen, 2007).

There is a substantial gap in literature regarding the study of innovation management within the context of innovation clusters. In general, it has not been clearly proven that innovative research activities fully contribute to regional development and industrial competitiveness of the region (Farinha, Ferreira and Gouveia, 2014). There were many case studies that illustrated the positive impact of a well-structured innovation management and entrepreneurial activities towards regional and national economic development. However, most of them are very context-specific. It was asserted that a different approach is needed for the effective development of a disparate region (Enright, 1999). Furthermore, the dichotomy regarding the presence of physical proximity in innovation clusters are still at large, which makes the meaning of the terminology arbitrary to academic experts. This proved that the innovation cluster is a moving concept that have not yet resolutely defined. Therefore, many researchers in the discipline of innovation policy had varying opinions on the concept (Davis, Creutzberg and Arthurs, 2009). Nonetheless, one of the most grounded conclusions is that the collaborative effort and knowledge sharing between different organisations across several sectors are fundamentally important for innovation, similar to the core idea behind system of innovation concept. In summary, the approach of innovation cluster is becoming increasingly popular for the study of public policy, and has been viewed as an important catalyst for the new and emerging economy, which is driven by the ever-changing force of technological revolution.

2.2.3 Complex System and Complexity Theory

Complex systems have been studied by humans for more than a hundred years. It is constantly evolving and encompasses many branches of science. The concept has been utilized in a field of public policy management (Geyer and Rihani, 2012), and could be used as a frame of reference to the formulation of a policy framework in this thesis. The main features of complexity theory do not differ greatly across disciplines except for some minor variations. There are prominent recurring characteristics across the literature surrounding complex systems and complexity science in several fields of practise including networks (Moffat, 2010), non-linearity (Styhre, 2002), emergence (Goldstein, 1999), and adaptation (Hornstein, 2004). In addition, there are many way to define a complex system, though most of them would similarly elaborate on the problems that complex systems posed to researchers and how pragmatic solutions are needed to solve these issues (Ladyman, Lambert and Wiesner, 2013).

There are a significant amount of properties in innovation system that are similar to the main features of complexity theory (Fischer and Fröhlich, 2001). First, an innovation system could be considered as a complex system because the similar composition, which consist of small sub-systems and their large amount of information flow among the members (Katz, 2006). This information flow could possibly generate emerging results that cannot be traced back to their root. This kind of phenomenon is called *emergence*. Emergence has been described an evolutionary process shaped by the numerosity of system's composition, i.e. the combining effort from many elements within the system could generate a radical outcome which could not be achieved with members with the same characteristics and capabilities (Filho and Heerdt, 2018). Therefore, It is asserted that the entities within an innovation system are usually engaging in more innovation-oriented activities when compared to several companies in isolation (Lenchuk and Vlaskin, 2010). This point also coincides with the non-linearity feature of a complex system according to complexity theory. With the right format of an organisation, synergies between many elements in the system could be created spontaneously. These synergies allow the whole system to achieve a greater innovative output than what an independent group of elements could accomplish. The prefered structure of an innovation cluster is described as a flexible and non-rigid type of network. In the same way, a complex system normally relies on a decentralized decision-making processes and system autonomy, which allows them to respond better to circumstantial changes. This mechanism ensures that the system as a whole has sufficient innovative capacity to quickly adapt itself in the wake of technological disruption (Lenchuk and Vlaskin, 2010). These are the desirable characteristics of the system that policy makers should aspire to attain when they adopt public policies that focus on the innovation system.

The mechanisms used to develop regional and sectoral innovation systems are strongly affected by its surrounding environment, especially both tangible and intangible resources and capabilities within the region or industry sector (Asheim and Coenen, 2006). These external factors could possibly influence the degree of cooperation and competition within an innovation system. This concept is similar to another characteristic of complex systems, in which the system often adapt to the environment in their vicinity. The ability to adapt is the key element of fostering a good cooperative relationship between multiple members within a specific boundary (Lenchuk and Vlaskin, 2010). Innovation have been regarded as an emergent outcome from a series of small events within the network, and these events usually originate via the opportunity created by a highly adaptive and unconstrained environment in complex systems (Filho and Heerdt, 2018). Nevertheless, it is almost impossible to capture all of the essence of a complex system within a singular model (Sugeno and Tanaka, 1991). Multiple case studies from existing innovation clusters might be required, in order to draw a clear conclusion on how innovation clusters could operate effectively and provide satisfactory results.

Since it was established that several characteristics of an innovation system match the features of a complex adaptive system, it might be appropriate to utilise several presumptions from the complex system theory in an attempt to formulate a public policy framework for an innovation cluster.

It was asserted that in order to extract the essence of innovation that could lead to the emergence of new ideas, public institutions need to offer a valid policy instruments with regard to the external environment (Tödtling and Trippl, 2005). Therefore, the holistic approach of analysing and managing this system would be employed by this thesis. This approach would offer utmost scrutiny over externalities which could vary greatly in different geographical locations or industrial settings. The governing institutions need to be mindful about those conditions if success is expected to be achieved in the establishment and operation of innovation clusters. Futhermore, the governing institue also need to ensure a fine balance between policy control and free interactions among actors within an innovation cluster (Filho and Heerdt, 2018).

2.3 Application of the Concepts in Industrial Settings

2.3.1 Innovation System and Industrial Development

In Scotland, it was found out that the problem in the Scottish innovation system was not because of their weakness in scientific inputs or the ineffectiveness of policy making, but the disconnect between scientific knowledge and its real application in the industry (Mastroeni *et al.*, 2017). In other words, Scotland struggled to transform their knowledge into products and services that would give their industrial sector competitive advantages. To solve this problem, this innovation system has to specifically put a lot more focus on industrial enterprises. More inclusivity needs to be put forth with the dealing of potential network building. The linkage that would be established should not be exclusive to strong actors in the same industry, but also between weak and strong industrial players (Roper, 2007). Knowledge accumulation and knowledge transfer are very essential for the development of innovation system. There should be a mechanism to encourage the movement of skilled labour towardss the network that was built. Without skilled workers to support the system, innovation would not happen regardless of how well-maintained the infrastructure of the system is. Many countries have more than enough skilled workers for a certain task. However, the difficult puzzle for them is how to mobilize all of these workers into appropriate slots that fit their skills and qualifications.

In the United States, there were two large-scale attempts to create the center of global innovation in technological advancement; one along the highway number 128 surrounding Boston and another in the area of Northern California which is now known as 'Silicon Valley'. Route 128 has been cited by many academic papers as a prime example of how regional innovation systems could fail (Kenney and Von Burg, 1999). This is a sharp contrast to how Silicon Valley has been considered by many people as a role model for innovation system. The primary argument for the failure of Route 128 in the 1980s was how the network did not support free information sharings between actors within the system. Most of the interactions were only among business partners because of the confidentiality concerns of certain actors (Qi, 2013). This phenomenon somewhat limited the potential of innovation diffusion to only some highly influential enterprises, which acted as central nodes within the system. Moreover, this alignment of the network was also more vulnerable compared to a decentralized system. In the case when central enterprise encounters a crisis, the system might lose its ability to innovate. The damage to the whole network would be considerably large, to the point that the system might collapse from this adverse effect.

As mentioned before, innovation system is a broad concept, which encompass all of the interaction among stakeholders within the denoted boundaries. It is generally more reasonable to narrow-down the prospect of observing every interactions within the holistic network of the system and streamline the process into something more relevant. This is the main reason why sub-national alternatives such as sectoral or regional were developed. Charles Edquist asserted that the modification of the approach is needed when applied to several different socio-technological environments (Edquist, 1996). Many successful implementations of a national innovation system became the aspiration for many countries. However, the successful attempt in implementing a national innovation system in a developed country would not be easily imitated in developing countries' cultural and political environment. Some mismatches between the approach and the variability of national industrial capabilities could leads to a possibility of system failure (Watkins *et al.*, 2015). There are two aspects that were considered as the weaknesses of the national innovation system approach. First, the conceptual diffuseness of many terminologies in the approach could leads to many different interpretations by different actors within the network. Second, the boundaries of the system are not specified by the approach (Edquist, 2010). This lack of tangible frontiers would further complicate the macro-level of national policies. Aside from the direct opposition, the national system of innovation also faces a wide array of real-world challenges. These issues including how to design a system that can withstand the rapid rate of globalization, the more prominent and ever-emerging roles of non-governmental intermediaries within the systems, the resistant to change of the state and bureaucracy, the various types of learning processes which require different ways to administrate, the friction among actors which could originated from uneven policy implementation, etc. All of these issues have to be carefully assessed, in order to improve the effectiveness of innovation system approach.

Most innovation policies based on the innovation system approach e.g. national innovation system, regional innovation system are wrongly considered by many policy makers to be a 'one size fit all' solution. In many circumstances, this approach would have several weaknesses in terms of solving specific context-based issues. This stems from the fact that specific problems in the system are difficult to identify and measure, even for the policy maker who work spatially within the system. Furthermore, the process of innovation is highly path-dependent, thus it is almost impossible to design an optimal innovation system. This was also a mistake of Thailand's innovation policies in the past, where the focus was often on how to set an optimal threshold for the system instead of adopting a more adaptive and flexible framework (Chaminade, Intarakumnerd and Sapprasert, 2012). In the previous decade, Thailand performed admirably well in the area of industrial growth by promoting effective means to boost the industrialization, such as the establishment of many industrial estates to facilitate logistical flow in the supply chain (Aveline, 2010). However, Thailand was also found to be performing badly in term of research and innovation, especially in the aspect of actual research applications and commercialization. Part of the problem was because of the weak collaborative network between industrial and manufacturing sector with research and development sector. This circumstance resulted in low impact of academic institution's researches.

2.3.2 Complex System within Industrial Context

There was an attempt to link the characteristics of complexity theory towards the study of regional innovation system and cluster (Martin and Sunley, 2007). Nevertheless, it was asserted that there are no dominant existing mechanisms that could effectively portray the system in the actual setting (Martin and Sunley, 2011). As a result, this type of research should involve careful analysis of the external environment. A 'meta-model' or framework that could illustrate the system should be made from the foundation of a specific ecosystem which is subjected to the impact from an adjacent cluster. There are several applications in the industry that could be considered as a complex system. With this consideration, this section would present both positives and negatives of having a complex system as a topological structure for industrial or technological development from multiple cases. Furthermore, some suggestions regarding the practical process of managing and maintaining a complex innovation system i.e., the combination of an innovation system and a complex system, by utilizing public policy instruments would also be gathered in the next subsequent section. The insights on how to effectively formulate a public policy framework for several different situations might be learned from these cases.

In the study by Fogelberg and Thorpenberg (2012), the interviews of stakeholders in five main categories within the innovation system were conducted. The categories were national agencies, regional authorities, large industry incumbents, university researchers, and small to medium enterprises. The objective was to gather the opinions of each sector on the function of the complex network within the system. The results show that they perceived the network as an entity which had no interest of its own and a neutral development partner. Theoretically, this finding could tremendously reduce the period of time in knowledge transferal from the research sector to the business sector, and improve the rate of innovation (Schilling and Phelps, 2007). Nevertheless, there are still a lot of problems that could arise in a practical setting, especially the process of managing every stakeholders in the system and maintaining their constant participation. This specific topic would be explained in more detail in the next section. Aside from the consideration of how to manage the system complexity, a robust topological network structure, where there are many interconnections between actors also has some prominent negative properties (Qi, 2013). Firstly, more frequent opportunity that each actor could interact with other parties within the system could lead to a higher chance of harmful relationships. Small fragments of negative interactions might constitute to a damaging and enduring impact on the system because of the high degree of interconnectiveness. Secondly, there will be some difficulties regarding the pooling of central resources into each part of the system. Preventive measures are needed in order not to evoke any discontent from the members of the system. Lastly, the interdependency of this complex structure would give rise to various possible issues when any single element is removed from the system. The degree of damage would be in proportion to the degree of importance of that specific element, or the number of extensive connections it currently has with other elements in the system.

In the highly successful aircraft industry in the United States, It was showed that the structure of the industry inhibited the form of a complex industrial cluster (Porter, 1990), which linked many relating sub-industries such as metal making, automobile, electronics, machinery and equipment, etc. together. It was concluded that the higher degree of complexity within the system and more network formation among stakeholders equate to the higher competitiveness of the industry. The findings regarding this benefits of network density in the US share some similarities with the findings on the Chinese aircraft industrial cluster, i.e. the performance of the aircraft industry is directly proportionated to the density and complexity of the network (Chu, Zhang and Jin, 2010). However, the appropriate management practice is also required, in order to control the multi-layered complex system of this proportion (Kim and Shim, 2018). Multi-level governance might be another key terminology which could link policy or managerial practices to the core concept of a complex system. There are also many major studies on multi-level governance within the context of national and regional systems of innovation (Koschatzky and Kroll, 2009).

It would be useful to perform a cross comparison to analyse the similarities and differences of practical usage between multi-level governance and the regulation of complex systems. Additionally, these two concepts could be used in conjunction because science and innovation policy usually apply a non-linear approach in the policy making process, in contrast to other fundamental public policies such as healthcare or education (Lyall, 2007). Because of the complex and multi-layered structure of innovation systems, it might be a better idea to change the strategic perspective of policy making from bilateral supply chain into multilateral supply chain. It is asserted that the bilateral supply chain emphasizes the importance of either technology-push or demand-pull system (Neher, 2005). Technology-push is a supply chain system in which the industry favour technological advancement, and will make the product based on technological progress. Conversely, demand-pull system is a supply chain system in which the market demand is carefully assessed before the full development of products and services. It is asserted that this classical concept is not effective in analysing complex systems such as innovation clusters. Instead, the researchers should use multi-perspective methods such as multi-level governance or multilateral analysis of the supply chain to formulate the infrastructure of innovation systems (Park, 2002).

2.4 Considerations for the Established Innovation Clusters

2.4.1 The Importance of Motivation and Social Incentives

An innovative network or cluster could emerge from several causations. The underlying motivation of each actor within a business network can be explained through game theoretic approach, i.e. each actor would form the relationship based on payoff-maximizing decision. It was asserted that most of interactions in the network came from individual's cost-benefit calculation derived from social exchange theory (Cowan, Jonard and Zimmermann, 2007). In addition to the concerns of circulating amount of knowledge between firms, organisations in the system would engage in partnership only in the case that mutual benefit exceeds the calculated cost of forming a partnership. These costs include not only in monetary terms but also other aspects such as reputation, time, influence, etc. (Muthusamy and White, 2005). Social exchange theory emphasises system member's motivation for cooperating which is not dissimilar from the core idea of game theory which contributed a lot of its ideas to complexity theory (Roughgarden, 2010). The model of social exchange theory explains how a network structure could be different, based on the format of alliance formation and the degree of embeddedness within a complex system (Nee and Ingram, 1998). Embeddedness is a requirement for the engineering of a good structure for innovation clusters. However, different issues from the proposed model could also arise on the actual implementation of the framework. This might include conflict between individual's motivation (Vaaland and Håkansson, 2003). The significant gap between the theoretical innovation system model and the actual implementation of an innovation cluster needs to be explored further, in order to maximize the benefit from this collaborative innovation model (Fogelberg and Thorpenberg, 2012).

In a research by Krueathep, Riccucci and Suwanmala (2010), three factors that are believed to be the main causes for inter-organisation collaboration within the network were identified. Firstly, it was asserted that collaborations happen because of the motivation to find a solution for a complex problem that could not possibly be solved by the attempt of a single party. This statement aligns with the concept of a complex system, where the system as a whole would be able to solve a problem via novel methods that are generated by the cooperation of many agents. This emerging method is usually a unique outcome of synergistic interactions between actors. The second motivation for collaboration is resource dependency. The probability of cooperation is proportionate to the level of dependacy between each actors, in regard to the utilisation of external resources from other agents (Pfeffer and Salancik, 2003). Lastly, it is asserted that the lack of knowledge and information transfer would lead to the tendency to collaborate (Grant and Baden-Fuller, 1995). This also includes the lack of financial and human resources for the operation. This drawback forces small local public organisations to cooperate to maintain their competitiveness. This is especially true in the case of profit-driven enterprises. Corporations within business network are forced to collaborate and share strategic resources with each other, in order to reduce their own operating and procurement cost (Osarenkhoe, 2010). In conclusion, the study regarding determinant characteristics for the formation of a network is beneficial to both public and private institutions. Despite that this thesis mainly focuses on innovation clusters as the initiative that would be primarily driven by public policy, the involvement of private sector would also have a large impact on the implementation of policies. Hence, it would be useful to study the subject of networking motivation from a corporate business perspective, in addition to the vision of the public sector.

It was observed that social capital could also influence the motivation towards external collaboration of an indvidual firm (Nahapiet and Ghoshal, 1998). In this context, researchers often focus on three dimensions of social capital; cognitive, structural, and relational. First, cognitive embeddedness is the choice in which organisation try to form a relationship due to their perception of missing resources. Second, structural embeddedness describes how firms seek to build a relationship with an agency that are close or similar to themselves in term of organisational culture, physical or network proximity, and manner of operation. In contrast to the two supposedly palpable types of social capital; the third dimension, relational embeddedness is built from intangible concepts like trust, obligation, and ethics. It was found that some firms give more emphasis to these values in the choosing of their partners rather than a pure calculable economical reason (Cowan, Jonard and Zimmermann, 2007). Unfortunately, this type of causations would be difficult to analyse and generalise into a model, which is another challenge for the formulation of a policy framework to improve inter-organisational collaboration. Nevertheless, it was stated that social capital in all of these three dimensions could facilitate knowledge sharing activities among companies within the system. Furthermore, it was also proved that the increment of knowledge sharing activities positively correlates to the performance and innovation of the cluster (Kim and Shim, 2018).

2.4.2 The Effect of Physical and Virtual Proximity

Aside from economical and societal aspects, proximity is another important consideration for the creation of innovation systems and innovation clusters. The concept of proximity in industrial cluster was also originally categorised into three big classifications; geographical, relational (or institutional), and organisational (Shaw and Gilly, 2000). It was later expanded into five categories; geographical, relational, organisational, social, and cognitive (Boschma, 2005). Despite both having the same prefix, it seemed that relational embeddedness and relational proximity does not share the same definition. Relational embeddedness of social capital is more similar to the concept of social proximity, while the concept of relational proximity shares several similarities with cognitive embeddedness instead. Nevertheless, it might be useful to link these two theories together to explain social networking phenomenon in innovation clusters. In one case study, a family business was investigated to explore the relationship between social capital, proximity, and innovative performance. In a network with low level of geographical distance, it was found that family businesses had higher conversion rates of local researches into substantial outputs than non-family businesses despite being less willing to invest on the research and development (Pucci *et al.*, 2017). On the contrary, there was no significant difference in innovative performance between family firms and non-family firms in a network with a high level of geographical distance. This result showed that both social embeddedness and network proximity would have a crucial role towards the development of complex innovation system within innovation clusters.

According to Lundvall and Johnson (1994), innovation stems from interactive process and learning economy within the organisation. Interactive processes can be enhanced by many factors, including physical proximity between actors. Physical proximity is one of the key points emphasised in the research that studied the success of Baden Wurttemberg cluster policy. It is stated that the interaction could take place rapidly because of the low geographical distance among important stakeholders (Staber, 2001). The results of this geographical proximity are the augmentation of both formal and informal networking. Despite that physical proximity has been foreshown as an important factor for increasing interactions between actors, it is suggested that mobile and informal business incubators will be increasingly more effective to grow new firms. This idea dated back to two decade ago, when various key characteristics between a traditional regional innovation system and new economy innovation system were presented (Table 2-1). The latter system was characterized by a more decentralized approach of cluster formation. Nevertheless, it is important to note that many science parks nowadays also include on-site business incubators. This development might bridge the gap between a classical concept of regional innovation system and a more contemporary concept of innovation system and cluster.

Table 2-1 Aspects of regional and new economy innovation systems (Source: Cooke, 2001)

Regional Innovation System (RIS)	New Economy Innovation System (NEIS)
R&D driven	Venture capital driven
User-producer relations	Serial start-ups
Technology-focused	Market-focused
Incremental innovation	Incremental and disruptive
Bank borrowing	Initial public offerings
External supply-chain networks	Internal Econets
Science park	Incubators

With the rapid evolution of information and communication technology, many researchers argued that being physically close in a business network would not provide substantial benefits akin to the perceived benefits prior to the beginning of the information age. It was debated that people could still effectively and economically connect and interact with each other despite the geographical distance (Rallet and Torre, 1999). Similarly, according to the survey extracted from the members of both science parks and innovation clusters of similar functions, most respondents noted that the differences are minor (Salvador, Mariotti and Conicella, 2013). In the comparison between Gwanggyo and Pangyo Technovalley in South Korea (Lee and Choi, 2013), it was found that Industry-academia cooperation is usually high when compared to other forms of interaction i.e. industry-industry or industry-government in both places. Since only Gwanggyo was situated near an academic institution, this implied that physical proximity may not be a significantly factor to the higher concentration of collaborative efforts. However, this outcome was possibly influenced by additional geographical features of the establishment. Pangyo's closer proximity to Seoul might contribute to its collaborative tendency to the academia despite the fact that the location is not fully integrated with the campus of any university. In addition to the proximity of employees, a well-established system of information storage and management should be included within the site. However, there is still a question regarding the necessities of physical location for this procedure. Most of the respondents in another survey stated that they were indifferent towards having a physical database for information (Premkamolnetr, 1999). On the other hand, the accessibility of information via local internet network was percieved as extremely crucial. Moreover, the coverage of communication is also emphasised by the participants of the survey. There were concerns that most of the tenants would not be aware of the range of information services that were offered by the science park.

On one hand, virtual clustering complements many existing aspects of an industrial cluster and a science park, especially how they could provide more opportunities for inter-firm linkages. On the other hand, physical proximity is still required because of the unique benefits it constitutes, which could be explain by the theory of proximity (Boschma, 2005). Location-based science parks normally benefit from almost all form of proximity effects, while virtual clusters would only benefit from cognitive and organisational proximity. Moreover, the creation of social and interpersonal linkage would be more noticeable in the physical settings of research collaboration. However, few researchers have provided a contrasting viewpoint on how cluster and proximity might be detrimental to the innovativeness of the participating enterprises. One of the possible shortcoming is entrenchment effect, which is sometimes associated with a strong network linkage. In strong network linkage, organisations could get locked-in to their network of local relationships and associated routines. Thus, their technological capabilities are not uniquely developed (Pucci *et al.*, 2017). This so called 'locked-in effect' leads to decreasing innovative performance of a firm. The relationship between social capital and the degree of innovation is similarly described by a curvilinear curve (Maurer and Ebers, 2006). At first, social capital is helpful for a company to break the external barrier and exchange the knowledge with each others. However, intense social capital might lead to a reduction in innovative performance. There were a lot of conflicting opinions in many researches on the effects of social capital towards innovation. It was concluded that social capital would have a different effect depending on the nature and typologies of the network in consideration (Inkpen and Tsang, 2005).

2.4.3 Knowledge Exchange Mechanisms

Rapid change in the technological landscape forces businesses and enterprises to adapt themselves according to the flow of innovation and technology disruption. However, the development of technological competencies solely by themselves are sometimes not feasible because of the large amount of time that needs to be invested in order to develop a certain expertise within the organisation. This is especially true for small and medium enterprises (SMEs). Business networking and inter-firm cooperation are becoming increasingly popular to these firms (Cowan, Jonard and Zimmermann, 2007). Since Thailand's automotive industry consists of a significant number of SMEs, it might be very beneficial to ascertain their rationality of decisions in choosing business partners. Nonetheless, these patterns are not easy to interpret, and even more difficult to explain to a non-mathematical oriented audience. Thus, the aim of this research is not about the explanation of the phenomenon based on the mathemathical model, but rather make an attempt to explain the causality in general language. The features of the formulated public policy framework should be intelligible for extensive group of individuals, inclusing both experts and laypeople who involved in the industry.

There are four basic factors of production in the school of classical economics; land, labour, capital, and entrepreneurship. In modern economics, Yoon (2017) asserted that the positive effects of these factors to industrial competitive advantages are weakened, in contrast to the escalating prominence of knowledge, information, and technology. A distinctive difference of the latter set of factors from the former is that they are transferable between enterprises to a significant degree, and usually contribute to innovativeness of an organisation (Sankowska, 2013). The need of research collaboration is rising in any learning environment. This need is derived from the fact that industrial competitors seek competitive advantages through the mean of knowledge, information and technology sharing among their business partners. Sharing information is usually a cost-effective practice to gain more competitive advantage, and also provide mutual benefits to both parties (Hong *et al.*, 2004). In addition, it is asserted that internal resources and capabilities are generally not sufficient for commercial enterprises to maintain their competitiveness among their competitors. In order to maximize their potential to innovate, firms need to leverage external knowledge from other organisations (Pucci *et al.*, 2017).

As mentioned earlier, cluster strategy is one way to promote external knowledge transfer by putting a group of companies together in close proximity (Muro and Katz, 2011). Many business clusters adopted the programme to include this ‘information transaction’ outside their own industrial boundary (Doeringer and Terkla, 1995). It has been mentioned previously in the last section that proximity is one of the key ingredients for innovative process. However, the positive relationship between proximity and innovation is not straightforward. Additionally, this relationship was shown to be highly dependent on other factors. For instance, It was found that the size of network usually has a curvilinear relationship with the concentration of collaborative efforts (Pucci *et al.*, 2017). To put it simply, this means that proximity generally contributes to a more frequent scientific collaborations, but would provide diminishing benefits when the size of network is growing larger. The possible explanation might be that the original infrastructure of the cluster will not have enough coverage for all proponents within the cluster. Therefore, there will be many factors that need to be predetermined before the effective uses of cluster strategies and policies.

Another reason for weak collaboration and low concentration of knowledge exchange is the aspect of spatial organisation. The cooperation within the aircraft industry in China was weak because most of its relating industrial enterprises are too scattered. As a result, high communication and logistical costs discouraged them from forming contacts or generating business links to other companies (Chu, Zhang and Jin, 2010). This was in accordance to the finding by Poapongsakorn and Techakanont (2008), regarding how geographical proximity of Thailand’s automotive enterprises could enhance their degree of collaboration and increase the concentration of business network within Thai automotive industry. This is another piece of important evidence that supports the idea behind the establishment of an innovation cluster. Aside from the technical and inter-organisational issues, organisation culture and intra-organisational issues are also important to the cultivation of innovation ecosystem. The shift from classical division of labour to consultative and interactive labour relations should be encouraged, in order to improve the learning environment within the organisation. It was asserted that a higher degree of organisational ownership of workforce attributed to the ease of management and innovation capacity of the firms (Lundvall, 1995). These features normally affect every aspect within an innovation system, but most of the study with the application for public policy would put them aside in favor of a more macro and overview analysis (Cooke, 2001).

The literature indicated that there might be three false assumptions in the studies regarding physical proximity and knowledge sharing. Firstly, there might be an overemphasis on knowledge generation via external sources of knowledge. It was proved that external knowledge could prevent the companies from being ‘locked-in’ with their current technological capabilities. However, this might not be fully applicable for large gate-keeper firms, since their capabilities are already at high level

(Boschma and Ter Wal, 2007). There might not be any new competencies that they could learn from their peers. Secondly, the assumption that all firms in a district would benefit equally from knowledge externalities. This is a pitfall that academic researchers usually make when analysing industrial or technological clusters. It is often assumed that each actor within the network can fully utilise the advantages of being within the clusters and gains substantial benefits from knowledge exchange activities. However, this is usually not the case because not every firm could absorb the same amount of technological knowledge, mainly due to their limitation of resources (Giuliani, 2005). The difference in absorptive capacity further complicates cluster approach and make it difficult to be properly assessed. There are a lot of discrepancies in several organisational metrics that stems from the different level of absorptive capacity in each firm, including innovative performance and growth, information management, etc. Thirdly, the incorrect presumption about the network topology within the cluster that it is exclusively internal. On the contrary, many firms also rely on relationships outside the cluster as their additional means to get external sources of knowledge (Keskin, 2011). Nonetheless, it was expected that any well-connected firms within a cluster would not gain significant improvement on innovative performance from non-local external ties, because the knowledge accumulation in a cluster was supposed to be sufficient for organisational growth.

2.4.4 Degree of Policy Intervention

Innovation clusters could occur naturally or be created artificially by policy intervention. These are considered to be two main types of technology and innovation clusters. Natural innovation cluster such as Silicon Valley rarely occur in normal conditions and require a lot of suitable factors to succeed. Alternatively, the location and strategic directions of artificially-formed clusters are designated and developed by central or local governing institutions. Most of the artificial clusters are created to simulate the success of natural technology or innovation clusters. The example of an artificially-created innovation cluster is Zhongguancun technology district in Beijing, which tried to imitate the mechanisms that led Silicon Valley to success. In fact, most innovation clusters that were recently established are systematically induced by national development policies (Lenchuk and Vlaskin, 2010). An artificial innovation cluster is designed to be the catalyst for the process of innovation. It normally involves both bottom-up and top-down interactions together in one synergistic system (Jucevičius and Grumadaitė, 2014).

The important question for this topic is: which elements of an innovation cluster contribute to the positive outcome of the innovation process? This outcome could be derived from public policy intervention directed at stakeholders in the industry. Alternatively, it could also be derived from stakeholder's free interaction among themselves. From the case study of Silicon Valley, there was a general consensus that a favourable network topology for new innovation to emerge is when each actor within the system can freely interacts (Filho and Heerdt, 2018). The idea of attributing more importance to a decentralized approach in a complex system rather than a centralized and controlled environment have been supported by several academic researches. This configuration is believed to be ideal for the fostering of an innovation ecosystem (Strumpf, 2002). Further examination in this topic is required to see whether or not top-down public policy intervention is vital for better innovative performance in a specific innovation cluster. Some innovation clusters are better-off without the constraints from the higher governing institution (Fromhold-Eisebith and Eisebith, 2005). Nevertheless, it is almost impossible to stimulate the interactions and collaborations between competitors in the same business without any forms of public policy intervention. The success factors would be very different in each innovation cluster, depending on several conditions and externalities. These factors would be discussed further during the process of framework formulation.

South Korea designed most of their innovation clusters to be highly organic and autonomous. In the later stage of the development, the evolution of their clusters is expected to happen spontaneously in response to technological and environmental changes without the intervention of public policies (Lee and Choi, 2013). There are four development stages of innovation clusters; pre-cluster, emergent, expanding, and restructuring. In the pre-cluster and emergent stage, the government has to impose several policy machinations to steer the clusters into an expected format. As a result, a well defined implementation and monitoring plan is compulsory to achieve the desirable outcome. The documentation of data is another important concern before an innovation cluster could be evaluated for its innovative performance. It is almost impossible to get the precise and critical measurement if there was a prior mistake in data documentation. To avoid this issue, the samples in this study should be carefully selected, so that all of the participants in the interview, survey, etc. are relevant to the objectives of the policy framework. The older example of a well-documented analysis regarding the failure factor of science parks was compiled by Danilov (1967). This paper was accepted by both academia and industrial stakeholders as a valid and contributing piece of information to the field of innovation policy (Henneberry, 1984). In summary, the faulty features that could lead to a failure of science parks are location, funding, communication, price, logistics, infrastructure, facilities, and the lack of collaboration. Conversely, these factors could also be considered as key success factors in the development of innovation clusters, which will be further elaborated in the concluding section of this chapter.

The main topic that should be explored by this thesis is the optimal degree of intervention from the government, as quoted by Michael Porter (1990), “government can reinforce but not create clusters”. It is safe to assume that the remark was meant for industrial clusters, not a contemporary model of innovation systems, however many policy researchers still uphold this principle. The example of pitfalls that could happen when clusters overly rely on governing organisations was presented by Fogelberg and Thorpenberg (2012). It is found that most of the projects that were adopted by the model of regional innovation system have overestimated supply-led solutions. As a result, these projects were not attactive enough for the business ventures in UK. Afterwards, the new regional innovation strategies that were developed by the UK government are decidedly more market-based. By providing clear incentives on the creation of business networks and appointing proper business champions within a region or industry, this type of programme could attract more business investors. According to an extensive business survey that was conducted, It was concluded that a larger business network with sufficient support agencies will promote higher growth rate of network formation.

2.4.5 Financial Support and Fiscal Policies

Financial funding was also a major problem among regional authorities at project management level. Most of the resources are often allocated to the development of the central infrastructure instead of outcome-based activities. In summary, the building of collaborative network needs to be further incentivized by more attractive schemes aside from fiscal policies, which is often not appealing to several small and medium enterprises. Despite all of the shortcomings and criticisms presented in this section, most stakeholders within the innovation system tend to agree that the concept and approach of the innovation system are extremely beneficial to the long-term economic development within the country, region, or industry (Fogelberg and Thorpenberg, 2012). It is believed that the involvement of all related actors would make academic researches more useful to an actual industrial setting. Nonetheless, fiscal policies from the government will be essential to the long-term commitment among stakeholders to cooperate. It is also important to acknowledge different ideals of each actors within the system, and the potential conflict of interests between them. This significant gap between the theoretical innovation system model and the actual implementation of the innovation system needs to be explored further by policy makers, in order to maximize the benefits from this concept.

Research-based firms were the main targets for multiple fiscal policies that were deployed in the Thai industrial sector since 2010. However, this strategy did not provide a solution to Thailand’s lack of innovation capabilities, because there were a lot of non-research-based firms with the potential for the market, but still lacking the capacity or willingness to participate in intensive research and development activities (Chaminade, Intarakumnerd and Sapprasert, 2012). This is also true in western countries, whereas small and medium enterprises also seemingly not behaving in accord to the ideal form of triple helix model of innovation. It is asserted that some actors lack necessary resources apart from financial resources to participate in knowledge-based innovation activities (Fogelberg and Thorpenberg, 2012). This situation discourages them from putting in effort to collaborate with other parties. Therefore, most small and medium enterprises (SMEs) tend to work in isolation in the incubation state of their business. The building of a collaborative network within this situation might cause an adverse effect on how it could possibly exclude some important parties from the system. Thus, it is very important to create a concrete but also flexible criterion in forming the network of collaborators to make sure that there would not be a case of limited participation.

2.5 Conclusion

This chapter has introduced several theoretical concepts related to the development of industrial collaboration. This includes the concept of innovation system, complex system, and innovation cluster. In summary, all of these concepts have several similarities and contain many interlinks between them. The public policy framework that would be formulated by this thesis will be based on these three key concepts. They will form a significant foundation for the framework, which aims to improve the operational efficiency of an electric bus research and manufacturing cluster in Thailand. At the end of the chapter, five main considerations were extracted as the commonalities between these three concepts. They are used as the foundational theoretical knowledge in the establishment and maintaining effective operation of the clusters, which will be applied in conjunction with the practical and tacit knowledge derived from external cases that will be investigated in the following chapter of this thesis.

The innovation system was introduced in the first section of this chapter as the framework that was designed to facilitate the innovative process within a specific boundary. This concept stressed that information flow and learning opportunities are the most important catalyst to innovation. Innovation system is a widely used concept in innovation policy discipline, as evidenced from a wide variety of applications presented in this literature review. There are four main categories of an innovation cluster; national, regional, sectoral, and technological. All of them have similar central ideas, but also contain differences in term of scope of the system. The choice to follow any of these frameworks would depend on the structure of the industry and the objective of public policy. By focusing on a specific sector of electric vehicles industry, this research decided to mainly utilise the concept of sectoral innovation systems for the formulation of a framework for the Thai electric bus industry, as they correspond to the current policy being adopted at national level. Even though the system of innovation is a well-regarded concept, it is not without flaws. Some limitations of the concept were explored at the end of the first section, most of which will be discussed further in the next chapter, in conjuction with the limitation of the concept of innovation clusters.

Another core concept that was introduced is the complex system, which is a multidisciplinary subject that could be applied to wide range of applications. The main argument that was settled within this section is that innovation system could be classified as a complex system because the matching features between the innovation system and the principle of complexity theory. These features include synergistic non-linear interactions between actors, extensive social network, adaptability to the environment, and the high possibility of emergence. This conclusion encourages the combined study of a complex system alongside the innovation system as the modus operandi in the investigation of how to manage the complexity of an innovation system in order to maximise the benefits from the information and knowledge network which would be generated by the formation of clusters. Social capital and organisational motivation have been identified as the most important parameters that could positively or negatively affect the performance of the system. In summary, the study of a complex system is a worthwhile pursuit for policy makers that could made the study of any specific innovation system more robust, and it is decidedly important to be considered in the intricate process of framework formulation within this thesis.

The concept of an innovation cluster was explored as the main topic for the whole research. It was stated that this concept was evolved from the original concept called 'industrial cluster' or ‘business cluster’ after the prominent rise of the Schumpeterian concept of ‘innovation’. However, innovation cluster has an imprecise definition and were used differently in many academic researches. Some researchers used the term to describe a virtual network cluster of organisations while some definitions put it as a general term that was used to describe a contemporary form of clustering that includes research institutions, industrial enterprises, and public organisations. Nonetheless, most academic applications underlined the importance of social Incentives, proximity, knowledge exchange, public policy intervention, and financial support to the success of any innovation clusters. Therefore, the public policy framework that would be developed in this thesis needs to put in significant considerations for these important parameters stressed by this literature review.

Motivation is proved to be a pivotal factor for the ongoing participation of actors within these forms of systems or networks. The main source of motivation is mainly but not limited to economic incentives. It was concluded that social and non-tangible incentives are also crucial to the development of the cluster. Similar to the core idea in complexity theory, the organisations usually group themselves together to heighten their ability to solve complex problems which they have no chance to resolve on their own. Furthermore, social science theory such as social capital could be useful in determining the effective means to design and develop an innovation cluster. In summary, the performance of the cluster could be seen as directly proportionate with the level of motivation from each actor within the system which can be altered by the appropriate policy development.

Virtual clustering in the industry does not completely replace physical clustering. Likewise, geographic proximity alone cannot guarantee the success of an industrial cluster (Kim and Shim, 2018). This conclusion might be, in a large part, regarding how this thesis views proximity as a parameter in the establishment and operation of an innovation cluster. This also raises a question about the requirement of geographical proximity for an effective collaborative network; the argument which would challenge the current strategy of Thailand innovation policy, regarding the establishment of physical locations for the conglomeration of research and industry sectors across several industries. The current state and motivation of the electric bus cluster’s inhabitants towards research and manufacturing collaboration with surrounding organisations should be analysed, in order to create spontaneous strategies for each stage in the development of this industry.

Knowledge is increasingly more important as resource in the operation of any organization. This is especially true for research-based system such as innovation cluster. Industrial actors are required to increase their inter-organisational collaboration. However, the lack of strength and longetivity of their collaboration is still an important topic that need to be addressed by policy makers. Weak collaboration might originate from the fear of losing important information to the competitors in the industry, and the supposition that this circumstance would make the company lose its competitive edge (Barson *et al.*, 2000). As a result, the governing institution must develop an effective means to encourage this type of collaboration; both internal collaboration within the cluster and external collaboration that links the cluster with the relevant adjacent industries. These linkages are decidedly necessary for the propagation and growth of the innovation clusters.

Policy instruments also need to be constantly evaluated, in order for the government to balance between top-down centralization and bottom-up decentralization policy schemes. There is a question about the degree of policy intervention that the governing institution needs to exert, in order to maximize the effectiveness of the cluster. The conclusion is that both the degree and the contents of the policies have to be in harmony with the current state of the industry. External environment surrounding the industry need to be considered to develop a proper policy plan. Additionally, there would be several differences in policy machination depending on the stage of the cluster’s development. The exception to this rule is the fiscal policies and financial support which are proven to be an essential tools to boost the motivation of the members of the cluster and also incentivise the growth of the industry, since there is still no proof in the literature detailing the negative consequences towards the cluster that could happen in the case of the oversupply of financial resources.

Chapter 3 Considerations in the Formulation of the Policy Framework

3.1 Introduction

In the previous chapter, three concepts that would be a foundation of the formulation of a framework were introduced and discussed: innovation system, industry and innovation cluster, and complex system. In this chapter, the joint topics from these three concepts will be discussed based on the previous application in an industry setting. The purpose of this chapter is to accumulate the existing knowledge of cluster studies to represent the recurring issues that occur within this format of system or clusters. Each case that was presented in this chapter will be allocated into a subsection that corresponds to their implication which will be related to the narrative of this thesis. The narrative of this chapter is to present multiple prominent issues which would be the main consideration for the framework. To counter these issues, the framework will be designed by utilising the selected tools that will also be introduced in this chapter. The rationale in the choice of each tool would be explained in this chapter, and later during the results and discussion in chapter 6-9 which will discuss the idea behind each component of the framework. It should be mentioned that the review of the literature will focus on an opaque adaptation of the tools in the form of IDEF0 and UML activity diagram, since they are utilised in a somewhat different purpose than its normal usage in comparison with other tools and techniques utilised in other components of the framework. In addition, the re-application of these two conceptual models could be observed as an original contribution of this thesis since they are applied to the outputs from previous components of the framework rather than existing as a stand-alone model like their usual application. This would be thoroughly explained at the end of this chapter by providing some relevant examples in application of these models.

3.2 Systemic Issues within Innovation Clusters

3.2.1 Inappropriate Structure of the Cluster

Past studies indicated that an industry need to put more emphasis on the development of new products and services to become competitive in the creative economy environment (Carneiro, 2000). It was asserted that higher confidence and expectation from stakeholders can be observed in a government-centric development programme (Yoon, 2017). Therefore, the adoption of government policy could be a more effective mechanism to nurture an innovation system when compared to the decentralized effort from a group of private enterprises. However, the bureaucratic state-dominated system generally has a potential to be inflexible and unable to timely adapt itself towards swift changes of competitive landscape (Thompson, 1965). Hence, more flexible, and adaptive middle organisations are sometimes employed in the implementation of innovation clusters.

For Asian countries, South Korea is one of the most active in the field of cluster policy. In the previous chapter, Gwanggyo and Pangyo Technovalley have been introduced as two different innovation clusters in South Korea. The deviation of activation strategy to promote industry-academia cooperation between these two innovation clusters was investigated. It was found that different activation strategies are required because of the infrastructural non-conformity between these two establishments (Lee and Choi, 2013). This difference is crucial to the success of industry-academia collaboration within clusters with different topological structure. In addition to physical clusters, virtual clusters such as tourism clusters were also extensively studied. Similar to the Thai tourism industry, the Korean tourism industry consist of wide variety of products and services that include multiple level of stakeholders within the supply chain. This makes the system more complex to manage than some of industry clusters which mainly comprise of large corporations (Thomas, Shaw and Page, 2011). Nevertheless, a conglomerate of small enterprises might have merits on the flexibility and the response time to market fluctuations. Smaller companies will be more agile and could adapt themselves quickly, which is a good characteristic for the member within newly formed innovation clusters (Kim and Shim, 2018). Without this flexibility, the whole system would not be able to function effectively, and the innovation within the cluster would be negatively affected. Finally, it is important to acknowledge that these cases of industrial and innovation clusters would be substantially different from the automotive sector in Thailand. Therefore, the approach in the formulation of a policy framework could be drastically different despite both industries sharing the same core concept of cluster development.

Another example of dichotomy between rigid and flexible structure of the cluster was the distinction between old and new economy conventions for industrial development in regional innovation system (Table 3-1). Even though new economy conventions were stated to be ideal for the cultivation of innovation, they are not strictly better than old economy conventions for most cases. There will be some circumstances where the old economy should take precedence in public policy settings. For example, some of the new economy practises would be unsuitable choices without the readiness of organisations within the innovation system (Bresnahan, Gambardella and Saxenian, 2001). Forcing a cluster towards innovation-building activities without a good foundation of operating framework that are readily available with sufficient information flow is a risky prospect. This might cause the industry to waste precious resources in developing an ineffectual system. On the other hand, most systems that focus solely on the old economy style of conventions would often be confronted, in the long-run, with economic downfall and could cause a wide-scale negative impact to the economy and development of the whole industry (Cooke, 2001). In summary, this finding supported the fact that the policy framework for innovation clusters should be tailor-made for a specific environment and circumstance, especially the gaps and limitations of the specific industry that it would be applied to. This topic will be discussed further during this chapter and within the ongoing process of framework formulation.

Table 3-1 The comparison of conventions in the old and new economy industry
(Source: Cooke, 2001)

Old Economy	New Economy
Centralised	Decentralised
Constant returns	Increasing returns
Value scarcity	Value abundance
Rising prices	Falling prices
Maximise firm value	Maximise network value
Incremental innovation	Disruptive innovation
Place proximity	Cyberspace
Machine-focused technology	Human-focused technology

The previous paragraph revealed one of the most important limitations on the study of different industrial clusters or innovation clusters; What is the extent that researchers could extrapolate their findings to broader applications of cluster policy? Essentially, there are many factors that should be further investigated, in order to ensure the accuracy and validity of the research that would be conducted in a specific setting. For example, the study of collaborative network management within a cluster could be altered because of the diverse corporate culture in different countries. There are many contributing factors to the outcome of each specific case, in which the researcher needs to take caution not to over-extrapolate their analysis from a single case to other applications (Krueathep, Riccucci and Suwanmala, 2010). For instance, an analysis of the network formation in China might not be fully compatible with the system of the Thai automotive industry, because the differences in geographic scale could affect the structure of governance and the operation of local authorities. It is unlikely for the researcher to be able to answer the same research question with the exact same research method. Some alterations in the design of a cluster research need to be considered, in order to capitalise on research findings and ensure its validity to the current situation at the same time (Brown, 2000).

3.2.2 Research Segregation

The objective for the establishment of an innovation cluster in the Thai industry was described in a paper written by Wonglimpiyarat (2006).

“Taking into account analysis of the degree of value creation of NSTDA, most programmes undertaken under NSTDA’s mission do not successfully progress to the commercialization stage. There is a lack of a strong and clear institutional environment to enhance efficiency of the technological development process. It is necessary that NSTDA invests numerous resources into R&D activities and aligns these innovative efforts with the needs of industrial markets to strengthen the competitiveness of its programme. NSTDA also needs to increase its role in the process of building up scientific and the technological capabilities and bringing technology to the marketplace. Focusing on particular clusters would be effective for development of successful innovations.”

With this issue at hand, the National Science and Technology Development Agency (NSTDA) came up with an initiative to promote research collaboration between the government, academic institutions, and industrial enterprises to overcome the lack of clear research direction and the lack of efficiency that was described above. National science centres in the same vein as science parks were established to facilitate the networking of actors within Thai industries. It was suggested that a specific design of infrastructure is necessary to stimulate a better and more sustainable performance of the cluster. However, the insights on the outcome of these initiatives were not fully presented by any Thai researchers. This thesis aims to contribute to this particular gap by including some framework to measure the performance of policy initiatives that are originated from the national policy.

There are several examples around the world regarding the negative effects of segregated, disconnected, and inefficient research. In Scotland, the effects from continuous devolution from UK central government of the Scottish innovation system was assessed. Initially, this devolution was speculated to be a pivotal shift towards more coherent innovation policies for regional development in Scotland (Mastroeni *et al.*, 2017). However, there were some stakeholders who were not convinced by the notion of independence from the UK supportive infrastructure, which resulted in less collaboration. This outcome aligned with the finding regarding the dependency of a regional economy to a strong shared value of industrial actors. It was found that a higher level of autonomy did not equate to better research efficiency without the unified objectives among several organisations within the cluster (Expósito-Langa, Molina-Morales and Tomás-Miquel, 2015).

In contrast, it was claimed that Gwanggyo and Pangyo Technovalley were more rapidly developed, in comparison to Deadeok Innopolis that was purely controlled by the central government. It was asserted that their higher autonomy led the establishments towards a more-focused research direction (Lee and Choi, 2013). This idea has close resemblance to ‘smart specialisation’, which is another emerging concept in the discipline of innovation policy. Smart specialisation addresses the importance of cohesion in technological and innovative research towards the economic development in a specified region. This cohesion can be theoretically achieved by the pooling of similar resources and competencies that are generated within the regional or sectoral boundary to create transformative products or services (Foray, 2014). If smart specialisation could not be achieved organically, a clear strategic vision, business model, and research direction need to be provided for stakeholders to follow (Landabaso and Foray, 2014). In other words, policy makers need to make sure that the promise of an innovation cluster such as tangible results in scientific researches, the provision of scientific community, and actual commercialisation of new products and services are fulfilled (Yoon, 2017).

3.2.3 Weak Inter-Organisational Linkages

According to the paper by Mastroeni et al. (2017), Scotland seemed to face similar issues to Thailand in the area of innovation policy. Despite having strong scientific-based activities, especially in higher-education sector, the knowledge that was created is not sufficiently translated into actual new products or processes. The lack of strength in collaboration and networking, including soft infrastructure such as financial network has been holding back the Scottish innovation system from realising its full potential (Roper *et al.*, 2007). Evidently, Scotland has been performing well in term of overall performance in innovation. However, most of the statistics were contributed by multinational corporations and universities rather than a group of small and medium local enterprises, which are predominant in the Scottish industrial environment (Mastroeni *et al.*, 2017). The core issue of this was attributed from the low expenditure on research and development among small and medium enterprises, and the low capacity to absorb knowledge that circulate within the established system. This situation was similarly described in a research about Thailand innovation system (Chaminade, Intarakumnerd and Sapprasert, 2012). The underlying reasons behind this phenomenon were identical to the explanation regarding the issue in Scottish innovation system.

It was found that most research and technology organisations (RTOs) in Scotland haven't operated in the most effective manner. The main problem is the disjoint in cooperation and communication between research institutes and industry sector within a specific region. This was the result from the lack of demand-led market analysis, which could connect research efforts with the process of industrial commercialisation (Miller, 2014). The organisational example that was designed to mitigate a portion of this issue is the Technology and Innovation Centre (TIC) of the University of Strathclyde, which was built to serve as a bridge between commercialisation and manufacturing activities with research and development activities by chaining several enterprises together in the same network. There are three main focuses for the Technology and Innovation Centre (TIC). Firstly, it aimed to increase the opportunity for interactions between net knowledge generators and net knowledge utilisers, especially small and medium business enterprises. Secondly, it offered additional services that could help business enterprises to capitalise on potential technologies, based on the forecasted market demand. Lastly, it created a cohesive management system within the TIC and its network to cope with the current industrial development and innovation policy of Scotland.

In another case located in a developing country, the Ministry of Science, Technology, Innovation, and Communications in Brazil created an innovation system based on the structure of Silicon Valley. It was hoped that the current state of national innovative performance will be boosted by this development. Brazil has been intensely investing in various initiatives and aimed to improve their innovation ecosystem. However, most of their investments did not reach their full potential, according to the measured outcome that was collected. For example, most of the expense in education policy did not effectively increase the number of graduates in science and engineering discipline. In addition, the additional investment in academic research also did not improve the average impact factor of researches originated in Brazil despite a sharp increment in research outputs (Filho and Heerdt, 2018). It was concluded that the lack of collaboration and knowledge sharing between researchers was the main weakness of innovation policy in Brazil. The combination of this issue and the low level of existing innovation, Brazil must heavily rely on overseas technologies for most of their products and services that were domestically manufactured.

Similar to developing countries, developed countries could also have an issue of insubstantial collaborative efforts in their established industrial linkage. A comparative study of regional clusters between Wales (UK) and Baden Wurttemberg (Germany) was conducted. Baden Wurttemberg was proved to be more successful because of several features that can be considered as key success factors for the development of interorganisational linkage within innovation clusters (Cooke, 2001). The most important characteristic that set Baden Wurttemberg apart from Wales is the higher concentration of vertical and horizontal linkage in several industrial activities. This included not only manufacturing activities but also non market-based social interactions. Therefore, it can be concluded that every types of interorganisational linkage are potentially important in the development and administration of an effective innovation cluster (Davis, Creutzberg and Arthurs, 2009).

3.2.4 Lack of Resources and Capabilities

It was emphasised in the previous chapter that knowledge is the most important resources for the creation of new products or processes, and also a significant resource in the system of innovation (Boekema *et al.*, 2000). There has been an increase in academic researches that focus on the efficient utilisation of existing knowledge which circulated within the system of interconnecting actors (Andersen and Christensen, 2005). In several cases, there might be an oversight of how a single body of knowledge could be used. One piece of information might not be fully utilised by the system because of the inefficiency in knowledge management mechanisms (Länsisalmi, Kivimäki and Elovainio, 2004). Additionally, it seemed that the information regarding technological change due to social factors is considerably difficult to predict, in contrast to a change due to technical factors. This gave rise to an extra challenge for the management of an innovation system, since it was established that social factors would play a key role in the shaping of innovation cluster. As a result, the governing organisations or policy makers need to consider many aspects within the system that are sometimes not a purely tangible entity (Aleksandras Vytautas, Irena and Alina, 2013).

The reasons behind the lack of investment in research and development of many developing counties are mostly related to the fact that there will be no guarantee for a good return in investment (Yoon, 2017). Many middle-world countries innovation, including Thailand, are driven by the entrepreneurship of small and medium sized business enterprises (SMEs). However, because of their limited financial resources and output capacity, the investments in research and development are often not prioritised when compared to the investments in other aspects, which would give them more immediate and substantial results (Hegde and Shapira, 2007). This is supported by the argument of several academic researchers which described the difficulty of smaller firms to invest in new technologies, because of the reduction in product life-cycle from a rapid rate of technological change (Austin, 1994;Agarwal and Audretsch, 2001;Bosman, Hartman and Sutherland, 2020). Despite the apparent shortcomings in economic value of the investment in research and development activities, many companies are forced to emulate this practice. Paradoxically, without the new products and services that are created by these investments, it is difficult for the enterprises to maintain their outdated business model when the importance of innovation is continuously escalating.

In example, Russia is a heavily centralised nation in the management of science, technology and innovation policy. The research conducted in Russian innovation system showed that public-private partnership between firms need to be externally supported by central government policy. It was asserted that private owned corporations spend a small amount of research and development expenditures, in comparison to their other expenses (Akhmetshina and Mustafin, 2015). Consequentially, there will be the lack of innovation activities within an industrial sector, which could harm the competitiveness of Russian economy in the global market. There are two accounts that could be used to explain this situation. First, the application of public-private cooperation in the context of national innovation policy is a challenging prospect to be properly applied by less politically powerful organisations (Ismail and Harris, 2014). Second, there were few tangible evidences to firmly prove the direct correlation between frequency of interactions among public-private enterprises and the performance of a firm (Dhewanto *et al.*, 2012). As a result, many enterprises are discouraged to invest their funds in either R&D or networking activities.

3.3 Important Features of the Policy Framework

3.3.1 Case Studies and Best Practices

In the past, best practices in the administration of innovation clusters have been studied extensively. The purpose of these studies was to explore the influential features and parameters of innovation clusters that could be considered as the driver for the successful knowledge transfer process within the system. Since the beginning, this thesis has been providing some perspectives on these case studies and best practices, and on how this thesis could apply these mechanisms on the formulation of public policy framework for Thai e-bus cluster. Many cases relied on a comparison between clusters in the same sector but in a different infrastructure and environment, e.g. the comparison between aircraft industry clusters in China and United States (Chu, Zhang and Jin, 2010). These types of studies will be the groundwork for comparative analysis that would be conducted in this thesis.

However, it should be noted that the case studies and best practices approach was also criticised that they are not fully appropriate for the formulation of innovation policy. It was asserted that the 'policy-mix' originated from the rigid and fragmented examples from cases are rarely adopted to its fullest extent. In contrast, it is highly suggested that empirical evidence is crucial in the process of forming innovation policy (Flanagan, Uyarra and Laranja, 2011). This suggestion aligns with the design of this thesis that the framework would collect empirical evidence from the actual setting in the Thai e-bus research and manufacturing cluster, in addition to the suggested 'policy-mix' that could be extracted from the previous literature, to tackle the complexity that existed in the multi-level and multi-actors that is apparent in the Thai automotive industry.

It was asserted that public policies and national strategies for the establishment of an innovation cluster in an advanced industrialized nation would be different from the establishment in a newly industrialized country (Park, 2002). The examples of advanced industrialized countries include Sweden, Germany, and the United Kingdom. On the other hand, the examples of newly industrialized countries include South Korea, Singapore, and Thailand. The main objective of the science park or innovation cluster in every country is to increase and accelerate research utilisation in industrial applications. However, it was found that the integration of scientific research with the industrial sector is normally established much later in newly industrialised countries when compared to advanced industrialised countries (Bell and Pavitt, 1997). The main idea behind the comparison between these two types of nations is the illustration of major differences within their innovation cluster development framework. For example, Sweden and South Korea was compared in a study by Park (2002). The structure of this research was divided into four main parts; background of the project, formulation of strategies, expected contribution to national and regional development, and perspective towards potential issues in the future. After that, a comparative analysis was performed to conclude the similarities and differences between science parks in South Korea and Sweden.

A case study from Thailand showed that there are five different dimensions that could hypothetically affect the probability of network formation among Thailand's government agencies. All dimensions were firstly assumed to be equally important to the network formation. However, the results from the study showed that many of them were not a meaningful criteria that can influence the decision to form a network (Krueathep, Riccucci and Suwanmala, 2010). The size of organisation, years of establishment, and complexity of the system were predicted to be directly proportionate to the degree of network collaboration. However, the results showed that these three factors are relatively insignificant, in comparison to other factors, namely task difficulty and management capacity. Task difficulty included two sub-sections: resources dependency, and task complexity. They were found to be strongly correlated to the degree of collaboration within the network. This correlation was explained as a causal effect of an immediate need in problem-solving capacity of the organisation (Pfeffer, 1987). Another dimension that is found to be significantly important is the management attitude towards network formation. If the management previously adopted a successful collaboration, there would be a greater tendency for network formation (Cummings and Kiesler, 2008). Nevertheless, it was found that the past individual experiences of manager did not have a direct effect on the probability of cooperation between actors.

Finally, local political and socioeconomic factors are found to be related to network formation. However according to the results, the effects are negligible (Krueathep, Riccucci and Suwanmala, 2010). The reason behind this circumstance might be influenced by a narrow research focus of this case, which does not contain enough data to explain the macro-level occurrences such as social or political climate. Nonetheless, it was stated that political factors might have intervening indirect impacts on network formation in a different manner, and they might be discovered in a different research approach. In summary, the National Science and Technology Development Agency (NSTDA) should try to induce more frequent coordination activities within the existing innovation systems that were already established in the form of science parks and research clusters. Furthermore, Industrial clusters have to be reformed into a new format that correspond to the cultivation of knowledge-based economy (Wonglimpiyarat, 2006). In conclusion, Thailand requires a more resounding governance in the formulation and implementation of public policies, in order to effectively adopt the groundwork for innovation system policy that was instituted by the NSTDA.

3.3.2 Specification of Organisational Structure and Boundaries

Setting up some aspects of the cluster to be prioritised in each stage of cluster development is essential to the effectiveness of cluster design, especially since it was established that innovation clusters are complex adaptive system, where evolution and change in the environment are common (Mastroeni *et al.*, 2017). These changes would not only impact a certain element of the system, but also have interlocking effects on several different parts within the system at the same time. In this regard, some predetermined specifications of the cluster must be assigned before the formulation of the controlling public policy framework, in order to reduce the chaos that could be incurred by the shift in environment. From the literature, three critical topics were identified for the formulation of policy framework and the subsequent development of innovation cluster: the specification of organisational boundaries within the cluster, the specification of intermediate gate-keeping organisation, and the specification of financing policies and incentives.

The mechanism that should be utilised in order to form an optimal structure of each cluster is one of the topics that was often contemplated by the researcher in this field (Phillips, 2002). Likewise, this thesis also highlights this topic as its primary research question. However, this topic is generally too expansive because it does not adequately define the boundaries of the mechanism that would be applied by the researcher. For instance, what will be the scope of the study regarding technology transfer mechanism. Does it warrant to include any form of informal interactions, since they were proven to have consequential impacts to the innovation system, in addition to formal business interactions? Therefore, this study would investigate only a few specific features of the system, so a more robust analysis of the electric bus research and manufacturing cluster could be provided. It was stated that most case studies will have significant limitations in the applicability of their findings (Jackson and Murphy, 2006). Nevertheless, case studies should still be used in order to fully understand the functions of a different complex innovation system model in each application. With a suitable research framework, the resulting analysis would present a more credible finding that could be associated to a more general implications in the real world (Nadvi, 1995).

The framework for complex network structure in the Thai electric vehicles cluster is expected to be in the format that is somewhat decentralized. This kind of network structure would be similar to what was labelled as 'small-world' network model (Watts and Strogatz, 1998). The network aims to create approximately evenly distributed connections between each node. Ideally, the length or distance of relationship that are formed by each element should be uniformly distributed. These distances represent how 'close' each node is with one another. Nevertheless, it does not mean that any single node must connect with every other node within the system. After a certain amount of time, the growth of this network structure will be characterized by two significant changes (Figure 3-1). Firstly, there will be an introduction of new nodes that introduce new connections within the existing nodes. Secondly, there will be opportunities for the existing nodes to re-invent the new relationship with other pre-existing node in the system. These changes might affect the built-in uniformity of the system, so that the system as a whole will be further away from the perfect evenly-distributed model (Qi, 2013). The question that should be raised regarding this phenomenon is that; should we let this free interaction propagate further and risk losing the stability within the system, or should we deploy some controlling mechanisms that could prevent the disorder from happening? This is identical to the question regarding the uses of public policy intervention against free interactions between actors, which was discussed in the previous chapter.

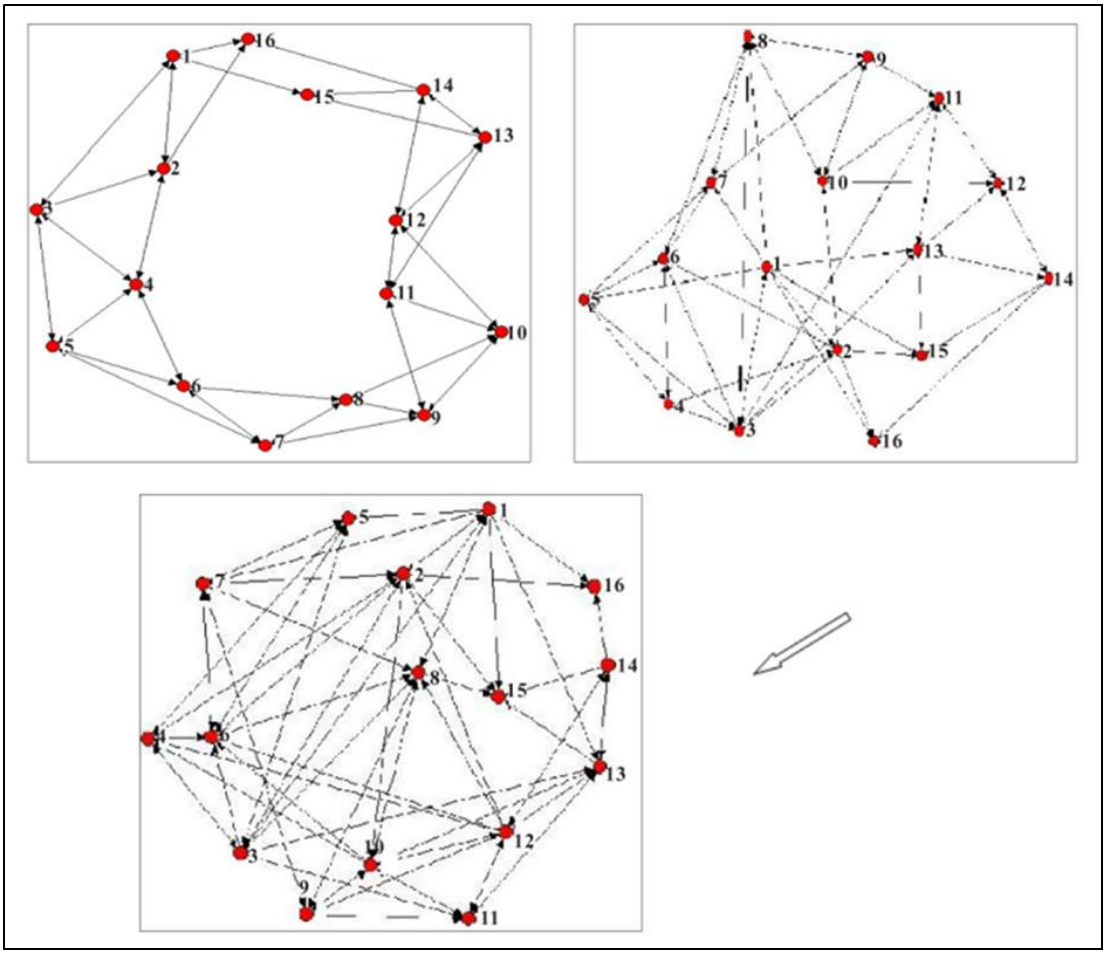

Figure 3-1 The changing state of a decentralised 'small world' network structure
(Source: Qi, 2013)

Aside from the emergence of new relationship within the network, there is another important characteristic of a 'small-world' network that match the model of innovation cluster. Actors within this set of boundaries within the network could absorb knowledge from the ongoing process, environment, and other actors more efficiently because they have sparse but meaningful relationships (Lin and Li, 2010). Consequentially, they could also adapt themselves quickly according to the norms within the system e.g., culture, technology, regulation, etc. This could result in ongoing loops of evolution to the whole system and its sub-system components (Filho and Heerdt, 2018). However, there will be a requisite to maintain these boundaries between each sub-system. Governing institutions must make sure that the barriers between boundaries are not too 'hard' to the point that they prevent any interactions between actors. On the other hand, they must also verify the existence of barriers, otherwise the sub-system could become underregulated. This deficiency could make the system lose its effectiveness because of the increasing amount of disorder within the system (Rossiter, 2009).

Scotland has a regional innovation system that is strongly supported by the connections and interactions between policy makers and policy targets. Despite that, it was asserted that the intervention of the public sector reduced the effectiveness of cluster policy because this has formed a bureaucratic barrier that was detrimental to the innovation ecosystem (Lyall, 2007). This assertion should be investigated in this thesis during the formulation of the framework because Thailand also has a government-centralised innovation system. It would be valuable to learn from the Scottish cluster policy about the negative aspects of governance that could cause an innovation system to function ineffectively. These suggestions can then be applied into the newly formulated policy framework by considering the level of control and command of the governing institution, including the consideration regarding organisation structure and the boundaries of the cluster.

3.3.3 The Assignment of the Intermediary Organisation

In order to improve the competitiveness of a technologically intensive industry, it is imperative that the proponents of the industry emphasise the development of new products and services through innovation (Yoon, 2017). As mentioned in the previous chapter, public policy is an effective means to nurture innovation system, in comparison to the purely conglomerate efforts from private enterprises. There would be more confidence and higher expectation from stakeholders if the initiative was controlled by legitimate governance (Wallner, 2008). However, the state-dominated system was sometimes found to be inflexible and cannot timely adapt itself in respond to changing competitive landscape (Styhre, 2007). Hence, a more flexible and adaptive middle organisation that could effectively facilitate small scale action plans would be highly beneficial to the implementation of innovation system policy. Another reason for the assignment of an intermediary is the potential emergence of new interactions within the decentralized structure. An intermediary organisation could act as a point of contact for members of the system to ensure their effective communication and collaboration (Howells, 2006). It was found that an intermediary agency could promote the diffusion of technologies within the industry cluster and catalyse the commercialization rate of new products and services (Park, 1999).

Without an intermediary, firms in a highly structural embedded network would seek to find as many partners as they can, because it would give them competitive advantages and more influx of information. As a result, they tend to align themselves at the centre of the network i.e., the position where an intermediary should be located at. This results in uneven power relations between stakeholders, which increases the risk of conflict and decreases the chance of cooperation (Smith, 2003). Innovation clusters inherently have high structural embeddedness because of the two main reasons. First, an innovation cluster demands the selection of enterprises within the same industrial sector, thus there will be a certain degree of similarity in their operation. Second, the government intervention and regulation would forcibly form the cluster into a densely pack network, which facilitate the flow of knowledge between actors (Cowan, Jonard and Zimmermann, 2007). Therefore, a decentralised network with an intermediary would be a suitable structure to solve this structural issue of innovation clusters. However, it is important to note that a bilateral model that were used by Cowan, Jonard and Zimmermann to study the emergence of innovation networks can provide only a partial explanation to complex systems, because several interactions within innovation clusters are not expected to be exclusively bilateral relationship.

It was strongly emphasised that a different format and assigned responsibilities of the intermediary will be required for different configurations of industry clusters (Clarke and Ramirez, 2014). It can be assumed that this circumstance is also an accurate assessment in the development of innovation clusters. Some of the main topics of concern for the assignment of intermediaries in industrial sectors include the nature of an industry. For example, the Korean tourism cluster is small and flexible, thus the role of intermediaries could be smaller than what it should be in large industrial sectors that normally incorporates a large number of rigidly-structured firms (Kim and Shim, 2018). Moreover, the country's national or regional development policy should also be another concern. The functions of the intermediary in innovation clusters of the developed country would differ from developing countries. Lastly, different roles of the intermediary are required in different types of collective organisational capabilities within the system. However, this aspect is difficult to ascertain because of the rapid shift of organisational capabilities in most technology-based industries (Shou and Intarakumnerd, 2013). Additionally, the complexity of the system could also contribute to the difficulty for an intermediary to adapt itself according to variety of demands by several corporations. The services of the existing intermediary must be slightly shifted over time, in accordance with the stage of technology diffusion. Alternatively, new intermediaries could be assigned for each specialised role (Chunhavuthiyanon and Intarakumnerd, 2014). All these reasons are fundamental for the design of roles and responsibilities of the intermediary in any specific innovation cluster.

The National Science and Technology Development Agency (NSTDA) could be described as the intermediary of the whole national innovation system in Thailand. Quantifiable metrics were collected to measure the effectiveness of NSTDA's mission since its establishment in 1992. Based on the balanced scorecard that was developed, it was found that the presence of the NSTDA did not have a significant overall impact on Thai industry. However, some research and industrial clustering programme that have been adopted are considered successful by several enterprises (Wonglimpiyarat, 2006). The difficulty in measuring the success of public policy schemes will be explored in more details in section 3.3.4 of this thesis. This existing knowledge would then be utilised again in the formulation of monitoring and measurement methods within the policy framework in the last part of this thesis in chapter 9.

3.3.4 Financing Policies and Fiscal Incentives

Innovation financing programme in the form of venture capital funding is one of the most common cluster policies to boost likelihood of investment in research and development in the industry (Akhmetshina and Mustafin, 2015). This point proves that an innovative economy is highly valued by many nations, no matter how different they are in terms of government structure, national policy, or social system. However, the challenges of research partnership in each nation or region would be different. Thailand should be mindful of how to determine the best approach for this development strategy, to ensure that the investments does not go to waste. This challenge is just one facet of many risks that an innovation cluster must confront. It was asserted that innovation could not happen if the enterprise does not take any risks (Caggese, 2012). Innovation itself is the result after the organisation took the risk by trying to implement novel and radical changes. If the outcome of this change turns out to be a successful effort, innovation would happen (Aleksandras Vytautas, Irena and Alina, 2013). The important point is that the regulator of the system or cluster must know how to manage these risks. The impact from a failure which could cause damage to other parts of the cluster need to be minimised, because it could discourage other actors within the system from being innovative.

It is beneficial to assess the level of motivation and the determinants of cooperative tendency between actors. The determinants of network formation at sub-national level of government agency in Thailand were studied by Krueathep, Riccucci and Suwanmala (2010). It was concluded that there is a positive repercussion on the network formation when the actors are linked with the sources of financial incentives. This finding might be valuable for the construction of innovation clusters in the future since the key concept of this study is comparable to the formation of government-induced network. Nevertheless, this result was extracted by a relatively static analysis. Hence, the study might not be able to fully explain the dynamics of network formation and the aggregation of social linkage between actors over a period. The findings of this study were designed to be informative but not totally decisive on what should be taken into considerations in the formation of a public-private network. The assessment of fiscal incentives is also particularly useful in term of setting up research direction for the development of an innovation cluster (Fosfuri and Rønde, 2004). It could provide extra insights from the perspective of stakeholders on how important each aspect in financing policy will be. This assessment could also provide solutions to how much of each type of incentives the government should incorporate into the formulation of policy framework. Moreover, it was also asserted that the positioning and network arrangement would be a key success factor to this category of financing policy (Keast and Hampson, 2007). More importantly, policy makers need to make sure that the promise of innovation clusters, such as tangible research results, availability of researchers, and actual commercialisation of new products or services are properly fulfilled (Mulema and Mazur, 2016).

There are also important constraints that could limit the performance of the research sector in an innovation cluster. The recommendation for policy makers and research funders is to provide more optimal funding schemes to the universities, so that they could afford to take more risk in research (Bedford *et al.*, 2018). For example, co-investment plans between the business sector and universities could relieve some financial damage in the case of research failure. Consequently, universities are more likely to break away from the pitfall of path-dependency and the linear model of innovation, allowing for more opportunities for research breakthrough (Krücken, 2003). There are three main guidelines for the universities within an innovation system. Firstly, the structure of the university needs to be sufficiently adaptive and flexible in order to effectively collaborate with external partners from several different industries who might have varying degrees of business conduct. Secondly, they need to cultivate an innovative culture among their staff and students, by focusing on the training that would ingrain creative thinking and reduce the resistance to innovate. Lastly, universities might need to shift their roles from a passive participation to an active participation within the industry. They need to be more proactive in their research i.e., actively promote their research outputs towards the application in industrial sector. Furthermore, they also need to be aware of industrial and business needs and effectively shift their research focus according to the market (Bedford *et al.*, 2018).

One obstacle faced by the Russian government in the formulation of public-private partnership was an unequal power among each partnership member within their innovation system. There was a deficit in equality of rights and responsibilities in several industry clusters. This resulted in an uneven distribution of public funds that were used to facilitate research collaboration and interactions between participants (Akhmetshina and Mustafin, 2015). To counter this incident, the national policy framework should be adopted to ensure the appropriate uses of central government funds, and to create clear guidelines and regulations to control each organisation within the boundary of an innovation cluster (Wonglimpiyarat, 2011). This topic of discussion will be included in the formulation of an evaluation scheme for public policy plan in this thesis.

3.4 Tools and Approaches in the Formulation of the Framework

3.4.1 The Business Process Modelling Techniques

There are many possible formats of public policy framework that could be used to facilitate the development and establishment of innovation clusters. The difference between each iteration of framework is usually related to the objectives of the cluster. For example, a specific framework might put additional emphasis on financial concerns, while another framework might not. On the other hand, the common trait among these iterations of policy framework should be the promotion of interaction, collaboration, and exchange of scientific knowledge because it was established that firms rarely innovate in isolation (Porto Gómez, Otegi Olaso and Zabala-Iturriagagoitia, 2015). The ultimate objective of the policy framework is often to increase the competitiveness of industrial actors within the system. It is becoming more likely for firms to be competing against each other despite the geographical distance between them in modern markets because of globalisation (Siebert and Klodt, 1998). Hence, many nations try to reinforce local and regional business owners with technology learning capability so that they could compete on the global stage. Despite having clearly defined aims, the innovation system and other similar approaches are still considered to be a conceptual model rather than a well-grounded theoretical approach (Edquist, 2010). Although, this fact might contribute to the ease of framework formulation, especially in term of its flexibility. Many related approaches and ideas could be combined without significant concern on the requirement of prevalent academic sources in the subject matter.

Information technology have changed the landscape of competition in business. Companies can no longer feel confident in their strategic position, even when their local performance is exceptional. Nowadays, many industries evolve into the stage of global competition where everyone in the same business have to compete with each others (Castells, 1996). As a result, inter-organisational connections have became vital for the survival of an enterprise. Under this circumstance, there have been a sharp rise on the development of business process modelling techniques, which resulted in a large pool of modelling techniques that business owners could apply (Aguilar-Saven, 2004). However, this also exposes them to risky situations when the choice of techniques and the tasks they need to accomplish are mismatched, which might result in the failure in the planning process. In order to choose the appropriate tools, an evaluative method was developed by Ying, Hong and Zhengchuan (2003). This model of evaluation might be useful in the formulation of the framework for innovation clusters and will be discussed in more detail in the next two sections. To summarise, information flow within the network need to be properly managed to ensure the accurate and effective exchanges of technological knowledge among the member of an innovation cluster. Physical contacts was shown to be valuable to the improvement of interpersonal relationships, similar to what was previously proven according to the literature review from the previous section. However, it was also argued that they are not as essential as the availability of knowledge and information flow (Premkamolnetr, 1999).

Some applications of business process modelling techniques could be found in some innovation system related literature despite not being very common. Most of the literature tend to utilise them for the nurture of inter-organisational collaborative networks in a business setting (Chen and Hsu, 2001), which are not dissimilar to the core concept established by this thesis. A comprehensive framework for cluster policy in the creation of an innovation cluster was presented as three interconnecting process models by Yoon (2017). Each of them corresponded to different stages in the formation of an innovation cluster. First is the design stage (Figure 3-2), which involved the idea on how collaborative network should be formed via a cyclical, self-organising ecosystem. However, the diagram is somewhat idealistic and does not indicate any operational strategies or contingency plans for a cluster. The networking stage (figure 3-3) filled in those gaps with action plans for the implementation of regional innovation systems. It covered the middle phase from the planning stage to the actual formation of a cluster. The final stage is evolution stage (figure 3-4). The diagram for this stage showed the change over time during overall transformation of a regional innovation cluster, from the beginning s the growth plateau, where a cluster could not be able to expand any further (Turkina, Oreshkin and Kali, 2019). Ideally, an innovation cluster is saturated at this point, which mean it satisfied all objectives that were assigned to them by the governing institution.

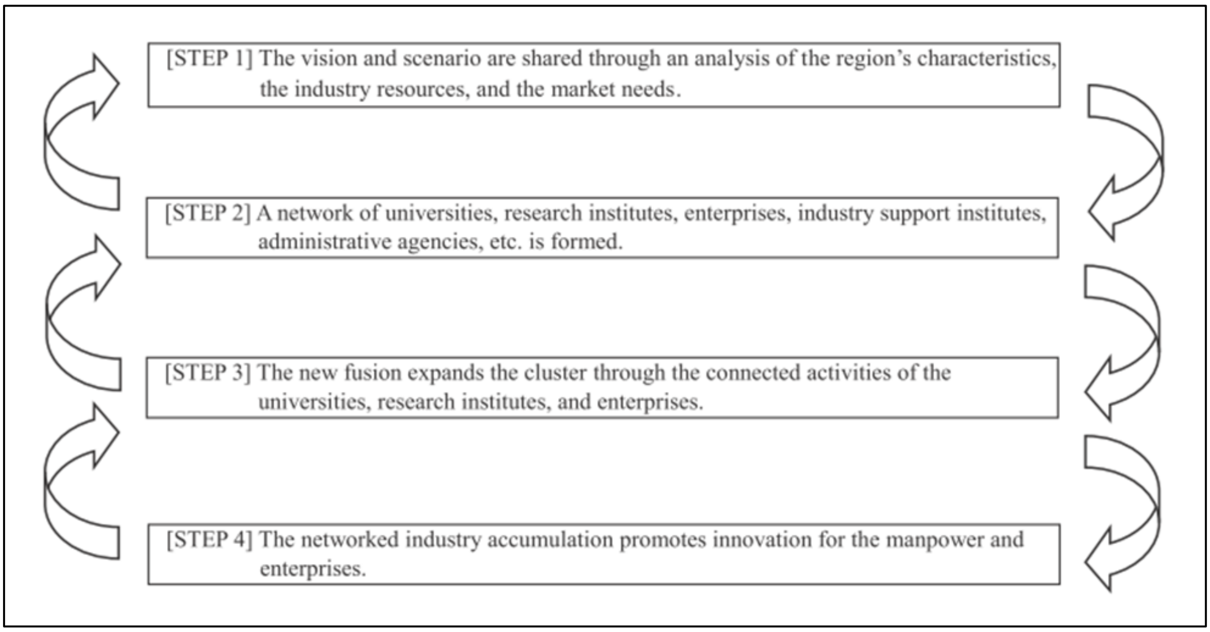

Figure 3-2 Design state of the regional innovation cluster
(Source: Yoon, 2017)

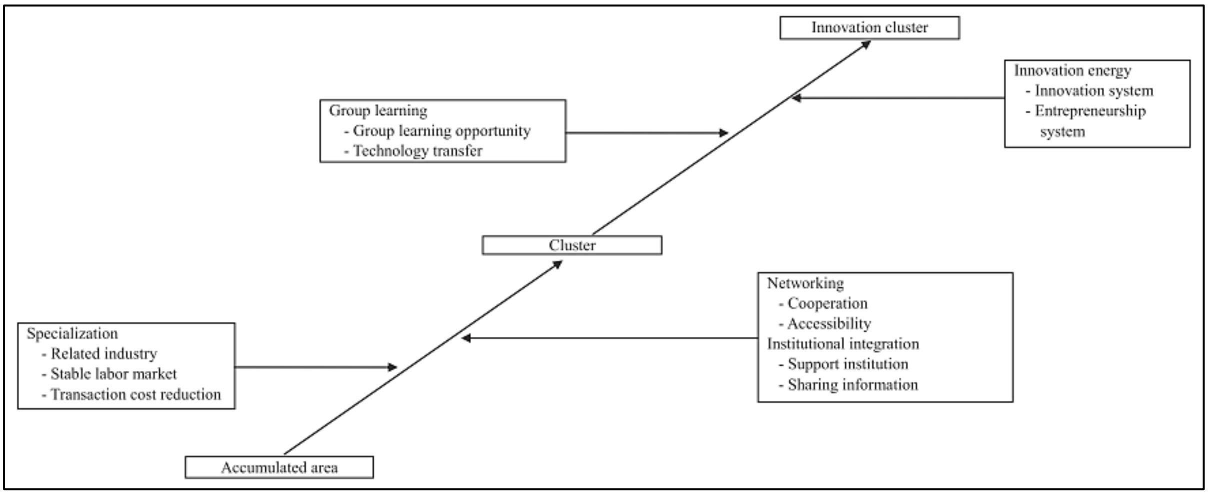

Figure 3-3 Network stage of the regional innovation cluster
(Source: Yoon, 2017)

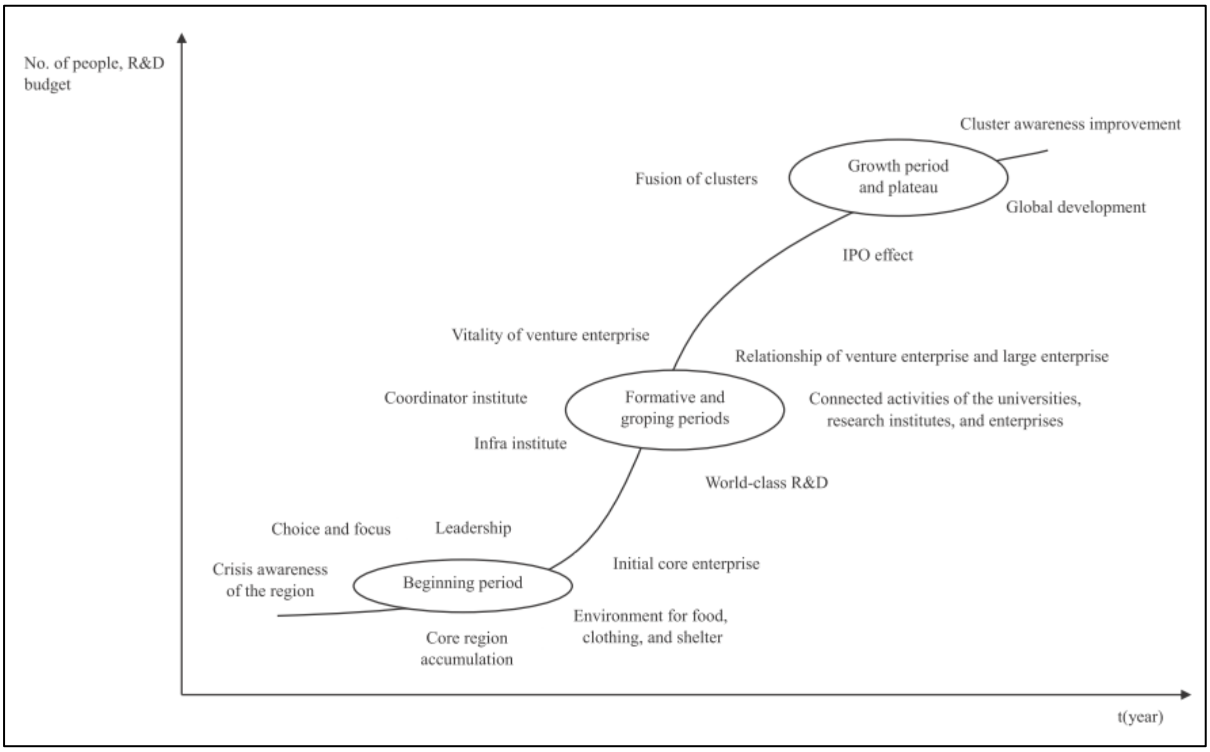

Figure 3-4 Evolution stage of the regional innovation cluster
(Source: Yoon, 2017)

3.4.2 Introduction to IDEF0 and UML Activity Diagram

There are two main reasons why there are failures of strategic planning in engineering management process. The first reason is the lack of comprehensive models to accurately represent the complex structure of the process (Rametsteiner and Weiss, 2006). The second reason is the disparity between the original intention of information and the understanding of individuals who receive the information (Khmelevsky, 2010). These two elements contributed to the issue of a poorly executed operation, originated from the lack of clarity and understanding in organisational strategy. Likewise, it was asserted that the success of the execution of strategy would largely depend on how well the knowledge is managed and successfully transferred among individuals within the system (Marques *et al.*, 2016). An integrated computer aided manufacturing definition for function modeling (IDEF) has been regarded as a steamlined and flexible tool with sufficient features to illustrate a complete representation of a specific complex system. IDEF0, which is part of this modelling family has been utilised by system engineers to analyse complex system, study the interactions between system's components, and model the ongoing operation of the elements within the system (Kappes, 1997). Therefore, its application is suitable for the design of some components in a policy framework for innovation clusters. The strengths of IDEF0 modelling system is clearly explained as follows;

"The language of IDEF0 is standardized with respect to syntax and semantics; therefore, models are well-defined, well-structured, easy to understand, easy to modify and use, and can be extended to any depth of detail. The IDEF0 models are also flexible, scalable, and adaptable to varying situations and conditions. The IDEF0 models can be considered to be three dimensional, because any two-dimensional IDEF0 function model diagram can be extended to child functions presented at different layers, or levels of the model. There is also no limitation on the number of child function layers." (Waissi et al., 2015)

To clarify, the child function is a concept employed in IDEF0 to reduce the apparent complexity of the model. It is conceptually convoluted to represent every part of the system by using a single encompassing diagram or model. Thus, the model should be seperated into several sub-sections or a simplified version of an overview model (Kim and Jang, 2002). A certain part of a policy framework which would be formulated for electric bus innovation clusters in Thailand would also be in this format. It is planned that IDEF0 would represents the overview of the system while several UML activity diagrams would be 'child functions' to the top layer that will be illustrated by IDEF0 diagram. This is because IDEF0 is easier to create, and the subtlety of its structure is expected to stimulate the understanding of general audiences. Despite being relatively simpler when compared to other modelling techniques, IDEF0 satisfies all of the requirements to be a suitable modelling method for the formulation of large-scale strategic planning i.e. flexible, scalable, standardised and simplified. In conclusion, this modelling technique is widely regarded as one of the most effective modelling language to be used in strategic planning and operation management (Tsironis, Gentsos and Moustakis, 2008), and in accordance to the main objectives of the policy framework that would be developed for Thai innovation clusters.

Despite being relatively simple to understand when compared to other categories of Unified Modeling Language (UML), activity diagrams were often transformed into a different format to enhance their comprehensibilty towards the audience, especially for process managers (Syriani and Ergin, 2012). Therefore, the designer should ensure that technical notations within the diagram are appropriate for the audience and their level of knowledge in system modelling discipline (Weitlaner, Guettinger and Kohlbacher, 2013). The most noteworthy weakness in activity diagrams are the possibility of the flow chart becoming too big and cumbersome, when they are designed for large and complex system. The solution to this issue is to separate the diagram into several sub-sections, for example, the public policy framework for an e-bus research and manufacturing cluster in Thailand will include several activity diagrams which are linked by the governing systemic model of IDEF0. The aim of this practice is to reduce the clutter in the individual diagrams and promote a clearer and more specific presentation to the audience.

García-Fernández and Garijo (2010) proposed activity diagrams as the model to effectively manage strategic decisions in financial valuation of projects. It was asserted that normal means of projects valuation such as net present value (NPV) or return on investment (ROI) are not suitable for determining optimal choices in uncertain situations. These uncertainties included level of demand and supply, resource costs, other externalities, etc. The main rationale for the preference of UML activity diagram over business process modeling and notation (BPMN) or Petri Nets is because it can provide more reactive flexibility in a design precess when compared to the latter methods (Eshuis and Wieringa, 2001;Birkmeier, Kloeckner and Overhage, 2010). Moreover, the method is suitable for managers and non-technical staff who don't have any background knowledge on some specific concepts in system engineering (Cysneiros and do Prado Leite, 2001). Activity diagrams rely on the abstraction of the concepts to their most basic and primitive form, which make them less likely to alienate the audience. In contrast, BPMN is normally used as a system model that could be easily handled by system analysts and software developers. Similarly, Petri Nets language is also highly technical and was intended to be used by trained computer scientists or software engineers (García-Fernández and Garijo, 2010). Moreover, the unified modeling language is more widely used and accepted. Therefore, the metamodel of activity diagrams could either be extended to satisfy the requirements in a future project, or be modified based on shifting inputs and parameters by other researchers without additional issues.

In addition to the suitability of the model, it is also important to consider the target audience who would be responsible for the further applications of the model. There are two distinct modelling sub-groups in the modelling community, one is called 'enterprise modellers' and another is called 'distributed object system modellers. The former group can be described as a more business-oriented individuals. They would concern mainly about business issues and how the process would influence their organisations or the life-cycle of their business (Fox and Grüninger, 1997). As a result, it is more natural to associate them with a simpler and more abstract modelling technique such as IDEF0. Conversely, the latter group is often more technical focused. They would be more comfortable with the modelling system which present a complete information and detailed explanation in the diagram (De Martino, Falcidieno and Haßinger, 1998). Therefore, UML would normally be a better choice for them because the system allows for more speciality and features within the model. It was argued that a direct translation from business model to programming language and vice versa are not appropriate (Kim *et al.*, 2003), but there was also a study that showed the complementary translation between one purpose to another (Gruhn and Laue, 2007). In summary, the effectiveness of the model would depend on the contextual meaning within the model, and how well it is disseminated to the audience. A direct translation from one language to another would function competently if the audience are sufficiently knowledgeable in both languages and has full comprehension on the basic premise of a specific system.

3.4.3 Applications of IDEF0 and Activity diagram in a Single Framework

According to the previous section, it can be assumed that the combination of IDEF0 and UML activity diagrams in a single application will not be an entirely novel approach. On the contrary, there are good reasons to apply both methods in a practical situation, especially if a system modeller needs a broader perspective on a single system or process (Figure 3.3.4). IDEF0 could be used as a business-oriented, highly conceptualised modelling system to incorporate the top level perspective, while UML could be used to describe a more activity-oriented details in the implementation of the same project (Kim *et al.*, 2003). In this thesis, IDEF0 would be designated as a supplementary modelling technique to describe a complex system of an innovation cluster in a primitive and basic format which could be easily understood by business oriented stakeholders. Another reason for this arrangement is because a UML activity diagram is not an effective model for the abstraction of several concepts and events that occurred within the system (Dumas and Ter Hofstede, 2001). On the other hand, IDEF0 enables system designers to link the objects and behaviour together in a system that could be broken down into basic units i.e. inputs, outputs, mechanisms, and controls. Nevertheless, it was stated that the lack of understanding in the actual implementation of the process could be induced by the sole utilisation of thr IDEF system without other supplementary materials, because the detailed descriptions of objects within the model are not represented properly (Imran *et al.*, 2010). As explained at the beginning of this chapter, a good framework should balance the influence between top-down and bottom-up perspective for policy instruments in its modelling process. Hence, the combination of both IDEF0 and UML activity diagrams will be a configuration that would be intuitive to wider group of audience.

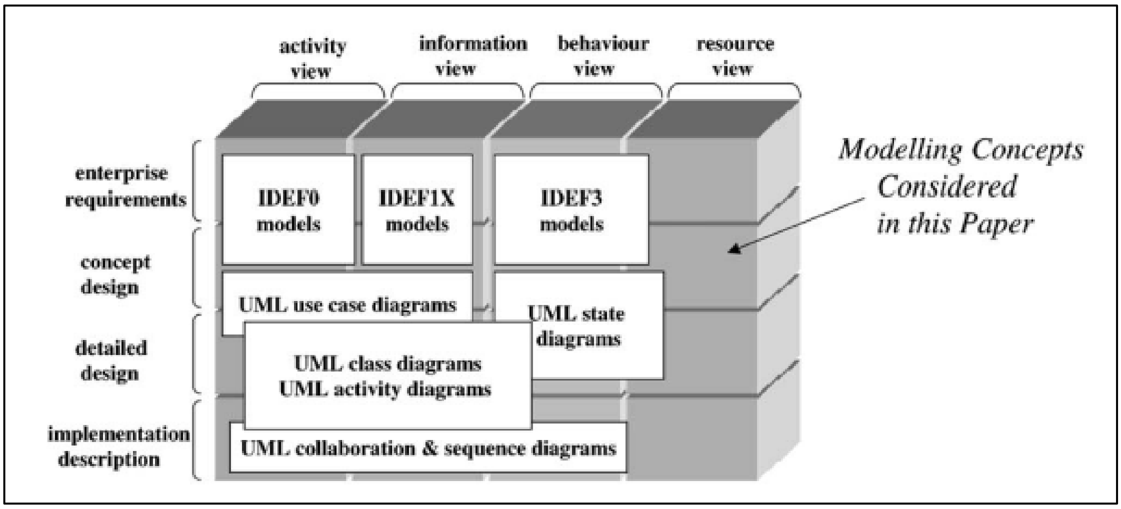

Figure 3-5 The suitable modelling concepts for each level of design specification and perspective (Source: Kim et al., 2003)

The integration of two different modeling languages in the same business process has been accomplished before by the work of Rodríguez et al. (2011). Class diagram and use case diagrams were both applied to represent the business process in detailed, while the extended business process modeling and notation (BPMN) were used to represent the top level architecture of the process. It is very important that the technical details and notations in the diagram are not overwhelming. If they are not self-explanatory, it was recommended to include the complete explanation to all terminologies and symbols in the diagram (Recker, 2010). The system modeling process is often an iterative process that need constant revisions, especially when the design involves a large number of stakeholders from several backgrounds. In one study, it was demonstrated that the perspective from IT specialists regarding the security of the system is incorporated into the model after it has been completed (Rodríguez *et al.*, 2011). After that, the model went through third and fourth iterations in order to further refine itself. In summary, the framework for business processes will be improved if it is constantly rehearsed to make sure that the processes are represented in the most precise manner (Phalp, 1998).

Due to the differences in the limitation of various modelling systems, it was proposed that the combination of multiple modelling techniques might be contributory to the depthness of the system diagram (Melão and Pidd, 2000). An example that showed the utilisation of both IDEF and UML modelling languages simultaneously in the same system was presented by Kim et al. (2003). In this paper, IDEF and UML modelling systems were designed to be a complementary pair in the system description of an electronics industry. It was stated that different IDEF methods i.e., IDEF0, IDEF1X, IDEF2, etc. are not exclusively designed to have an overaching framework. Multiple uses of IDEF would give rise to issues of inefficient communication among different domain of experts because of the incoherence across each version of the IDEF model. On the other hand, UML would be more suitable for the design of an interconnected framework that includes multiple perspectives in several areas (Kim *et al.*, 2003). Other modelling language apart from IDEF and UML also contains unique positive and negative aspects that are attributed to themselves. The usage of multiple modelling languages might be viable or even better than the usage of a single modelling language for complex system design in both engineering and business process (Vangheluwe, De Lara and Mosterman, 2002). It can be concluded that the consolidation of IDEF and UML system models will offer significant potentials that are normally overlooked in the application of a single technique model. However, more expense would be incurred in the utilisation of more than one modelling technique. System managers and policy makers should weigh positive and negetive facets in both options before commencing on the design process.

A framework for the evaluation of business process modelling techniques was designed by Ying et al. (2003). This framework can justify the suitability of IDEF0 and UML activity diagram in the formulation of a policy framework in an innovation cluster. According to this appraising framework, there are four core objectives of a process modelling: to facilitate human understanding and communication, to support process improvement and management, to automate guidance in process operation, and to automate support execution (Ying, Hong and Zhengchuan, 2003). The modelling system needs to be able to provide solutions for all these objectives to make the system run smoothly. In other words, the choice of modelling technique needs to clearly describe the process in the form of four basic questions: what activities would be performed, when activities would be performed, where activity would be performed, and who would perform these activities? The resolution to these four questions would lead to the verification of the process via the system model. Consequentially, there will be a higher chance for a valid holistic representation of the system, in which the interconnections of internal activities would be properly illustrated (Willaert *et al.*, 2007). Their feasibility in the making of policy implementation plan are summarised based on the aforementioned evaluation method designed by Ying et al. (2003) as follows;

- *Validity* – It is difficult to verify at this stage because activity diagrams could be convoluted at the bigger scale. This might affect the validity of the strategy that incorporates the diagram.
- *Comprehensibility* – This is the most important aspect that would be considered when making a choice of modelling techniques. The comprehensibility need to be very high to ensure that every stakeholders understands an overview of the process.
- *Flexibility* – This is one of the reasons that two distinctive techniques were applied instead of just one technique. Multiple formats of the model could provide more flexibility during the formulation process. Both of the alternatives could be swapped and exchanged if needed.
- *Multiple Perspective* – Similar to the factor above, the choice of two techniques would facilitate the different scale of perspective during the formulative process. IDEF0 is set to be a top-view perspective of the process, while activity diagram would illustrate activities within the cluster in a more detailed manner.
- *Suitability* – There is no specific conclusive evidence that this choice of modelling techniques would be suitable for the policy framework, since there are still no application of these techniques to the development of innovation clusters.
- *Expressiveness* – In contrast to information technology process modelling, business process modelling does not require a wide array of notations. This characteristic would be in line with IDEF0 and activity diagram, which aim to retain the simplicity by using minimal notations.
- *Coherence* – IDEF0 and activity diagrams are quite similar in terms of their structure, so the model is expected to be coherent despite the usage of two different modelling methods.
- *Completeness* – It is difficult to illustrate every element and interaction within an innovation cluster, both during the establishment and operational stage. Several activity diagrams might be necessary to illustrate the complete depth of an innovation cluster.
- *Efficiency* – Because the whole framework have to be designed within the limited timespan amidst the rapid change of technologies. The techniques that would be utilised need to counter this issue by being both comprehensive and unsophisticated.
- *Effectiveness* – This aspect is rather difficult to determine before the framework is being applied in the actual environment. It is recommended to assess this metric later after the formulation of the framework is completed.
- *Formality* – This feature need to be kept at minimum level, because the audience of this framework is not guaranteed to be knowledgable in the technicalities of business process modelling techniques. IDEF0 and activity diagram would be easy to understand because the uses of their basic ‘blocks and arrows’ design.

- *Arbitrariness* – Similar to suitability, it is difficult to tell whether or not these techniques would have sufficient degree of freedom towards the modification of framework, since there was no prior research that utilised the combination of these techniques on the application regarding innovation clusters and innovation policy.

3.4.4 Monitoring and Evaluation

The final part of the framework that would be formulated by this thesis will deal with the performance measurement of an innovation cluster. The accuracy of these measures was proved to be a vital concern for a policy plan resulting from the framework (Boschma, 2006). The challenge that could arise is the difficulty regarding the measuring of success and how to justify that the strategy being employed by policy makers is appropriate. There are several ways to measure the success, although it depends on the structure and the purposes of an innovation cluster (Brenner and Schlump, 2011). From the case study in the UK, different approaches were needed for the evaluation of three different models in regional innovation system. There was no definitive model for the creation of monitoring tool for all three cases (Thomas, 2000). In addition, it would take a long time to assess the actual effectiveness in a steadily operating innovation cluster. These reasons lead to the circumstance that most research were unable to generalise its findings into a theoretical model despite their commitment to regional and industrial inclusivity.

The benefits of science parks were discovered to form very slowly and could be ambiguous from the perspective of the national economy. These benefits are slowly forming over the year during the operation of science parks. Thus, the measure of success should be derived from the benefits over a long period of time (Ferguson and Olofsson, 2004). The most common measure of success is occupancy rate within science parks, which would constantly improve when science parks are becoming more mature (Dabrowska, 2016). However, it was asserted that occupancy rate might not reflects actual effectiveness of research and development activities within the system, especially in regard to average-based data gathered from various science parks throughout the UK and USA (Henneberry, 1984). The main reason why this metric did not work was because a lot of specific vital information was concealed by the averaging approach. For instance, average occupancy rate from one set of data to another set might entails many major differences if there are a lot of outliers. This point accentuates the significance in discovering appropriate measures that could properly evaluate the success of science parks. The literature about the performance measurement of science parks bear several resemblances to the measure of success in the field of innovation cluster (Sun, Lin and Tzeng, 2009). Many public organisations in Thailand such as NSTDA have extensive experiences regarding this topic. The baseline framework that was formerly developed is largely accepted by the stakeholders in many industrial clustering programmes (Wonglimpiyarat, 2006).

3.5 Conclusion

In conclusion, the development of innovation clusters has proved to be a challenging effort for policy makers. The complexity of network structure and interconnectivity of each elements within the system is overwhelmingly large, to the extent that many existing concepts in the realm of cluster and innovation policy could not be effectively utilised (Park, 2002;Flanagan, Uyarra and Laranja, 2011). A new perspective on system design must be made not just in the infrastructural aspects but also other important factors, such as the difference in organisation culture, government structure, power and influence, and the existing resources and capabilities. An in-depth review of the current innovation system within the scope of the study is essential for the formulation of public policy framework aiming at the development of innovation clusters. Furthermore, case studies and best practises from other innovation clusters around the world would also support the process of framework formulation within this thesis.

Innovation clusters need to be properly designed and managed in order to provide maximum benefits to the industry and corresponding enterprises. The creation of innovation clusters does not automatically lead to performance improvement on innovation, especially if there are several disconnections within a collaborative network (Lee, 2010). Therefore, policy makers and implementers should make sure that the interconnectivity within the network exists and applicable for all actors. Putting several actors together in the same physical proximity does not guarantee that they would form local external ties together. Sometimes firms might be more comfortable to go for distant external ties (Boschma, 2006). An effective clustering approach requires more than just a fitting geographical location and actors. It is also the matter of empowerment and autonomy of the network that would be created. This is a challenging prospect for policy makers because every firm is different, and the framework should not treat them as identical elements in the system (Liu and White, 2001). It was asserted there would be some companies that could reap significant benefits from the cluster while some companies fail to prosper. Treating every actor within the network equally might be a mistake that could generate prominent issues within the clusters (Chapman, 2004). The leading companies are vital to the survival of clusters, but there would be a struggle to maintain their level of involvement when they have already exploited all of learning benefits from the clustering. Furthermore, there would be a lot of socio-cultural issues that need to be considered at an organisational level, regional level, and national level (Elenkov, Judge and Wright, 2005). It is arguably more difficult to design a framework based on the assumption that all elements are different, but the resulting framework would be a considerably more effective design.

For the situation of innovation policy in Thailand, five types of systemic problems within the national innovation system were specified (Chaminade, Intarakumnerd and Sapprasert, 2012). This research might offer a good starting point to the formulation of policy framework which likely to encounter some of these issues. The first type of problem is infrastructure problem. This refers to inadequate provision of research and development facilities that prevent innately innovative organisations to deliver maximum impact from their technological development. In contrast, capability problem refers to the lack of scientific and technological expertise to absorb the new knowledge that is generated within the system. Network problem is the third type of systemic problem. It refers to the disconnection between each actor within the system. The benefits from the network are not fully realised because the members are not motivated to cooperate. Institutional problem refers to a flawed activation plan towards the implementation of innovation policy. The lack of middle agencies who could support the collaborative activities can also be categorised into this type of problem. Lastly, transition or lock-in problem are connected to the path dependence of actors within the network. It is more likely for private enterprises to persist with a profitable and matured technology instead of a riskier emerging prospect. This would result in the resistance to innovate, which can be amplified by industrial policies that promote the optimisation of production and manufacturing in its current state.

From the case studies outlined in this chapter, four crucial features for the design and formulation of a public policy framework for innovation clusters were summarised in section 3.3: best practices and examples of both existing cluster and recent situations within a specific topical industry, a specification of organisational boundary for both external boundary which encompass the cluster and internal boundary which separate each actor preferably by their roles and responsibilities, the assignment of an intermediary organisation who could oversees the development of the cluster without bias or prejudice, and the target-based fiscal policies and incentives for each actors within the cluster. These four features would then be a main consideration for the design of each component of the framework. In addition to the tools, practical empirical information will be gathered during the formulation of this framework. This will be systematically elaborated in the research methods chapter. This ensure that this framework does not just utilise the existing literature and concepts to present and capture the situation. As explained before, the over-reliance of the existing framework and concepts is possibly the pitfall when designing a public policy which involve fast-moving technologies such as electric vehicles where the parameters are changing on a regular basis. Additionally, this is also often deemed to be ineffectual for the policy making against the complex multi-level system such as the automotive industry in Thailand.

Roughly, considerations outlined in the case studies and best practices section would be supported by the in-depth study of the EV industry that would be detailed in the next chapter. Furthermore, an in-depth data collection from the industry, which includes SWOT analysis and external drivers' analysis in the Thai e-bus industry will be conducted. Both of which would lead to the summarisation of industrial and policy gaps in the Thai automotive and e-bus research and manufacturing industry. Next, the specification of organisational boundaries would be covered by the stakeholder's analysis for internal boundaries and the reimagining of e-bus supply chains for the external boundaries of the cluster. For intermediary organisations, this thesis dedicates one section in chapter 7 for this topic that entails the purpose, the positioning, and the forward plan for this entity within the ongoing developmental process of the cluster. Lastly, fiscal policies and incentives would not be directly designed by this framework because the financial budget is technically difficult to ascertain. Instead, technology roadmaps and business model canvases will be developed and presented to facilitate the targeting of fiscal policies and financial incentives provided by policy makers and the government.

This thesis aims to modify and combine these techniques with an original holistical method, in order to formulate a consistent framework which seamlessly integrates all of the techniques together into a single coherent public policy framework. The finished public policy framework should be able to yield a convincing policy plan for any specific industry, specifically electric bus cluster in this case. The framework and the resulting policy plan should be made in such a way that they are both accessible to the larger audience and have considerable benefits to the majority of actors within any cluster or system of interests. Moreover, it should be designed by considering most of the systemic issues that normally happens within innovation clusters. These systemic issues were outlined in section 3.2 of this chapter as an introduction towards the main consideration for the development of both cluster policy and policy framework that would be developed by this thesis.

Chapter 4 Research Methodology

4.1 Research Philosophy

The main idea behind the concept of clusters is to increase the frequency of interorganisational collaborations. However, different approaches beyond the classical philosophical standpoint might be needed to solve the problem because of the diverse relationship between system's actors. Since many different possibilities must be considered, the purely positivist or interpretivist point of view would not be very effective because it only assumes direct causations which does not sufficiently explain the complexity of the clusters that could arise from multiple factors that were reflected in chapter 2. Conversely, this research would not aim to find a theory that can be empirically proved, but to explore the multitude of possibilities that can be used to explain the phenomena. This argument is especially useful for the analysis and development of a policy mix that could be utilised within a complex system such as innovation clusters. As a result, this research proposes critical realism (Bhaskar, 1975) as its approach to study the topic of innovation cluster within an actual industrial setting of EV industry. Critical realism approach focuses on the identification of causal relationship in the real world, which is similar to constructivism. However, the most distinct disagreement between constructivist and critical realist paradigm is the view on the origin of causal power in social constructs. Constructivist views individuals as the only source of causal power in social realm (Peters et al., 2013). Alternatively, critical realist assumes that the relationship between individuals could also emanate causal power, and this power could alter the event within the system of interest. In other words, individuals as a group might constitute to a different causal effect, the concept which coincide with innovation system approach and complexity theory.

The utilisation of critical realism in analysing organisational mechanisms were supported by Mingers and Standing (2017). They elaborated how traditional positivist standpoint was inadequate to explain some events that were induced by intangible force, which existence cannot be empirically proven. At the same time, they also asserted that the total constructionism standpoint is susceptible to ontological and epistemological fallacy, because of how it totally disregards empirical causal relationships which could be substantial to generate a convincing conclusion for social problems. On the contrary, Brown (2014) argued that critical realism is a poor philosophical position for social research on a highly integrated complex system, whereas each element in the system does not have coherent meaning outside the system. The examples of these are money in a capitalist system or profit in a business system. He argued that critical realism often tries to separate each of these elements into local and specific case study to make sense of the system. As a result, the conclusion from the research will be case-specific and not generalisable. This argument might have its merit when there is a need for generalisation of a hypothesis or a model. However, the output in this research that would come from the data collection and data analysis that utilised the approach of critical realism would not concern about universal generalisation. The results would only be valid for the current situation in Thailand's EV industry. Nonetheless, it was already asserted that the policy framework itself would be applicable to other adjacent applications. This is possible because the framework is not directly related to the data collected, contrasting with the policy plan that aim to solve specific issues within Thai EV and e-bus industry.

In conclusion, even though critical realism might seem to be ideal for this research, it also has a few shortcomings. Firstly, critical realism tends to work best when there are clear set of research objectives, data, and underlying theory. It is geared toward answering concrete research questions in a flexible manner. As a result, the answer would not be generalisable into other reality outside the boundary of the system. Secondly, critical realism is arguably not as well-defined as other main philosophical paradigms, such as positivism and interpretivism. The conceptualisation of critical realism is limited, and it still does not distinguish itself enough in the realm of research application.

However, the benefits of critical realism are also impactful to this research. Critical realism is well-suited for a study that want to describe the agency-structure relationship by acknowledge the causal power of both individuals and ties between individuals. It is a suitable paradigm to study the unpredictable, but explicable events that could occurred within the complex system of innovation clusters. The overlapping ideas between the underlying assumptions and concepts of this research and critical realism is apparent, especially the concept of emergence which is the main feature of critical realism and innovation system. Thereupon, it is believed that the assets and compatibility of critical realism to the study of innovation clusters outweighs its own limitations, and it would be the ideal philosophical paradigm for the objectives of this study. This decision of a philosophical stance led to the choice of multiple in-depth interviews of multiple groups of stakeholders as the main data collection method throughout the research. This compatibility would be explained throughout the chapter.

4.2 Phase 1: Finding the Gaps

4.2.1 Objectives

At the beginning of this research, it was not decided which industry segment in Thailand would be the foundation for the formulation of the policy framework. Initially, there were four potential industries that were considered as contenders for this research. These included the rubber industry, automotive industry, computer hardware industry and tourism industry. The criteria for these choices of industries were the impact and potential that these industries would affect the Thai economy within the next 10 years. The choice of the industry as a 'vehicle' to study policy-making in a complex system such as innovation clusters was determined after the preliminary interviews that were conducted during July 2019 (Jangbua, 2019;Noomwong and Sutheejaruwat, 2019;Wongdeethai, 2019). The interview data from this phase of the data collection will constitute to the final decision on which industry in Thailand that would be the subject for the formulation of a public policy framework and policy mix in this thesis. After the discussion between the researcher and the supervisor, in addition to the early approval of the office of National Higher Education Science Research and Innovation Policy Council (NXPO), the segment of electric vehicles within the Thai automotive industry was chosen to be the research focus. This decision was made during the middle of the first phase of the data collection, thus the design of several interview questions during this phase was partially altered for a more developed insights towards electric vehicles industry.

In chapter 1, it was established that there were some attempts from the policy makers to create a strong foundation for the Thai electric vehicles industry, by the conglomeration of several key stakeholders in a unified cluster. However, these efforts have not been successfully implemented because there are still several gaps in the previous set of national policy. According to the literature in chapter 2, innovation clusters are strongly affected by their surrounding environment. This includes both tangible and intangible factors, such as capital movement or the relationship between actors (Asheim and Coenen, 2006). This is the first main reason why the current state of the environment surrounding the electric vehicles industry in Thailand should be studied before any attempt to capture its main issues and devise feasible solutions. Additionally, the study of the current state of the electric vehicles industry in Thailand could serve as a verification for the applicability of this research. The ability to utilise this research method in an actual public policy planning in the future would be tested, as a secondary objective for the whole process of the data collection.

The expected outcome of the preliminary interviews will be the responses that could be distilled into conclusive evidence which identify the current gaps in the Thai electric vehicles cluster. Despite having the electric vehicles industry as a main research topic, the segment of electric bus was not yet assigned to be the focus in this research prior to the first phase of data collection. Furthermore, it was also unclear whether the research would continue towards the development of policy framework for the electric vehicles industry rather than other potential industries in Thailand, since half of the research objective is to develop a suitable policy framework for any industry that is faced with disruption. As a result, many respondents of the interviews in the first phase were not directly involved with the development of electric vehicle industry. In addition, the questions designed for these interviews were leaning towards the general development of a cluster instead of specific questions about the electric vehicles industry. These questions address multiple prospects that were explored in chapter 3, such as the importance of proximity towards the degree of collaboration (Premkamolnetr, 1999), the escalating impact of inter-organisational knowledge, information, and technology exchange towards industrial competitiveness (Yoon, 2017), and the extent that the formation of innovation cluster could be catalysed by the intervention of public policy.

4.2.2 Research Design

In summary, the concept of data collection in this research can be considered as a scoping study (Arksey and O'Malley, 2005), because the main objective is to map the key notion surrounding the industry and cluster with a broader scope of methodology. However, scoping study or scoping review is still obscure and underdeveloped as a research method in comparison to the systematic reviewing process, which technically encompasses the in-depth interview method (Munn *et al.*, 2018). Thus, this research established semi-structure interview as the main data collection method that would be used in both the first and the second phase of data collection. It is selected over structured and unstructured interviews because it is the best fit to the objective of a scoping study and the underpinning research philosophy of critical realism. Unstructured interview lacks clear direction and are prone to have the fragmented outputs that would be difficult to analyse in the frame of a single research focus (Dana, Dawes and Peterson, 2013). Structured interview was initially the preferred method. However, it was found that interviewees have a propensity to go off-topic very often during some interviews that were conducted during the first phase. Furthermore, different interviewees are expected to have different levels of contribution based on their differing expertise despite being asked the same set of questions. For example, policy makers might be more contributing in policy-related questions when compared to industrial-based respondents. The time limit for each question would also lead to the potential loss of valuable information that could be extracted from the interviewees. These limitation does not comply with the objective of scoping study and critical realism philosophy, hence semi-structure interview is preferred. Moreover, each interview would be tailor-made for each type of stakeholders. This design could provide extra flexibility when the respondents have further insights on the topic of their expertise.

Qualitative data collection in the form of a series of interviews was chosen over other methods in this research because the formulation of a public policy plan for the electric bus industry would require precise and in-depth qualitative information rather than the breadth that quantitative data normally offers (Eriksson, 2016). Regarding other research methods in the sphere of qualitative analysis, the observation is less suitable because it could not provide adequately detailed outputs for the formulation of a policy plan and would lean towards a more interpretivism approach. It is predicted that the mechanism regarding inter-organisational collaboration among Thai stakeholders would be too inherent to extract the in-depth information by simply observing. In contrast, a more direct approach of questions and answers via the in-depth interview with experts in each stakeholder groups would be more appropriate. Ethnography and narrative research are also not suitable because they are too time-consuming for a scoping study. It was decidedly unnecessary to be immersed in the process of electric vehicles manufacturing, since this research aims to address the issues in the national level of public policy rather than to solve smaller-scale manufacturing problems. This research is more likely to be an exploratory research, thus theory-based methods such as grounded theory or discourse analysis are not a good fit for the design (Starks and Brown Trinidad, 2007). Firstly, the framework and its policy plan that this research would develop is not a theory. The policy plan itself will not be universally applicable to other environments aside from Thai industry. Nevertheless, the policy framework would possess a certain degree of generality, but it can be replicated only when the data collection process is repeated in a different research design. Secondly, this research would not prove or disprove an existing theory or practise, so the critical research approaches would be inessential.

4.2.3 Data Collection

In the first phase of data collection, three face-to-face interviews were conducted to gather the information regarding the development of innovation cluster of the high potential industries in Thailand. Each informant specialised in different topics and was responsible for different aspects in the development of the innovation cluster. All interviews were planned to be approximately one hour long. The interviews were recorded by a voice recording device, for them to be transcribed later in the process of data analysis.

The first informant is a policy maker from the office of National Higher Education Science Research and Innovation Policy Council (NXPO) who is responsible for the national policy for the development of electric vehicles industry in Thailand. Hence, the questions in this interview were focused on the aspect of public policy in automotive industry and the mobilisation for the collaborative effort of stakeholders. Additionally, this informant also served as the main point of contact that could lead to other interviewees who originate from several different segments within the Thai automotive industry and supply chain (Wongdeethai, 2019).

The second informants were two university professors from the engineering faculty who engaged in the research topics relating to the state of the automotive industry and the manufacturing of electric vehicles in Thailand. This session was joined by another doctoral researcher from the University of Strathclyde who studies the requirement of technological capabilities among Thai original equipment manufacturers (OEMs) for the transition towards electric vehicles manufacturing industry. The questions in this session were mostly regarding the current capabilities of Thai researchers and manufacturers in the automotive industry (Noomwong and Sutheejaruwat, 2019).

The third informant was a senior advisor of Food Innopolis, which is one of the most recent innovation cluster initiatives in Thailand. Food Innopolis is generally responsible for the improvement of research and development in food and agricultural industry. It provides necessary resources such as locations, equipment, and technological expertise to both domestic and overseas clients who interest to improve their food-based products. This interview focused on the experience in the creation of an innovation cluster and the issues that the organisation encountered during its formation and growth period (Jangbua, 2019).

Table 4-1 Interviewees information sheet for phase 1 of data collection.

Name	Group	Position	Expertise
TW	Policy	EV Policy Expert	Oversee the development of public policy for electric vehicles industry and adoption in Thailand.
NN	Research	Automotive Engineering Professor	Advisor to the government in the development of research and manufacturing cluster for electric vehicles.
PS	Research	Industrial Engineering Professor	Advisor to the government in the development of research and manufacturing cluster for electric vehicles.
AJ	Policy	Food Cluster Advisor	Manage the activities of agricultural and food sector's research-industry intermediary organisation.

In summary, the data that were collected from the first phase are somewhat fragmented because of the different focus of each interview. Fortunately, the electric vehicles industry was expected to be the research topic prior to the conduction of these three interviews. As a result, the responses from these interviews were not completely abandoned. The analysed information was applied in the first part of the formulation of policy framework, which involve the current state and detrimental issues within the Thai electric vehicles industry.

4.2.4 Data Analysis

The process of data analysis in this section would be treated as a template for the analysis of all interviews that were conducted in this research. The simplified version of thematic analysis was used to analyse the data. This method is often used to identify recurring topics, themes and concepts inside a set of texts from the transcription of an interview or other text-based qualitative data (Guest, 2012). The first phase of data analysis employed a more inductive approach to set the theme for the following second phase, which will be oriented in a more deductive manner. In the first phase, there are no presumption for interview responses. All data that were collected will be analysed impartially and thoroughly with the 4-steps process: transcription, coding, theming, and concluding. In most cases, thematic analysis normally contains 6 stages. However, the procedure of data analysis in this research combined the third step (generating themes), the fourth step (reviewing themes), and the fifth step (defining themes) into a single step (theming). Since all these stages have a singular objective, the additional steps in the original concept of thematic analysis were omitted to maintain equal commitment and workload among the revised 4-steps in this reformed process of data analysis.

The full transcriptions of the interviews were written in text format during the first step of data analysis. This process also included the translation from Thai to English language, since all interviews were conducted with local people who are more comfortable with Thai language. Clutter during the interviews were also trimmed out, including small parts of the content that was deemed to be irrelevant i.e., small talk, off-topic speech, etc. After the transcriptions were finished, all of them were combined into a single coding sheet which summarised similar questions and answers together. Then, all responses were collectively analysed and grouped into multiple grouping of major themes shared by these responses (generating themes). This process was repeated several times (reviewing and redefining themes) to appropriately conceptualise the interview responses into multiple perspectives. Finally, these themes were recorded and marked according to the frequency they appeared across multiple interviews. This process would present each theme in order of their perceived importance among interviewees and will be vital to the identification of gaps in the electric vehicles industry and cluster, which could be further refined into the structure of policy framework during the next phase of data collection.

Table 4-2 Summary of the data collected in phase 1.

Cluster Questions	**Data collected**
What are the issues that presented in industry clusters?	The decision to include section 6.4 (Issues in the current e-bus cluster) into the framework.
What will be the public policy-based solution?	Responses are used to formulate an appropriate structure of chapter 8: implementation.
How should stakeholders adapt?	Considerations for the formulation of the framework and the inclusion of section 7.3 (Business model canvas).
What are the gaps in Thai industry and economy?	Inputs that help to determine an appropriate cluster to study.
What are important factors to include in cluster research?	Responses are used to formulate an appropriate structure and tools within the framework.
EV Industry Questions	**Data collected**
What is the current situation of electric vehicle industry in Thailand?	The data that can be applied in chapter 6: The current state of electric bus industry in Thailand.
What are the current issues in the Thai EV industry?	Inputs which are applied in section 6.4 (Issues in the current e-bus cluster).

What are the drivers for EV market?	Inputs which are applied in section 6.1 (The drivers for electric bus industry).
What is the current public policy for EV?	Inputs which are the consideration for multiple scenarios method in section 8.1 (Scenario design for the Thai e-bus industry).
What is the current research focus for EV?	Inputs which are applied in section 7.2 (Technology roadmapping).
What would be opportunities in EVs economy?	Inputs which are applied in section 6.3 (Competitors analysis).
What businesses are at risk?	Inputs which are applied in section 6.2 (Stakeholders analysis).
Which products will increase in value?	Inputs which are applied in section 7.1 (Supply chain revision).

There was a minor difference between data analysis in the first and the second phase. The first phase was a more intensive approach where all data sources are combined in a single analysis. This approach was enabled by the smaller amount of data in the first phase, with the sample size of three respondents. On the other hand, there was an additional step to segment the data according to their respective relevance to each component within the framework. This will be fully explained in the next section. The results from the data analysis in the first phase were used to frame the design of the interview questions in the second phase. Important topics were selected, based on the frequency of response. They were integrated into the main objectives of the second phase of data collection.

4.3 Phase 2: Formulating the Policy Framework

4.3.1 Objectives

The main objective for the second phase of data collection was to collect relevant information to formulate a convincing policy plan that would be impactful towards the development of the e-bus research and manufacturing cluster and to finalise the policy framework outlined in the first phase. The most recent information regarding the development in the electric vehicle industry in Thailand, especially within the segment of electric bus research and manufacturing were gathered during this phase. The interview questions in this phase were specifically designed for each group of stakeholders, according to the expected contribution that each group could provide. For example, the interviews with academic researchers were focused on the development of electric bus and relating technologies. This included their opinions on the potential of e-buses in the current situation and the future. It should be noted that the data collection employed by this research is the main method to get insights to develop an accurate policy plan or policy mix for electric vehicles cluster in Thailand. It rarely plays a vital role in shaping the structure of the policy framework. There is a single exception for this circumstance, when a policy implementation plan is split into 4 different scenarios in chapter 8 because of the comment of few interviewees who has experience in EV-based policies in Thailand. This will be explained later in chapter 8.

The formulation of the policy plan was concurrently developed along with the process of data collection. Therefore, the data was continuously collected until sufficient information were gathered to successfully develop each part of the policy plan. There are four main sections of the policy framework. Each section would correspond to each chapter in this thesis from chapter 6 to chapter 9. The contents from each section were originated from the analysis of the interviews. Chapter 6 would focus on the current state of the Thai electric bus industry. This will include several analyses based on the information regarding the current gaps and the future goals of the industry and its stakeholders. Chapter 7 would focus on the vision and the organisation of the e-bus cluster. Most data in this section were treated as the inputs for the creation of an integrative plan that considered multiple facets of opinions from every group of stakeholders. Chapter 8 would focus on the implementation of the policy plan, by assuming 4 different implementation scenarios. Most collected data will be applied as the ideas for the design of the public policy initiatives. Chapter 9 would focus on the monitoring and evaluation of the e-bus cluster. Hence, potential metrics that can be considered as the performance indicators will be obtained from the interviews.

4.3.2 Research Design

This phase of the data collection focused on the key topics to establish a successful and prolonged electric bus research and manufacturing cluster. In example, the topics included the expectation in stakeholder's involvement and their boundaries of responsibilities, the potential exchange of information and interactions between stakeholders in the industry, and the business perspective of private enterprises and the feasibility of electric bus manufacturing. The data related to these topics would be gathered from several stakeholders in Thai EV industry. The interviewees included bus manufacturers and assemblers, government agencies who are responsible for the public policy regarding electric vehicles, research groups who would have research applications for the e-bus industry, and potential e-bus purchasers and users. The sample would be selected based on the willingness to participate and the impact level towards e-bus industry of each candidate. It is important to designate a diverse sample set for the sake of differing viewpoints that could originate from different status and stance in the bus manufacturing supply chain. However, it is also practical to consider the level of impact of each organisation towards the development of the industry. Smaller company's opinions will be important to the design of a policy plan but might not be an accurate representation of the whole industry. On the other hand, bigger companies would have a more impactful interview response. Therefore, the design of the data collection and analysis must prioritise the important of each piece of information. The results from these interviews were expected to be pivotal to the formulation of an effective policy framework and its corresponding policy plan regarding the adoption of electric bus in Thailand.

The other methods that were also occasionally used in this phase of data collection are the focus group and the attendance at seminars. A focus group was conducted once during the interview with bus operators, due to the lack of inputs from each individual participant. In fact, multiple focus groups might be a better method for the data collection than the interviews for the gathering of ideas that could lead to an effectual framework design. However, it was difficult to arrange a focus group where the complete attendance is guaranteed because the sample of this research is several important figures in Thai electric vehicle industry. Interviews are significantly easier to arrange, which facilitate the continuity of the process of data collection in a short duration. The attendance in seminars is an alternate method to gather information regarding the current progress of electric vehicles industry in Thailand. Most seminars that were attended for the purpose of data collection were held by the electric vehicle committee of Thailand (Kurovart *et al.*, 2020;Massamadon *et al.*, 2020). The proceedings of these seminars were recorded in the same way as each interview i.e., using a sound recording device. These seminars typically contained updated information and provide a good overview to the current state of the Thai electric vehicle industry. Nonetheless, they also tended to diverge into other topics that are beyond the scope of this research. Furthermore, several seminars were repetitive in contents, especially when there was no prominent development within the industry. Unfortunately, under the situation of Covid-19 pandemic, the attempts to form additional focus groups were cancelled. The planned focus group was later converted into a short online group interview with a lower number of participants.

4.3.3 Data Collection

A semi-structure in-depth interview was still a preferred method for the collection of data in the second phase. However, the boundary of the interview sample was kept strictly within the segment of electric bus industry in Thailand. The sample group of these interviews included five major types of stakeholders: policy makers, researchers, manufacturers, operators, and users. Nonetheless, operators and users would be considered as the same group in many instances during the results and discussion section of this thesis. It was found that both groups frequently exhibit overlapping interests across different inputs of public policy relating to the adoption of electric buses. Furthermore, seminar attendances were recorded as additional data sources for the collection of primary data in this phase. All individual interviews, focus group interviews, and seminar proceedings were recorded by a voice recording device. These recordings were transcribed into the text format of English language during the process of data analysis.

The first group of interviews consists of policy makers i.e., people who have direct or indirect influence over the change in the public policy that could affect the electric vehicle industry. The interview results from this group of stakeholders entailed the overall situation of electric bus research and manufacturing cluster in Thailand, and several suggestions regarding the utilisation of available policy instruments to rally this industry.

The second group of interviews consists of e-bus importers and potential manufacturers. The focus of these interviews was mainly about business conduct, business strategy, and the feasibility of e-bus assembling and marketing in Thailand. They provided more insights to the supply and demand conditions of the current electric bus market. Furthermore, some feedbacks towards the recent government policy for the industry were also gathered.

The third group of interviews consists of academic researchers who were working on e-bus related projects. This also included the main research funding agency who is funding most research programmes on electric buses in Thailand. The interview questions were altered towards the research-oriented activities. The results from these interviews were about the current technological capabilities and progress in the development of e-bus manufacturing process among the funded stakeholders.

The final group of interviews in this phase consists of both public bus operators and general users i.e., bus drivers and passengers. This part was initially planned to be a focus group; however, it was evolved into a method akin to a group interview due to the lower number of outputs and interactions between each respondent than what was originally expected. Some questions were improvised during the interviews to adapt towards this change and to promote the continuity of the discussions.

Table 4-3 Interviewees information sheet for phase 2 of data collection.

Name	Group	Position	Expertise
TW	Policy	EV Policy Expert	Oversee the development of public policy for electric vehicles industry and adoption in Thailand.
PS	Manufacturer (Import)	CTO of an importing company	Professor in automotive engineering who have expertise in electric vehicles.
AT	Manufacturer (Import)	CEO of an importing company	Importer of e-bus from overseas Chinese manufacturer.
SS	Operator (Public)	Procurement Agent	Procure electric buses for Bangkok Mass Transit Authority (BMTA) which is the largest bus-based public transport organisation in Thailand.
PN	Operator (Private)	Coordinator manufacturer-operator	Being in the bus operating business for at least 10 years. Coordinate the procurement between Skywell and private operators.
O1	User	Operating Company	No Expertise.
O2	User	Operating Company	No Expertise.
O3	User	Operating Company	No Expertise.
SW	Research	EV program director	Oversee the governmental funding of EV-based research for universities, technical institutions, and private researchers in Thailand.
YL	Policy	Director of an EV-based organisation	The director of the public organisation which promote the adoption of EVs.
SC	Manufacturer (Domestic)	CEO of domestic assembly garage	The owner of one of the biggest assembly garages for ICE bus in Thailand.

In summary, the data in this phase were collected from multiple groups of people with varying degree of knowledge regarding electric buses, which can be a challenge for the data analysis. However, the questions in these interviews were maintained to be relatively similar across each group, with a focus towards the gathering of sufficient information in five aspects of the electric bus industry: the actors within the system, the current progress of the industry, the feedback and sensitivity towards the industry, the strategy utilised by stakeholders, and the metrics to measure stakeholder's performance. This boundary was designed to facilitate the transition of the analysed data into the inputs for the formulation of a policy framework and its corresponding policy plan.

4.3.4 Data Analysis

Similar from the first phase of data analysis, thematic analysis was used to assemble the data into key topics that would be applied into the framework. Raw data in the form of interview transcriptions were also applied in the design of a policy plan for the electric bus industry. Therefore, the results and discussion section of this thesis would consist of several components that would be generated by the amalgamation of the collected data and the analysed information. Furthermore, the formulative process of this framework was designed to be a circulating procedure that would be concurrently developed along with the process of data collection and analysis. The alignment between the structure of the policy framework and the contents in the policy plan was constantly revised, based on the new inputs and outputs from the interviews and the theming of the data respectively. Table 4-4 summarises the interview questions and links them to their presence among the contents in each section of the framework prior to the theming process that would be described in the next paragraph. Please take notes that this is only a rough method to simplify and visualise the data, since the actual contents are more linked to the responses to the questions rather than the questions themselves.

Table 4-4 Summary of the data collected in phase 2.

	Section in the Thesis												
Question Topics	6.1	6.2	6.3	6.4	7.1	7.2	7.3	7.4	8.1	8.2	8.3	9.1	9.2
Current situation of EV industry in Thailand	x		x	x	x	x	x	x	x	x	x	x	
How to measure the success of policy													x
Prospective e-bus assemblers		x			x								
Risks of manufacturers		x	x	x							x		
Suggestions for stakeholders		x		x			x	x			x	x	
Risk for BMTA as public operator		x		x			x		x		x	x	
Current issues in the industry	x		x	x		x	x		x		x		x
Motivation for purchasing e-bus	x						x						
Alternatives to e-bus	x												
Policy limitation				x	x					x	x		
Who is the current mediator in e-bus industry		x						x					x
Current domestic research		x			x	x			x				
The existence of e-bus cluster		x			x				x				

Overseas product and industry			x		x		x						
Uses of overseas case studies		x	x	x		x	x						
Battery manufacturing in Thailand				x	x			x					
Current drivers for e-bus	x					x						x	x
Target market		x	x		x		x			x	x		
Buyers other than BMTA		x			x		x		x				
What would likely to be imported			x		x	x			x				
Confidence in e-bus				x		x	x			x	x		x
Metrics to measure the framework						x		x	x			x	x
Problems of this study									x				
Fiscal policy and tax incentives			x		x		x			x			x
Technological development						x				x			x
Conflicting opinion		x	x			x	x	x	x			x	x
Recommendation for industry				x			x			x	x		
Domestic vs overseas			x						x				
Risk for private operators		x		x	x		x			x	x		
Low technological capabilities					x	x							
Suggestions for cluster								x		x	x		x

There is a difference in the theming process between this phase and the first phase, despite both phases utilised the same method of data analysis. In this phase, important themes from the previous phase were guided into the structure of the framework in a format of a single component per a single section within a chapter of this thesis. As mentioned before in the introduction chapter, each section of the results and discussion portion of this thesis would correspond to each component that was specifically designed via the verification of industrial gaps in the first phase of the research. Therefore, the theming for each section was already decided in advance, which simplified the process of data analysis in the second part of this research. the remaining task for the data analysis in the second phase is the arrangement of all relevant contents from the collected data into each section within a chapter, based on their implications towards public policies in the electric vehicles industry.

A single piece of information from the interview transcription could be utilised multiple time throughout the process of framework formulation. For example, the remark regarding the high developmental cost of battery technology for electric buses could be applied in the design of a technology roadmap (section 7.2), the identification of cost structure for bus manufacturers (section 7.3), and the design of multiple scenarios for e-bus industry (section 8.1). After the analysed information were assigned to all applicable components in the framework, they were categorised in an additional re-theming process. Irrelevant pieces of information will be excluded from the chapter if they did not match the context of the corresponding component in the framework. There are minor modifications during the re-theming process, but the purpose is still relatively the same as the theming step in the first phase. The fidelity of finalised information that would be used in the writing of this thesis would be improved by this procedure. All re-themed information was also ranked according to their frequency of appearance in the transcription. This repeated practice could provide further insights to the recurring themes within the context of each specific component.

Most of the writing in the results and discussion section of this thesis are the conceptualisation of the themes which were extracted from the data by the process of data analysis. The formulation of the public policy plan for the electric bus research and manufacturing cluster in Thailand will primarily refer to this conceptualisation of themes as its references. Most of the citations in the results and discussion chapters would address some quotes from the interviews and seminar. Additionally, tables and figures will be included periodically to facilitate the distribution of contents within the paragraph. Furthermore, they are essential ingredients for the fulfilment of one of the objectives of this research, which is the conveyance of the formulated framework and policy plan in a comprehensible format to both the experts of the topics and laypeople.

4.4 Phase 3: Evaluating the Framework

4.4.1 Objectives

Initially, this research was designed to have only two phases of the data collection: preliminary interviews and main data collection. However, after the research design of this thesis was presented to several people, a single flaw of this research design was pointed out. This flaw is the lack of assessment on the actual effectiveness of the proposed policy framework in the real setting. Therefore, the decision was made to include another phase of data collection after the finalisation of the policy framework and its corresponding policy plan for electric bus industry. This phase would focus on the gathering of stakeholder's feedback on the accuracy, practicality, and legibility of the framework and its corresponding policy plan. The data would be used to triangulate with the findings from this research to increase the validity of the research findings. This triangulation process will be conducted after the third phase of data collection via an online survey. The objective of this survey is the collection of feedbacks from participants who were exposed to the underlying ideas and mechanisms of the formulation of this policy framework and the research outputs that were generated.

At the end of the formulation process of this policy framework, the findings of this research were triangulated with this final phase of the data collection. This means that the validity of the findings was tested by the convergence of information from multiple data sources (Carter *et al.*, 2014). It is expected that this method will improve the trustworthiness of this thesis and its usability in the future. The outcome of this survey was mainly collected in the form of quantitative data to measure the perceived benefits, precision, and feasibility of this policy framework. Furthermore, these results also included text-based suggestions that could reflect the perceived usefulness of the resulting policy plan which was formulated to improve collaborative efforts in the electric bus research and manufacturing cluster and hasten the national-level adoption of electric buses.

4.4.2 Research Design

The third phase was designed to be less time-consuming in comparison to the previous phases of data collection since the main purpose is to verify the validity of the framework and the policy plan rather than to use the gathered data to strengthen the development of the framework. An online survey was utilised as the main method for the data collection in this phase since it is easier to obtain participants than a traditional paper survey. Furthermore, an online survey comprises an ability to reach the respondents who would have busy schedule or live far away. In addition, a data collection using a traditional mean was more difficult to be arranged due to the circumstance of Covid-19 pandemic. Nonetheless, an online survey is usually perceived as an inferior option to the traditional paper survey, in term of the expected response rate and the response time (Wright, 2005). This might pose a risk and contradict with the main aim of this phase to get quick responses from the respondents. However, the timing of this online survey was planned to be instantly after the presentation of the policy framework to the participants, thus it was expected that this negative effect would be mitigated.

Unlike the previous two phases, the collection of quantitative data is deemed to be critical in the third phase. It was decided that the breadth of data would be highly contributing to the evaluation of the policy framework. The collected results from this phase were expected to have high deviation due to the wider assortment of the participants from more segments within the e-bus supply chain. Therefore, the quantitative data collection and analysis was selected to simplify this potential deviation into calculable variables. Nevertheless, it was still used in conjunction with the collection of qualitative data in the form of the questions at the end of a questionnaire to ensure that the depth of insights from the survey was not completely discarded. 7-points Likert scale was used as the main quantitative data collection method in the questionnaire. A more popular 5-points Likert scale was considered at first, but it was discarded in favour of 7-points Likert scale. It was anticipated that the higher degree of variance in the results would be more beneficial to the appraisal of the framework.

4.4.3 Data Collection

The third phase of data collection was designed to triangulate and measure the effectiveness of a policy plan that would be formulated by the framework with the inclusion of collective feedback of stakeholders into the research design. The objective of this phase of data collection is the gathering of feedbacks from the sample which was selected among the target audience of this policy framework and policy plan. This group of target audience included people who involved in the Thai automotive industry, primarily in the electric bus research and manufacturing sector. This sample group would attend the presentation session regarding the policy framework, before providing feedbacks via an online questionnaire. This process included both the stakeholders who participated in the interviews and the stakeholders who did not participate in the earlier phase of data collection. Furthermore, some participants outside of the boundary that was set in the second phase were also invited to increase the potential sample size for an effective quantitative analysis. Anybody who showed interests in the subject could participate in this presentation and the subsequent session of online questionnaires. This can be accomplished because one of the main objectives of this survey is the measurement of the legibility of the policy framework, thus the inputs from laypeople could be critical for this evaluation.

The presentation of the framework would take approximately 30 minutes. The mechanisms within the policy framework and the resulting policy plan for the electric bus cluster will be explained in this presentation session. Afterward, an online questionnaire would be shared via an online link. The sample size for the questionnaire was planned to be at least 30 people, which would consist of 15 people who are the policy makers, 5 people who are the researchers, 5 people who are related to the bus manufacturers, and 5 people who involve in bus transportation services including users. Additional participants would be welcomed to participate, and they could also provide any suggestions in the 15-minutes discussion session that will be held immediately after the presentation. After that, the online survey will be conducted. The online questionnaire was designed to be in two parts. The first part would utilise the 7-point Likert scale to measure the reception of the respondents towards this policy framework in three areas: accuracy, perceived benefits, and ease of understanding. Each component in the framework will also be individually assessed to augment the specificity of the feedback. The second part would be a qualitative survey to gather more in-depth suggestions towards further additions and modifications of the policy framework. The first part of the questionnaire is mandatory, while the second part is fully optional for all participants. However, additional comments and suggestions will be strongly encouraged during the discussion session. The full detail of this phase of data collection will be further explained in section 9.3.

4.4.4 Data Analysis

Most qualitative data in this phase was utilised as additional suggestions to improve the policy framework in later iterations. The questions in this phase focused on possible additions and alterations to the current format of the policy framework and the content of a policy plan for electric bus industry. These suggestions would be compiled and summarised in chapter 9 and chapter 10 of this thesis. Since the provision of additional suggestions are optional for the survey participants, these data will not be fully analysed in the same manner as the analysis of qualitative data in the other phases. On the other hand, quantitative data would be the main feature in this phase. The appraisal of the framework and the policy plan for the electric bus industry are based on the response from an online questionnaire that was structured in the format of 7-point Likert scale. This scale was used to assess the opinions of participants on the overview of the policy framework and its components. For the whole framework, the measures that were used are the overall benefit of this policy framework to the stakeholders, the accessibility of the concept, and the accuracy of information. For individual components, the measures that were used are the perceived benefit from each component to the stakeholders, the ease of understanding, and the correctness based on the current situation in the industry.

The calculation of basic descriptive statistics was utilised in the analysis of this set of quantitative data. Types of descriptive statistics that were collected are the distribution of the value, central tendency of the value, and the variability of the value. The analysed data would be visualised in the frequency distribution tables. The descriptive summary would be created regarding these statistical values and their relationship to the effectiveness of the policy framework which was perceived by the participants. Since the primary objective of this phase is already fulfilled in this process, the usage of inferential statistics will be disregarded. Nevertheless, it is entirely possible to set up a hypothesis for the inference to the general population of the target audience. In addition, there might be interesting details that could be extracted from different groups of samples i.e., the difference in feedbacks between each group of stakeholders. However, the research will need a larger sample size in all possible target groups. Moreover, the outputs from the Likert scale survey are ordinal variables which are not suitable for inferential statistical analysis. A deeper statistical calculation might be the feature of an independent research that can be extended from this study. Nevertheless, the project would require a larger sample size and a wider scope of the data collection.

4.5 Conclusion

Both qualitative and quantitative research methods were utilised in this research. They were applied in accordance with the different objectives for the collection of data. The different objectives required the variation of depth, breadth, timeliness, and volume of the data. More importantly, the expected outcomes were factored into the research design of this thesis. As a result, a significant portion of the collected data was expected to be beneficial to the formulation of the policy plan for e-bus cluster in Thailand. The process of data collection in this research was separated into 3 parts: preliminary interviews, main data collection, and feedback survey.

Preliminary Interviews were designed as a probing data collection process to determine an appropriate industry to study the development and operation of its innovation cluster. Most of the data collected in this specified industry served as the inputs for the formulation of the framework. The data was collected at the end of the first year in this PhD. programme, separately from the other phases of data collection. Multiple in-depth interviews with the experts were employed as the data collection method. The interviews were transcribed and analysed to confirm the suitability of electric vehicle industry in Thailand as a research subject that would be investigated though the lens of the established research design.

The main data collection in the second phase utilised multiple qualitative methods. This included interviews, group interviews, and seminar attendance. The plan was changed multiple time due to the impact of the global pandemic in 2020, thus some interviews were arranged to be online instead of a physical setting. The data was completely collected in Thailand during a 6-month period at the end of the second year in this PhD. programme. They were analysed by the approach of thematic analysis and were transformed into the inputs for the formulation of a policy plan for electric bus research and manufacturing cluster in Thailand, and to a lesser degree the final structure of the policy framework.

A feedback survey was designed to conclude and validate the findings in this research. The design of the framework and the details within the policy plan were briefly investigated by several stakeholders during a brief online presentation which was held at the end of the third year in this PhD. Programme. The accuracy, benefits, and accessibility of the framework and its corresponding policy plan were assessed by both quantitative and qualitative surveys in an online format. The results and discussion from this session were compiled into the list of suggestions for the future development of this public policy framework.

All the participants in the interviews, group interview, and online survey gave consent for their anonymised responses from the interviews and online questionnaires to be utilised for the purpose of this research. The official consent form provided by the university of Strathclyde was presented to the participants to obtain their permission for this information to be officially publish as a PhD. thesis. This form was put in the thesis in the appendix section.

Chapter 5 The Development within Electric Vehicles Industry

5.1 Introduction

The electric vehicle industry was not the main subject when this research topic was initially formed. The choice of industry was designated following the decision to made public policies and innovation cluster the main research subject. The electric vehicles industry was chosen given the global shift towards decarbonization and the current size of the Thai automotive sector which is purely based on ICE vehicles. This led to the high treat of losing national economic stability from a failure to adapt into a new industrial paradigm based on EVs manufacturing. Nevertheless, the aim of this research largely stayed the same during the whole study. This aim is to find an accurate and effective means to formulate and implement public policies in the complex environment of innovation cluster. As such, the public policy framework was developed to respond to this goal. As explained in the previous chapter, it was practically difficult to design data collection methods for this research without the designation of a particular industry or a specific cluster to be the main subject of interest. Therefore, the electric vehicle industry, in particular the electric bus research and manufacturing cluster in Thailand was designated as a vehicle to fulfill the original research purpose. In this chapter, the electric vehicle industry will be reviewed. Important attributes and characteristics of the electric vehicle industry will be extracted and analysed based on the global situation. This information will be used in conjunction with the newly collected data from the Thai EV and e-bus industry in the next chapter to identify and describe the gaps between the Thai and global EV industry. This juxtaposition will serve as the catalyst towards the development of the policy implementation plan which would be presented in the later chapter of this thesis. The formation of this policy plan will be extremely beneficial for the applicability and accessibility of the public policy framework that would be formulated as the main deliverable of this research. It is expected that the practical information that is embedded within the framework will greatly facilitate the understanding towards the process and rationale behind the formulation of this framework for any general audience.

5.2 Important Attributes of the Electric Vehicles Industry

5.2.1 History of Electric Vehicles

The progression of the electric vehicle industry is considered by the public as a novel technological development that would be highly impactful towards the future of ground transport. However, the origin of electric cars dated back to the beginning of automotive industry. They were first introduced along with the attempt to invent electric motor (Høyer, 2008). The electric car was introduced approximately about the same period of time in which the combustion engine car was introduced to the market (Kirsch, 2000). However, The research and development of electric cars then faded after the breakthrough of cost-reduction and the superior quality control in the manufacturing of internal combustion engine, resulting in significantly cheaper and less defective ICEVs in comparison to EVs (Kancherla and Daim, 2018). At the start of the new millennium, more advanced battery technologies and a looming threat of global warming drove many car manufacturers to start focusing on the research and development of electric vehicles once again. However, the main issue in the commercialisation of electric vehicles are the driving range per one fully charged cycle and the cost of battery manufacturing and materials (Newbery and Strbac, 2016). This issue leads to the insufficient market demand for electric cars, which prevent the manufacturers to operate a financially feasible production cycle. Nevertheless, it was revealed that the complete implementation of renewable energy as the main fuel source for vehicles will provide substantial economic and environmental benefits to any countries that are importing a large amount of fossil fuel (Machol and Rizk, 2013). If global car manufacturers could cross the technological barrier of high battery manufacturing cost and its inadequate performance, the adoption of electric vehicles throughout the globe would be significantly more plausible.

There was research that studied the adoption of public policy to promote the market diffusion of electric vehicles. In example, policy intervention and the role of zero emission vehicles mandate in California, USA (ZEV) were extensively studied (Collantes and Sperling, 2008). In one study, a mathematical model was devised to predict the cost-benefit outcome of the transition from ICEVs to EVs from 2015 to 2050 (Greene, Park and Liu, 2014). This model was utilized to calculate the nationwide outcome from the adoption of electric vehicles. The results showed that the adoption of electric vehicles offers a considerable number of benefits, such as the reduction in greenhouse gas emission, the reduction of petroleum usage, and the improvement of air quality. Nevertheless, it was also asserted that government subsidies are necessary for the zero emission vehicles mandate to progress (Kemp, 2005). These additional costs might initially make the campaign for a cleaner transportation system seems costly, since it would incur a large amount of net loss to the government. However, the benefits will exceed the cost and the break-even point will be reached before 2050, granting that the actual circumstance in the real world would not be notably different from the assumptions within the model. It was predicted that the price of battery electric vehicles and fuel cell electric vehicles will be less than the comparable model of internal combustion engine vehicles and hybrid electric vehicles by the year 2040 (Greene, Park and Liu, 2014). This situation is expected to be the main driver for the significant growth of the electric vehicle market during the next decade (2030-2040).

5.2.2 Battery Performance and Driving Range

Driving range is often viewed as the most prominent weaknesses of electric cars (Egbue and Long, 2012). In the case of battery electric vehicles (BEVs), The manufacturing of BEV's components is planned by several incumbent original equipment manufacturers (OEMs) in the automotive industry. Nonetheless, several components in BEVs require different expertise in the manufacturing process, which would come from a completely different set of suppliers from the manufacturing of ICEVs (Beaume and Midler, 2009;Serohi, 2022). Hence, it could be assumed that electric vehicle's technology is disruptive towards the existing supply chain of internal combustion engine vehicle's manufacturing. There are two general types of BEVs that are being produced. The first type is the mass market model that attempt to lower the price barrier of electric vehicles and improve its competitiveness in the automobile market. Because of the discounted manufacturing costs, the performance of BEVs in this category could be viewed as inferior to their ICEVs counterparts, especially in terms of driving range (Duke, Andrews and Anderson, 2009;Mashhoodi and van der Blij, 2021). It was reported that mass market BEVs were struggling in term of sales because their price is still relatively higher than the conventional vehicles, and does not provide satisfactory value to the potential purchasers (Hardman, Steinberger-Wilckens and van Der Horst, 2013;Viola, 2021). The second type of BEVs were produced to serve niche markets. The most prominent example of this type of BEVs is an earlier model of Tesla. In the manufacturing of these vehicles, cost reduction was dismissed in favour of luxury features such as the digitalization of a driving system, improved car performance, comparable driving range to ICEVs, high quality chassis, etc. This marketing strategy allowed them to secure a remarkable sum of funding for the reinvestment in the other market segment of EVs. This included a more affordable mass market BEVs which are planned to feature a comparable driving range to ICEVs. Nevertheless, the introduction of BEVs to mass market is still likely to be difficult due to technological lock-in of petrol vehicles and additional issues in public awareness and perceptions of EVs (Browne, O'Mahony and Caulfield, 2012;Syamnur *et al.*, 2019).

Whereas the focus in the manufacturing of the private-owned electric cars is mostly related to the battery as an individual part, the public-owned electric bus needs to rely more on the overall development of charging infrastructure (Kameda and Mukai, 2011). It was found that the longevity of battery is the main concern for bus operators instead of the driving range and overall performance of the vehicle. The capacity of most batteries would drop below 80% after approximately two years of continuous usage A well-designed charging infrastructure and electronics system inside an e-bus would be essential to reduce this drawback. This might include a control logic software, a built-in solar panel, or a different type of battery. Lithium-Titanate batteries were found to be a more efficient choice compared to the more popular Lithium-Iron Phosphate and Lithium-Cobalt based composite, but they could not be mass-produced and is relatively more expensive (Vilppo and Markkula, 2015). These two reasons would make them an inappropriate choice for public transport. It is important to note that the design of some external components in an ICE bus can be retained in the manufacturing of an electric bus. Nevertheless, an additional process in the inspection regarding the integration of new electronics system of an e-bus and the existing body and chassis of an ICE-bus would be required (Lin *et al.*, 2017). Opting for e-buses that utilise the battery switching method instead of the plugged-in charging is another choice that the government could consider. It was stated that the battery could be swapped within approximately 10 minutes (Gao *et al.*, 2017). This method could mitigate the issue of charging time, since the batteries could be charged separately (An, Jing and Kim, 2020). However, additional batteries are required to be in the reserve, which would potentially double the investment cost for bus operators.

5.2.3 Charging and Infrastructure

The preparation of charging infrastructure is an important issue for the adoption of electric vehicles. Nonetheless, this depends on the circumstance and the number of electric vehicles within the area. For public and private urban transport, the concern regarding availability of charging station would be less important because of the relatively short travel distance. In Norway, the collected data showed that most users prefer charging their electric cars at home when they are inactive during the night (Lorentzen *et al.*, 2017). Fast charging will be crucial only in a long-distance travelling, which mostly occur outside the city. From this information, it was concluded that the current driving range of electric cars is viable in the transportation within urban areas (Azadfar, Sreeram and Harries, 2015). On the other hand, the full implementation of zero emission vehicles in the transportation system will require the development of multiple charging stations in rural areas. This arrangement could be considered as a more demanding stage of development, for the transformation towards the full adoption of electric vehicles. Therefore, policy support and market drivers are compulsory for this arrangement. Even though the Norwegian government currently provide up to 100% of the installation cost, the number of fast charging stations in Norway are still relatively scarce, because the Norwegians mostly use EVs only for urban transportation (Lorentzen *et al.*, 2017). This would also apply for the early stage of electric vehicles adoption in any country, where the government must absorb most of the loss to stimulate charging station business. Otherwise, the market for EVs would be only limited to urban areas (Philipsen *et al.*, 2016). In Thailand, the adoption of public and private EVs in urban areas would be a more feasible and appropriate target for the country. Fortunately, it is now viable to develop this market without the large number of charging stations being installed, which would take a considerable amount of time and financial funding. Thailand could focus on the provision of home-charging equipment for EVs, and focus on their safety and efficiency (Thananusak *et al.*, 2017). Additionally, the improvement and modification of public transport system is required in the adoption of electric buses in public services (Boribun, Paolaor and Kulworawanichpong, 2013).

Two additional concerns that would adhere to the preparation of charging infrastructure are the pricing model and payment method. Charging time in the station is considered to be one of the major obstracles for electric vehicles, since it is normally much slower than the refueling of conventional vehicles (Hidrue *et al.*, 2011). However, a reliable residential charging option could offset this disadvantage. There are two primary pricing model for the charging services; cost per charging time and cost per amount of discharged power. Both options have their distinctive drawbacks. If the cost is calculated by time, there would be a major issue in quality control and performance because of the differences in charging efficiency across various types of the battery and charging facilities (Lu *et al.*, 2017). On the contrary, if the cost is calculated by power, there would be a risk of lengthy charging time. Therefore, the combination of time and power pricing model were proposed (Wei *et* *al.*, 2014). The pricing model would also be different in accordance to the charging speed. A station with faster charging speeds could apply a premium in their pricing model when compared to normal charging stations (Ghosh and Aggarwal, 2017). Normal charging outlets in public places such as workplace or public office should also be developed. This activity would require extra regulations from the government, especially when regular household sockets are susceptible to constant fire hazard. The norms of charging equipment must be regulated by the government in the public charging stations (Neubauer and Wood, 2014). The owners of these public space should be responsible for the provision of charging services, and devise the appropriate and fair pricing schemes.

The wide assortment of payment methods would be the second issue for the charging station. There were a lot of debates against the sole usage of RFID tag as a payment for public charging, resulting in the demand for cash or credit cards payment options (Lorentzen *et al.*, 2017). However, this issue is expected to be less concerning when the payment process is developed enough to be more reliable and convenient than the usage of credit cards or cash. Organisations responsible for the management of the payment system should foster the awareness and knowledge among users, regarding the method to use this form of payment. A lot of people would prefer vehicles charging as a service that is not too 'exotic' to the point that it requires exclusive method of payment (Johnson, 2009). Other payment methods such as short message service (SMS), smartphone application, or classic approaches such as cash and credit card should also be included as backup solutions. There was a question of what should be developed first; the market demand for EVs or the readiness of charging infrastructure. Although, it was found that the possession of a well-developed infrastructural network and the adoption of public policies that aimed to promote the usage of EVs were not adequate to increase the EV's sales in Norway (Lorentzen *et al.*, 2017). It was argued that the market for electric vehicles should be sufficiently developed first, especially in the reduction of price barriers to purchase electric vehicles (Kodjak, 2012). After the market size for EVs is considerably larger, the government could then focus on the establishment of a nationwide network of charging infrastructure, by providing fiscal incentives to the potential start-ups or incumbents organisation in energy business.

5.2.4 Examples of Existing Frameworks

A framework called 'Switched on Scotland' was published by the Scottish government in 2013 to address the intention to replace all domestic fossil-fuelled vehicles by the year 2050. This framework was developed through the collaboration between the government, energy sector, automotive enterprises, and electric mobility companies. This consortium consists of 120 experts that represented 78 different organisations. The roadmap created a long-term vision for the state of road-based transportation in Scotland within the next 30-40 years. According to the framework, several stakeholders initially insisted that a short-term plan should also be covered. However, the consensus is that it might not be appropriate to establish a short-term plan at the beginning of the initiative. Several challenges and risks in the early state of electric vehicle's adoption would induce a sizable market disruption that would not be easy for the short-term plan to adjust towards (Beeton, Davison and Tuck, 2016). Instead, it was proposed that the roadmap could be revised every 5 years to amend its action plans and measure the success of policy initiatives that were originally proposed within the framework. Furthermore, the objectives that would be considered as pertinent to the status in the industry could be set anew within this period. The framework for this roadmap is shown in Figure 4-1. The representation of several gears showed that every component should operate in conjunction, and the whole operation would only go as fast as the slowest component. Thus, it is ideal to develop all major components in this framework equitably. Seven development areas were identified by this framework: market development, policy framework, energy systems, sustainable development, communication and education, economics opportunities, and recharging. Throughout these areas, there would be 42 enabling measures (Figure 4-2) which provide a comprehensive target that should be achieved prior to the realisation of a fossil-fuelled free domestic road in 2050.

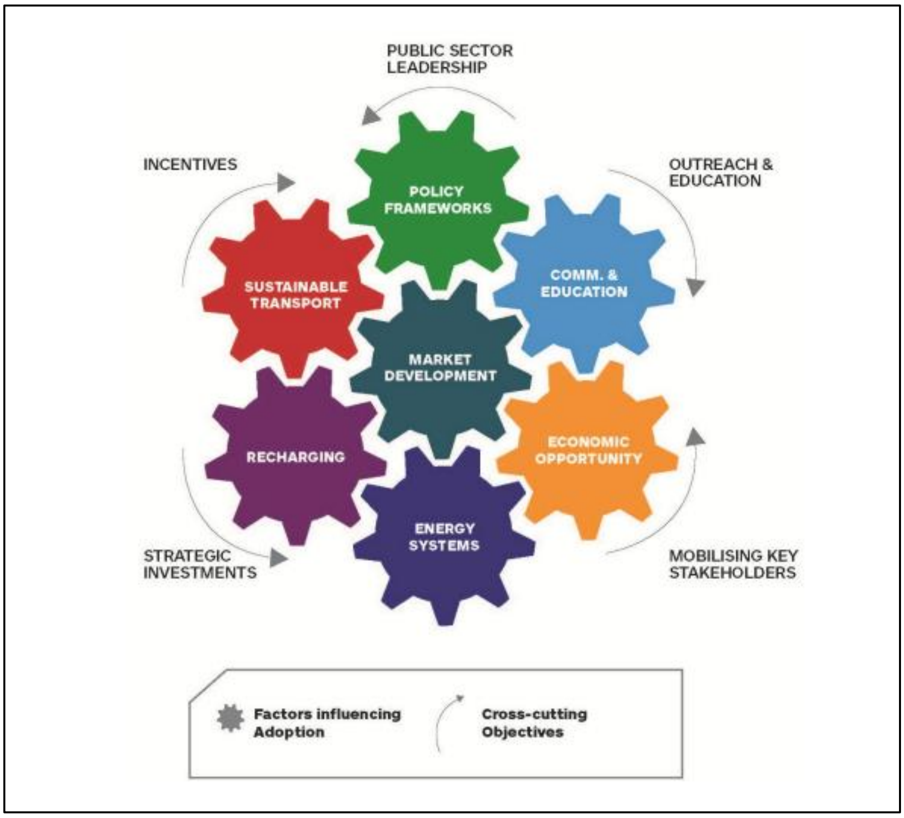

Figure 5-1 The framework developed for the 'Switched on Scotland Roadmap'.
(Source: Beeton, Davison and Tuck, 2016)

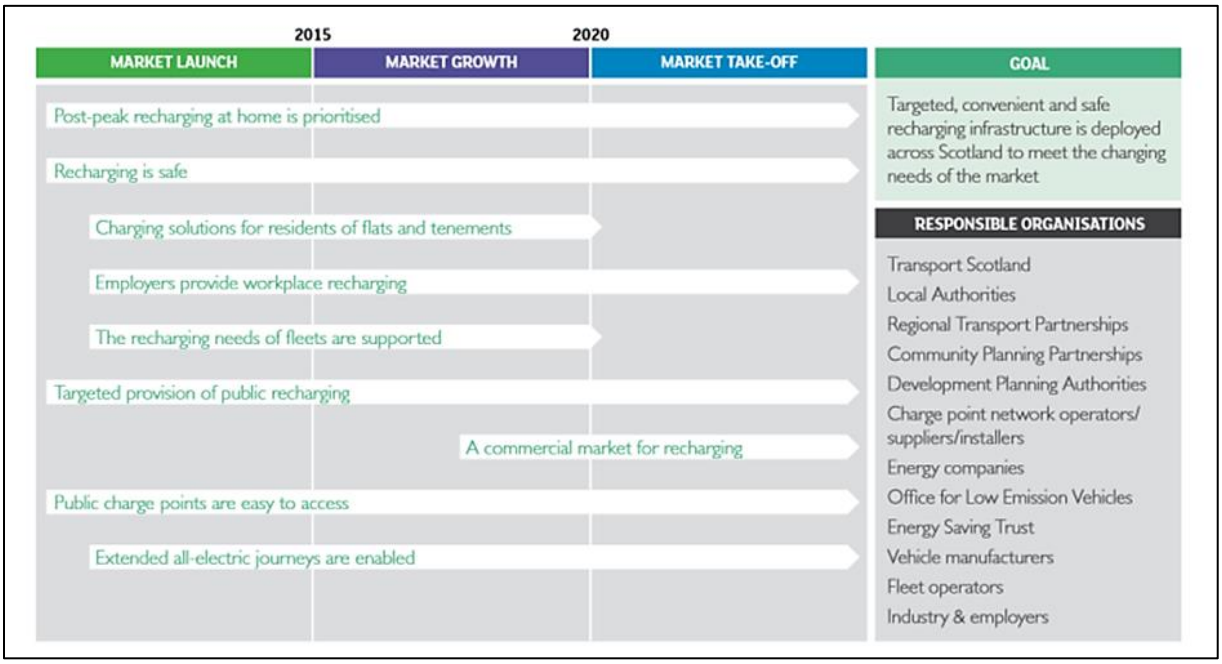

Figure 5-2 The enabling measures identified in the recharging section of the 'Switched on Scotland Roadmap'. (Source: Beeton, Davison and Tuck, 2016)

One of the companies which has the most advanced market development for electric vehicles at the present is Tesla Motor. The technology roadmap for Tesla's electric vehicles and relating technologies was specifically developed to provide a guideline within the time span of 10 years for Tesla Motor. The purpose of this framework is to support Tesla to become the global market leader in electric vehicles industry (Kancherla and Daim, 2018). It was mentioned that technology roadmap could be used in either national level or corporate level (Phaal, Farrukh and Probert, 2004), thus this roadmap would be a useful example for the formulation of policy framework in this thesis. Four consecutive steps have been taken to successfully implement this technology roadmap. The first three steps consist of the identification of customer's needs and market drivers, corresponding products and services that could serve those needs, and the technologies required to develop those products and services. After that, these three aspects were colour coded to provide a clear overview for the whole roadmap (Figure 4-3). The roadmap shared some similarities with the 'Switched on Scotland' roadmap in which they both included three stages of technological development. From Tesla Motor's roadmap, it could be summarised that there are few prominent features of electric vehicles that should be developed with a priority, for example the capacity and charging speed of battery. These two features linked to the greatest number of business drivers, which implicated that they would be highly impactful to the growth of Tesla's electric cars market. The last stage of the design of this roadmap was the identification of the gaps between existing technological capabilities of the company and the minimum requirements of manufacturing standard of the EV industry (Figure 4-4). This practise would be highly beneficial to an entity that are particularly lacking in technological capabilities, in comparison to the industry.

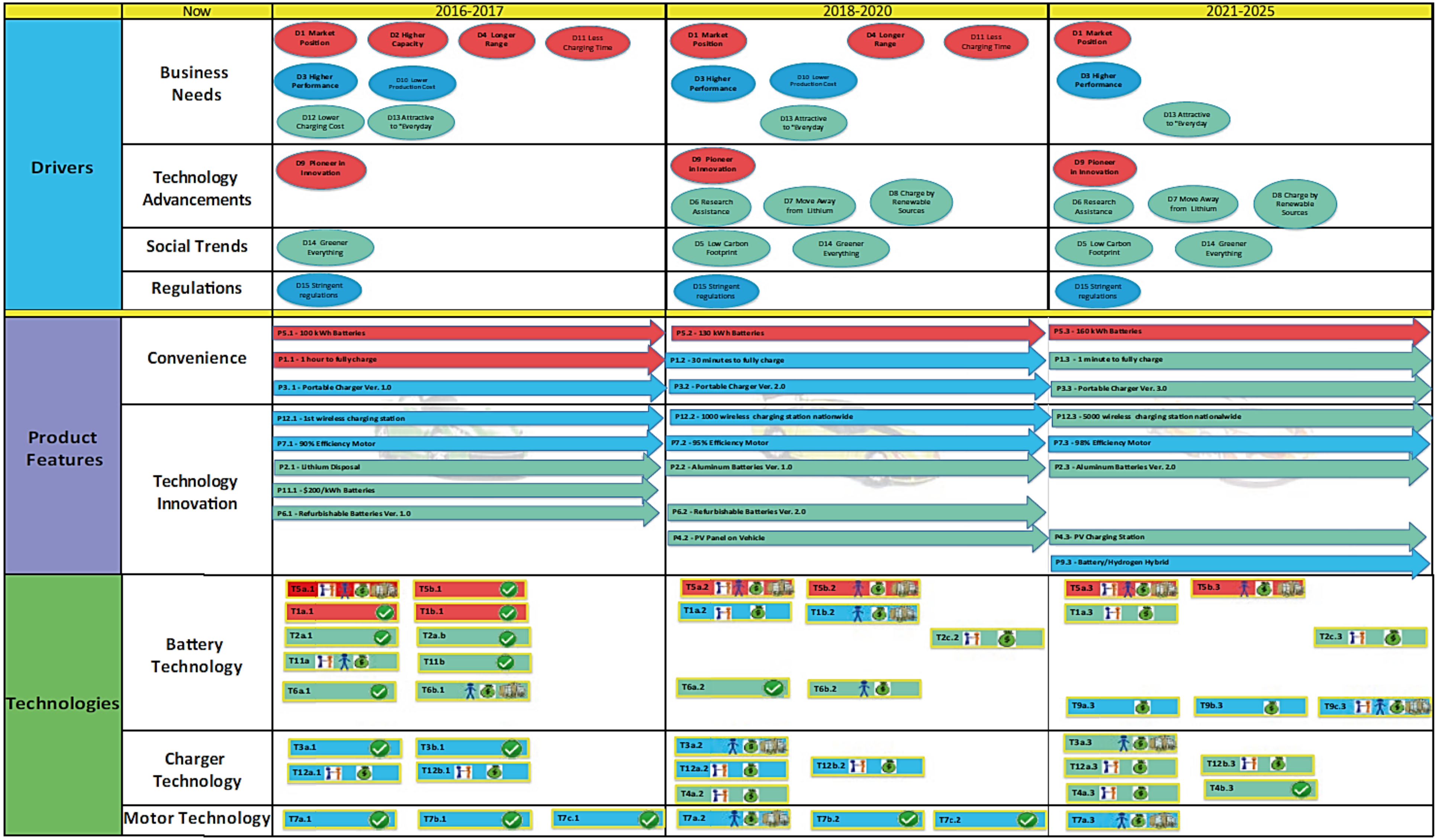

Figure 5-3 Overall roadmap for the manufacturing of Tesla electric vehicles
(Source: Kancherla and Daim, 2018)

Product Features		ID	Technologies Needed	Gaps
P1.2	30 minutes to Fully Charge	T1a.2 T1b.2 T1c.2	Fast charging electronics Battery charging controller Charger protection	Lithium battery has a limit in charging rate. Unless change battery material to be lithium free, 30 minute to fully charge is not possible.
P2.2	Lithium Free Batteries	T2c.2	Aluminum battery	In research phase, not in production yet
P3.2	Portable Charger Ver. 2.0	T3a.2	Fast Portable charger	Increased charging capacity
P4.2	PV Panel on Vehicle	T4a.2	Integrated PV panel	Light-weight, durable PV material
P5.2	130 kWh Batteries	T5a.2 T5b.2	Battery storage capacity Battery protection	High power density technology Overheating and overcharging protection
P6.2	Refurbish-able Batteries Ver. 2.0	T6a.2 T6b.2	Chemical recycling Refurbish process	Currently Available Cost efficient refurbish process
P7.2	95% Efficiency Motors	T7a.2 T7b.2 T7c.2	Electronic motor design Motor control electronics Motor overheating protection	High performance magnet Currently Available Currently Available
P12.2	1000 Wireless Stations	T12a.2 T12b.2	Wireless charging Wireless charging station design	High power wireless charging High Efficiency/low noise charging station design

Figure 5-4 Technological gaps of Tesla Motor during 2018 to 2020
(Source: Kancherla and Daim, 2018)

5.3 The Supply: Strategic Direction in Electric Vehicle's Research

5.3.1 Current Progress in the Industry

The investment in electric vehicles industry can be categorised into three major types: first movers, quick followers, and laggards. This relationship is visualised in Figure 4-5 where major automotive enterprises are grouped into clusters. The firms in a green cluster have high incentive to invest i.e., having strong research assets but trailing in the current competitive field. These companies are generally the first movers, especially when they have opportunities to collaborate in electric vehicle's battery research to share the risks and accelerate their collective progress (Robinson and Chiang, 2002). The companies in a grey cluster are quick followers that currently possess moderate market share and have fewer research assets (Freeman and Soete, 1997). Finally, the laggards could be categorized into two sub-groups; they are either a blue cluster which have high assets but low incentive to invest due to the concern to maintain their market share in their current business model, or they are a red cluster which have high incentive to invest because of low market share, but have little to no opportunity to innovate in the new products (Jovanovic and MacDonald, 1994). It should be noted that PSA is an outlier in the red cluster because of their partnership with Mitsubishi. This partnership allowed them to leverage Mitsubishi's assets in EV research and manufacturing. Similarly, Nissan and Renault also formed a partnership in their investment in electric vehicles industry, thus earning them a bigger market share of EVs industry. In conclusion, It was suggested that most car manufacturers should further build up their asset positions for EV by the means of collaboration and strategic alliances (Wesseling *et al.*, 2015). These partnership deals could provide them with the reduction of manufacturing costs, which is an important issue in EVs industry since most companies are unable to produce cost-competitive electric vehicles. Furthermore, they could request the government to adopt more EV-based policies and regulations to increase the growth opportunity in electric vehicles market.

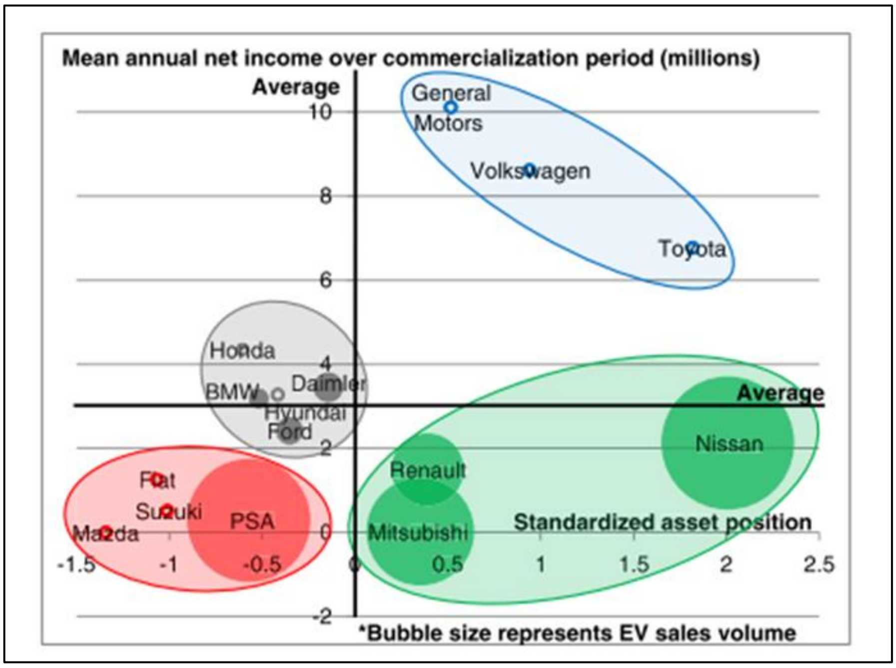

Figure 5-5 Performance distribution of global automotive firms during the EV commercialisation
(Source: Wesseling et al., 2015)

In the less competitive field of public transport, major government policies and regulations should be imposed for the full-scale adoption of electric buses. The financial imbursement to public bus operators is crucial due to the high initial cost of procuring and operating electric bus services, as well as the installation of infrastructure throughout the designated area (Kunith, Mendelevitch and Goehlich, 2017). Furthermore, the production and sales target should also be assigned to the local original equipment manufacturers (OEMs). According to a prediction by Lin et al. (2017), the number of electric buses in urban China would increase with 20.9% annual growth during the period of 2016-2025. Additional examples of electric bus adoption and operation could be learned from China and Taiwan, both of which have already set a long term vision to increase the amount of active e-buses in their major cities (Tzeng, Lin and Opricovic, 2005). In summary, there are two major considerations for the adoption of electric buses in both countries. The first topic is the design of the powertrain and electronic system that would be applied in the vehicles. The second topic is the formulation of government public policies to support the adoption of e-buses in public transportation system. The second consideration will be a major element that would be explored in this thesis.

5.3.2 Technological Disruption

There are ongoing debates in the discipline of technology and innovation studies regarding what could be considered as a disruptive innovation. Electric vehicles are one of the technologies that could be grouped into this conundrum. For instance, the market pioneer such as Tesla Motor was classified as 'miscategorised' by the person who defined the term himself because of their reliance towards exclusive high-end segment of the EVs market (Christensen, Raynor and McDonald, 2013). It was asserted that the existing definition of 'disruptive innovation' was not sufficiently robust to help identifying a disruptive innovation among other new technologies (Markides, 2006). The term is normally used to label a technology in hindsight not in foresight, which usually mean that the effects of a technology in question have already been evaluated by the industry. This weakness causes the recent notion of 'disruptive innovation' to bear less weight towards considerations of many stakeholders who are able to instigate the revolution within the industry (King and Baatartogtokh, 2015). A new criterion to identify disruptive technology by using the existing principle that was established by the literature in this particular field was proposed by Hardman, Steinberger-Wilckens and van Der Horst (2013). This principle consists of seven characteristics that are commonly presented in several widely accepted and existing disruptive technologies. However, it should be noted that these characteristics are not exclusively presented in disruptive technologies. Furthermore, various disruptive technologies might not contain some of these traits. This study synthesised seven characteristics into three fundamental concepts that were established to be constantly presented in any impactful disruptive technologies. In other word, these three criteria could be a set of working definitions to the terminology of 'disruptive innovation'.

Seven case studies from different technologies were used as resources for the identification of important characteristics of disruptive technology (Hardman, Steinberger-Wilckens and van Der Horst, 2013). Three common fundamental traits of disruptive technologies were identified. First, the technology must disrupt the current market leaders i.e., the new technology is heavily invested by new entrants in the industry. Second, the technology must disrupt the end users by changing the way they use the technology. Third, the technology must disrupt the current infrastructure that was originally built to support the previous technology. By responding to these criteria, the developers of a potentially disruptive technology could have an easier time to strategically plan for the introduction of their new products or services. Additionally, the barrier to entry of the market could also be partially mitigated. Similarly, existing market leaders could also use these criteria to identify the threat of a new technology and strengthen their decision-making in accordance with the potential adoption of the disruptive technology.

The market entry for fuel cell electric vehicles (FCEVs) technology will be more difficult than battery electric vehicles (BEVs) due to the higher requirement of infrastructural refurbishment and the change among the suppliers for vehicle's energy source (Thomas, 2009). This makes FCEVs highly disruptive in all three levels according to the criteria: new suppliers, new methods to utilise the technology, and new infrastructure. On the contrary, BEVs would be highly disruptive on only two levels; new methods to utilise the technology and new infrastructure. Entrepreneurs in FCEVs industry could replicate the strategy of Tesla and aim for a niche market before going into the mass market, since niche markets offer a safer environment for market growth due to lower competition. In fact, fuel cell electric vehicles have already achieved comparable range to ICEVs, but the production cost is even more expensive than many high-end BEVs (Tollefson, 2010). In spite of this circumstance, many people advocate the development of fuel cell vehicles as an alternative or a competing technology to battery electric vehicles (Offer *et al.*, 2010). Moreover, the fuel cell technology will have a wider range of applications aside from the automotive industry. This includes recreational and lifestyle applications (Agnolucci, 2007). This feature could provide extra incentives for the investment in fuel cell technology, since its development could be more readily transferred into other businesses in case of the market failure in fuel cell electric vehicles industry.

5.3.3 Research Commercialisation

The commercialization of the academic research is an important topic that was previously mentioned in this thesis. It was asserted that the lack of commercialisation capabilities in emerging technology such as EVs could be traced back to how researchers rely too heavily on forward thinking without taking the current situation into consideration (Parker and Mainelli, 2001). The area of technological development was often selected based on global market opportunities and its potential rather than the pre-existing strengths of the industry. It was asserted that the generation of actual commercial outputs that originated from the exchange of information within the whole system would be the key success factors for electric vehicles industry (Graham-Rowe *et al.*, 2012). The bottom-up and demand-led approach towards the development of electric vehicles should be employed in conjunction with the framework for industrial research, to guarantee a significant number of marketable research outputs for the whole industry.

For the application of electric buses in public transportation, the issue of research commercialisation might not be as prominent as the profit-oriented electric car industry. Nevertheless, public policy intervention will be crucial for the alignment between research outputs and industrial needs, otherwise there would be less motivators for manufacturing firms to concentrate on the new investment in EV (Leurent and Windisch, 2011). Moreover, the government should also provide additional fiscal incentives for the development of electric bus industry in an early stage. In an early stage, it is expected that quality control and safety issues could strongly affect the manufacturing speed of e-buses. In response to this issue, the government should designate local OEMs to additionally manufacture some components for the e-bus (Hua *et al.*, 2014). In operation, an electric bus service provider would require additional expertise that would be different from a skillset regarding the standard ICE bus.

The government or service operators could outsource the operation and infrastructure to the company who is more specialised in e-bus administration, until they could absorb the necessary knowledge and technical capabilities (Lin *et al.*, 2017). However, national budget and public opinions should be assessed before the commitment to this type of decision. This technological learning between mentor and mentee firms is required to break down technological frontiers in research and development process. Local companies might be able to achieve the result beyond their current capabilities via the cooperation with another organisation. Additionally, the collaborative effort between public and private organisation can also ensure that the research and development process within electric bus industry could provide the solutions that are matched by the current environmental and transportation public policies.

5.3.4 Policy Instruments

The policy instrument that is usually employed to promote EVs industry was the regulation that restricts car manufacturer's output of internal combustion engine vehicles (ICEVs). The prime example of this type of policy is 'zero-emission vehicle mandate' (ZEV) that was adopted by Californian Air Resource Board (CARB) in 1990. This policy was proved to be a successful instrument to promote the development of research assets in EVs industry (Wesseling *et al.*, 2015). The result from the mandate indicated that many automotive companies increased their research efforts on EVs and related technologies. However, the mandate ultimately failed to increase the sales of electric vehicles in that period. It was suggested that ZEV, as a primarily technology-push mandate, did not influence the full stimulation in EVs industry because of the lack in demand-building activities within the electric vehicles market (Kemp, 2005). Therefore, the government should also promote and provide supporting regulations for the EV market to increase public demand for electric vehicles. This should be carried out in addition to the activities that aim to encourage the increment of EVs research and manufacturing outputs, in order to have a completely successful implementation of the EV policy.

There are a lot of uncertainties regarding network externalities and the feedback from the adoption of EV-related public policies. It is important to assess the impact from these uncertainties in order to devise the appropriate response (Pierson, 1993). A single scenario model was proposed by Greene, Park and Liu (2014) to highlight the importance of these uncertainties during the period of 2015 to 2050. It was found that the economic net present value (NPV) for the state of California after the full adoption of electric vehicles will be larger than the costs of transition. Additionally, this advantage was expected to be even greater if the adoption of electric vehicles occurs throughout the rest of the United States. The requirement for government subsidies would be proportionally lower due to the benefits of research and technology spillover. According to the projection in this model, battery electric vehicles (BEVs) would no longer be considered as a risky investment by private enterprises and general consumers from 2030 and onwards. In contrast, hydrogen fuel cell vehicles (FCEVs) would still be perceived as a high-risk alternative due to the low production volume of hydrogen fuel. In conclusion, the combined effects of time constraints, profound technological and market uncertainties, network externalities, energy market deficiencies, and the central role of costs-benefits calculation would make this vehicular transition a challenging subject for the formulation of public policy (Tran *et al.*, 2012).

It can be implied that the net economic loss from the adoption of electric vehicles would have to be initially endured before the sustainability in energy utilisation and transportation system could be achieved (Gass, Schmidt and Schmid, 2014). The government should designate small pilot regions for the implementation of electric vehicles, especially when the nation has limited budget. Similarly, it is more cost-effective for electric bus public transportation system to be implemented in the area that has abundant access to the cleaner and renewable electricity. It was asserted that this practise would facilitate the monitoring of a tangible outcome in environmental benefits (Lin *et al.*, 2017). Electricity providers must also revisit their infrastructural design and modify them in accordance to the incremental diffusion of electric vehicles to the public (Steen, 2017). Tangible policy targets such as the metrics that were utilised in ZEV mandate should be specified, in order to drive the smaller action plans and policy initiatives. It was stated that the timing and intensity of public policies also need to be considered carefully because the balance between risks and their respective benefits in the policy implementation would be difficult to sustain (Wang *et al.*, 2018). In conclusion, the policy framework for electric vehicles should be modified over time based on circumstantial changes in the electric vehicle industry and other aspects of national policy such as population demographic, industrial economics, political situation, etc.

5.4 The Demand: The Business Model in Electric Vehicles Industry

5.4.1 Current Situation in the Industry

One of the significant challenges in the technological transition from internal combustion engine vehicles to electric vehicles industry is the high growth of ICE vehicles ownership in the developing countries. This situation contrasts with the global trends that promote more efficient and environmental-friendly vehicles (MacKenzie and Walsh, 1990;Tengström, 2018;Sintowoko and Hidayat, 2021). As a result, the domestic automotive industry in many developing countries would be clashing with global trends of automobiles usage. One of the main reasons is because electric vehicles are not yet perceived as fully feasible for commercial applications without the large-scale installation of charging station network (Forrest *et al.*, 2020). Moreover, it is time-consuming for a complete transition of all types of automobiles into electric vehicles, because this change would require a major overhaul of the current transportation system in many countries. Nevertheless, the transition of this magnitude could be facilitated by the adoption of public policy framework.

In Norway, the history of public policy development regarding the expansion of the network of charging infrastructure throughout the country was studied. It was found that the availability of fast charging stations is important but not an essential criteria for most purchasing decision of EV users. In contrast, financial incentives such as the reduction or exemption in value added tax, purchase taxes, electricity cost, or road tolls were hightly valued by EV users (Lorentzen *et al.*, 2017). Nevertheless, it should be noted that it is comparatively expensive to own a car in Norway. this was caused by high gasoline price, expensive road tolls, and a considerable amount of car related tax. It was asserted that these circumstances have changed the preference of car owner based on their perception towards the total expense of the vehicles (Mersky *et al.*, 2016). Many of fiscal policies relating to EVs in Norway dated back to the 1990s, however the growth for EVs started to become noticeable later in the 2010s (figure 4-7). This might imply that a considerable amount of time could be taken before the positive results from EV policies can be observed. Nonetheless, this setback might depends on many other circumstances, especially the state of EV’s research and development.

Arguably, the sharp incremental progress of EV industry in recent years could be due to the leapfrogging of electric vehicle’s battery technologies (Lu *et al.*, 2016). This is one of the possible explanations for the late growth of EV market in Norway. The combination of progress in R&D, cost-reduction in manufacturing, and multiple fiscal policies that were employed by the Norwegian government resulted in the comparable pricing of BEVs and their ICEVs counterparts. This was the predominant motivator for Norwegian population to purchase an EV (Bjerkan, Nørbech and Nordtømme, 2016). Similarly, the government of other countries should adopt fiscal policies that can reduce the price of electric vehicles in order to create more market demand (Holtsmark and Skonhoft, 2014). However, the amount of financial risks would depend on the size of the automotive industry in each country. The promising development of EV's battery and the higher market demand would be the main factors for several countries to effectively transform significant portion of urban transport options into electric vehicles (Kurani, Sperling and Turrentine, 1996).

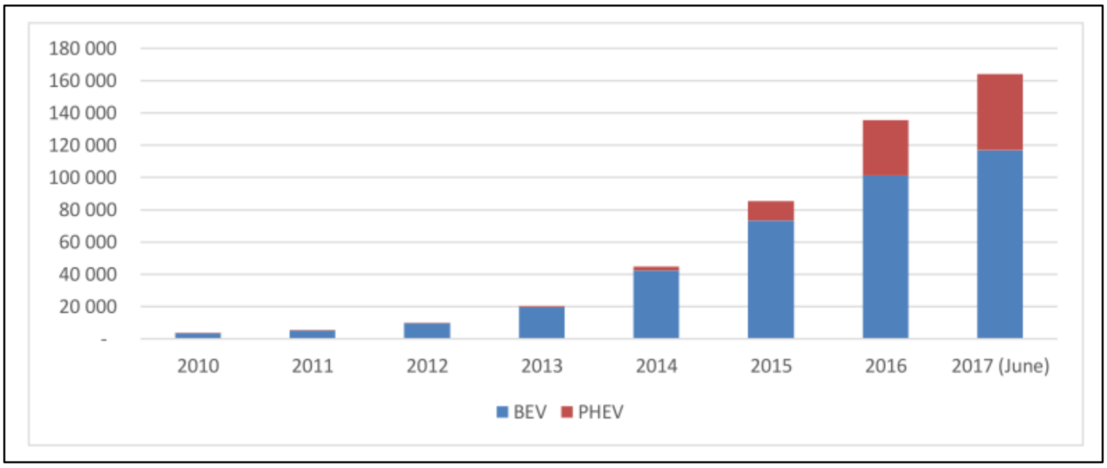

Figure 5-6 The number of electric vehicles in Norway
(Source: Lorentzen et al., 2017)

5.4.2 Costs and Benefits of Electric Vehicles

Since the barriers of most electric vehicles are still too high for many potential buyers, the competitiveness EVs when compared to ICEVs need to be properly assessed by the policy makers before the adoption of national policy to transform all domestic vehicles into EVs. The example for such assessment was conducted by Singaporean researchers in the format of the total cost of ownership model. It was stated that this type of model was used for the value assessment of battery electric vehicles in many countries (Al-Alawi and Bradley, 2013). The proposed cost of ownership model included a flexible structure of multiple variable regression that enable the addition of new factors into a model. As a result, it is reactive towards the change in fiscal policy instruments that might be utilised by the government in the future. The current global trends of public policies relating to the adoption of electric vehicles are mostly related to fiscal policies. This normally includes tax credit; as a vehicle's price discount either a fixed or proportionate to the level of carbon emission (Gass, Schmidt and Schmid, 2014), or as a subsidy to the enterprises which can reduce their cost of vehicle's production (Lévay, Drossinos and Thiel, 2017). Thus, these policy schemes can be applied at least two times, both at the federal and local level. Nonetheless, it was stated that these fiscal policies are not fully effective in term of raising the sales and adoption rate of electric vehicles (Kester *et al.*, 2018). The calculation based on this type of model could be a valuable information for this thesis, because there is still no publication of the study related to the comparative analysis of economic impacts between ICEVs and EVs in Thailand.

The total cost of ownership model of electric vehicles in Singapore showed that the amount of supporting public policies from the government was not sufficient for BEVs to fully compete with ICEVs in 2015 (Li and Kochhan, 2017). It was concluded that there are more factors beside the economic benefits to consider e.g., the readiness of charging infrastructure, the awareness of users, the image of electric vehicles, etc. Singapore is a unique setting, because the purchasing cost of a car is normally inflated. This is meant to limit the amount of vehicles on the island and mitigate the issue of traffic congestion (Olszewski, 2007). Conversely, this could be seen as additional opportunity for the government to fully exempt the additional charge in the purchasing of electric vehicles. This change would be noticeable to the potential consumers in the market and might create a large impact towards the greater adoption of electric vehicles. Additionally, it was asserted that the shift towards electric vehicles are not fast enough for any nation to observe clear economic and environmental impacts (Li and Kochhan, 2017). Hence, the governments must alter their focus from the demonstration of EVs into the actual adoption within the upcoming decade. It was further elaborated that electric vehicles already possessed adequate technical specifications that could satisfy the Singaporean automobiles market, and could become an economically competitive business (Li and Kochhan, 2017). This stems from the lower daily-average driving range of cars in Singapore when compared to other countries. Hence, the weakness of driving range in most EVs would be less of a concern for the drivers in Singapore.

It was indicated that BEVs in sharing-based service could be more economically feasible for the purchasers in Singapore. The projection from this model indicated that all small-sized electric vehicles will be competitive to gasoline vehicles within 5 years from 2017 (Li and Kochhan, 2017). These projections did not include the possibility of policy intervention that could be exercised by the Singaporean government to further discount the cost of ownership for an EV. It was calculated that the exemption of additional registration fees (ARF) in Singapore would assist BEVs to survive in a highly competitive automobiles market and become a viable business option for all types of sharing-based service within the year 2020 (Li and Kochhan, 2017). Nevertheless, it was asserted that the government should promote the speed of EVs adoption by focusing on the planning and installation of charging infrastructure throughout the island (Xue and Gwee, 2017). In conclusion, electric vehicles would be economically viable for general users within a decade, but not without government policy supports. This conclusion is made based on a specific context in Singapore, in which many infrastructural changes might be easier to implement because of its status as a relatively small country. Nonetheless, this case could be a useful implication for many other cities that plan to adopt electric vehicles into their urban transportation system.

The model used to calculate the cost of ownership for an electric car usually also includes the cost of charging services that is derived from the pricing model of electrical infrastructure and charging station business. It was expected that most model would provide a varying results, since there is a distinct charging pattern for each type of electric vehicles (Hagman *et al.*, 2016). The cost of public charging service is expected to be marginally proportional to the amount of people that are using the infrastructure. If a specific station has a large concentration of people using its services, the price could be set in a more profitable manner by the company who operate the service. Another aspect that could promote the charging station business is the improvement of electricity transmission efficiency (San Román *et al.*, 2011). This improvement could be an attractive feature for the start-up enterprise to reduce their operating costs and reinforce environmental impacts from the nationwide transition towards EVs. Public policies could be used to coerce many companies into investing in EV charging stations. It is possible that the abundant of charging station would effectively reduce the cost of ownership for an EV until this vehicular option is generally perceived as affordable to the consumers (Soulopoulos, 2017).

5.4.3 The Assessment of Market Demand

Since the transitioning from ICEVS to EVs was accepted as a prominent option to reduce the carbon dioxide emission from land-based transportation system, the United Kingdom government and the European Commission have been adopting public policies to promote the proliferation of electric vehicles. However, the increment of EVs sales and the rate of market diffusion were still not at the satisfactory level for the government (Nilsson and Nykvist, 2016). The issue of demand in the EV market was centralised as the main driver for the implementation of public policies. The link between adverse effects from the uncertainties in each category and consumer's demand for EVs were extensively studied to explore additional options for the adoption of EV policies (Morton, Anable and Brand, 2014). There were six locations of uncertainties across the proposed framework (figure 4-8). It was asserted that the policies that were supposed to mitigate uncertainties in these locations are not sufficiently effective to enhance the demand for electric cars. This framework then highlighted the policy changes that should be made. However, this framework only represented a simplified model of a more complex system and use the information that was based on the static parameters of uncertainties. It was suggested that the dynamics view of an actual electric vehicles industry should be studied in this type of research (Dyerson and Pilkington, 2000). Similarly, the policy framework presented in this thesis would also acknowledge this limitation that could potentially impact the underlying rationale of the study, especially on the consideration of significant progress in the EV industry at the present.

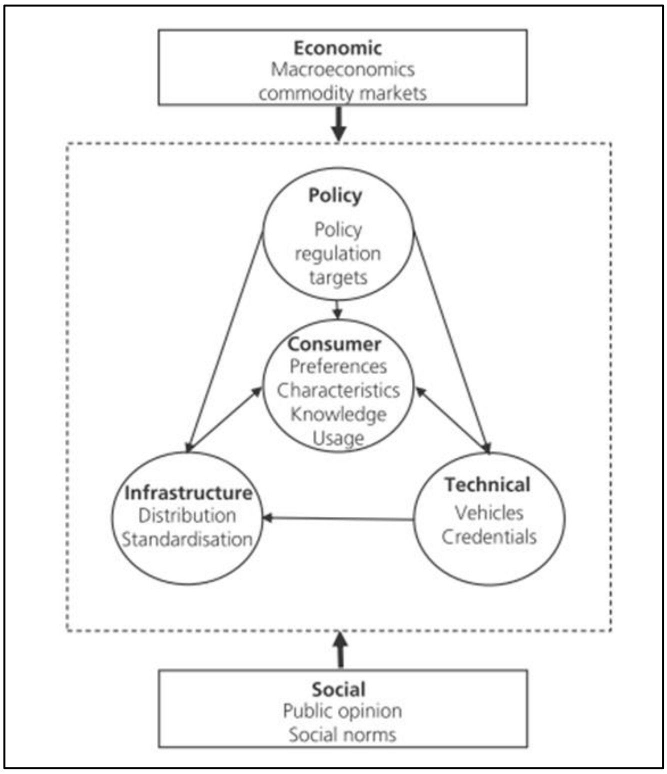

Figure 5-7 A conceptual framework regarding the locations of uncertainty of the market demand (Source: Morton, Anable and Brand, 2014)

The first and most important location of uncertainty is consumer-based uncertainty. It consists of four distinctive aspects. The first aspect is the preference of drivers on different features of the electric cars. The consumer's demographics of the electric vehicles market is a valuable topic to analyse. For example, the age group could be related to the purchasing behaviour. The older people might be more resistance to the new technology than the younger people. There is also an uncertainty in the driving behaviour of EV's users in comparison to ICEV's users. Lastly, there is a gap of knowledge in the personal maintenance of electric cars for users that needs to be filled in by the disemmination of knowledge on the basic operation of electric vehicles.

There are three aspects of uncertainty in the public policy setting; financial backing of the government, taxation and fiscal regulations, and setting up a target region to market EVs. It is concluded in the previous chapter that financial incentives and fiscal policy are essential towards the development of innovation cluster. Furthermore, it is proved to be vital to the commercialisation of EVs and most likely one of the main drivers for the initial growth of the EV industry. However, this need to be implemented in conjunction with the set boundaries of geographical areas since it would be easier to control the budget and measure the results from the implementation of the public policy.

The third location of uncertainty is within the infrastructural requirements for the adoption of electric vehicles, primarily charging stations. These charging stations need to be developed in consideration of both location placements and the regulations of electricity discharge. Currently, there are still a lot of uncertainties in both areas, and the relationship between the amount of charging stations and the growth of EVs usage is still questionable. Researchers were still unable to systematically prove the correlation between the concentration of charging infrastructure to the actual demand of EVs.

There would be several technical uncertainties regarding the risks of the technological substitution for many of the components in EVs. For example, there are many variations of Lithium ion batteries which is the current mainstream battery technology for EVs, some of them would be inferior to other variations in the future or even become obsolete. This gives rise to the uncertainties in manufacturing process because most of them require different manufacturing specifications (Kim *et al.*, 2019). Another specific technical uncertainty is the environmental credentials of electric vehicles. According to the literature presented in this chapter, there are still some debates regarding how much pollution could be reduced by the complete transition of land-based transports from ICEVs to EVs.

Economic and societal factors are classified as the external environment which have a low direct interfence with the demand in the EV market. Economic factors consist of the shift in the macro-economic conditions of the global economy, including financial recession, economic instability, and volatility of the international commodity markets. The market of electric vehicles would likely be affected by the price of oil and essential metallic material that would be used as a major component of a battery in an electric car. Moreover, the condition of the local economy should also be assessed, especially within the region that would be the target for the policy implementation. The last location of uncertainty is the uncertainty in societal factors. This consists of public opinion in the emerging market of EVs which could strongly affect the demand for the vehicles. Similarly, there would be an effect from social norms towards the personal viewpoints regarding the electric vehicles. It is found that social norms could project its assessment onto personal opinions and influence the decision-making process of the public. Hence, any attempt to propagate electric vehicles to the larger mass market should not be underestimated by the policy makers.

5.4.4 The New Frontier of Electric Vehicles Business

There are two main motivating factors for automotive enterprises to innovate in a radically different operating pattern in electric vehicles manufacturing. Firstly, the current market performance will affect the risk-taking tendency of an enterprise. The market share of a private enterprise is likely to influence the decision regarding the investment in a new venture. More profitable companies would have a lower incentive to innovate in the new field of products and services especially in the area that has significantly different requirements compared to their current expertise (Boone, 2001). On the other hand, companies who are currently in disadvantaged market positions would have more incentive to invest because it is an opportunity to recover from the failure in their old business model (Wesseling *et al.*, 2015). Conversely, the second motivation to innovate is mostly proportionate to the size and the current market performance of an enterprise. This motivating factor is generally linked to the strength of existing assets of a firm. The examples of these assets are technological assets e.g., research and development knowledge, infrastructural assets e.g., charging infrastructure, complementary assets e.g., distribution channels, reputational assets e.g., brand value. Larger companies normally possess the larger amount of assets. Therefore, they also have a greater opportunity to invest in a novel and radical technology (Nieto and Quevedo, 2005). In summary, the design of a policy framework should include some analysis on the business model and multiple investment scenarios for potential electric vehicle's manufacturers. This could create more confidence among major stakeholders of automotive industry and reduce their aversion to the investment risks.

The barriers to entry of the EV industry are mainly affected by the lock-in effect of ICEVs technologies. This were explained in three areas; the economy of scale of the incumbent, the learning difficulty, and the network effect (Hardman, Steinberger-Wilckens and van Der Horst, 2013). Conversely, these effects can be offset by several events in the automotive industry e.g., the support from public policy to promote EV's proliferation, the occurrence of technological breakthrough, the preference shift towards electric vehicles, and the strong support of the scientific community. It was asserted that the lack of infrastructure is the main obstacle for the growth of electric vehicles, especially for hydrogen fuel cell electric vehicles (FCEVs) (Hildermeier and Villareal, 2011). A pre-development phase of setting up the refuelling infrastructure would be compulsory to the increment of market penetration for FCEVs and BEVs in rural areas. However, this can be a risky endeavour since the technological development is still ongoing. There is no guarantee of which technology would be the next major driving force for the automotive business, especially when there are currently a large amount of continuing research on alternative fuel sources for land transport (Jalihal and Reddy, 2006;Semelsberger, Borup and Greene, 2006;Valera and Agarwal, 2019). In conclusion, electric vehicles need to be proven as a superior option to the existing offerings. Only after that, the technology would then penetrate into a bigger portion of the market up to the point where the technology would be universally regarded as a new norm (Hardman, Steinberger-Wilckens and van Der Horst, 2013).

5.5 Conclusion

Electric transportation is still a rapidly developing branch of technologies despite its actual age. This results from the leapfrogging of electrical power storage technologies in recent years, which quickly improved its efficacy for usage in transport and logistics. Combining this fact with the global environmental concern many countries have started to invest in the development of electric vehicles industry and its related technologies. Nevertheless, electric vehicles are still often considered as a luxury and a less-affordable alternative in comparison to the internal conbustion engine vehicle. The downside of electric vehicles includes the inferior values regarding driving range and charging time, in comparison to the driving range and refuelling speed of gasoline vehicles. Additionally, they are often priced at a premium since the technologies used to manufacture them are still relatively new and expensive to develop. Unfortunately, this situation reduces the market size for electric vehicles and also reduces their mass-market appeal to most of the automobile manufacturers. In spite of this, many countries still attempt to promote the adoption of electric vehicles since they were proven to be a better alternative compared to ICEVs with regards to environmental benefits. The main challenge for the formulation of public policy regarding the transition towards electric vehicles is the disparity between the supply and the demand in EVs industry. Therefore, an innovation system that would be developed to support the industry should maintain the balance between the the supply-led innovative research process and the demand-led research commercialisation.

For the supply side of electric vehicles, many global level manufacturers have been developing their capabilities to produce EVs in the recent years. Technological capabilities had been an important hurdle to many companies, but this issue was commonly countered by the adoption of strategic alliance strategies among less technological capable firms. This movement is expected to be a result from the potentially disruptive manufacturing process of electric vehicles, which largely differ from the usual process of manufacturing gasoline vehicles. Aside from the disruption in the manufacturing process, the automobile's supply chain would also be disrupted. Combining these potential disruptions with the increasing popularity of electric vehicles among the public, many companies are preparing themselves to the potential paradigm shift in the automotive industry. Despite the advancement of electric vehicle's research, there are still several commercialisation related issues. Electric vehicles were considered to be less practical and more problematic in actual road conditions. However, it is suggested that this issue can be mitigated by proposing a demand-led approach towards research commercialisation, the topic which would be summarised in the next paragraph.

The demand of electric vehicles are often stated to be not sizable enough for the full commercialisation at large scale i.e., national or global scale. This promotes many countries to designate the pilot area to test and commercialise electric vehicles in a smaller and more controlled environment. As mentioned before, the pricing of electric vehicles is perhaps the most prominent barrier to their full adoption among the people. The government is forced to provide several incentives to the potential drivers of electric vehicles to make them more marketable to the customers. These incentives include facilitation such as free charging space and extra parking lot, to the financial discount in the form of tax rebates and toll fees. It was assessed that the cost and benefits analysis will be needed to accurately forecast the demand of EVs in each different setting. Aside from the calculable cost and benefits of EVs, many factors such as environmental concerns of the users, public image of EVs, and socio-political climate of the industry also affects the movement of the demand in the market. Ultimately, it is prudent to have appropriate policy instruments to instigate the demand and drive this industry forward. All of these has to be done in conjunction with the development of market trends within adjacent industries. The synergistic technological development in autonomous driving, shared services, and connected platform from vehicles to external environment have to be carefully considered as well.

The policy framework is an essential component that could guide and facilitate the adoption of electric vehicles. This includes government initiation and support incentives to drive the investment into the electric vehicles industry. Automotive enterprises can be encouraged to invest in the manufacturing process of electric vehicles, but the investment would not be economically feasible for them without the sizable market to support their business. The national agenda to promote the sales of EVs must consider different customer groups beyond early-adopters, since the size of that market segment is limited. In addition, the actual uses of electric vehicles should be advocated to the public to show that electric vehicles are not just an experimental technology. The transition from ICEVs to EVs will not be immediate, thus it is important to take an initiative and promote confidence among drivers before the maturity of the EVs market. The electricity and charging infrastructure to support the full adoption of EVs must be developed prior to a nationwide proliferation of EVs. The locations of each charging station are important elements to be considered, because the current battery specification for EVs is still limited to a shorter driving range compared to ICEVs. The action plans of the framework should include various subjects surrounding the transition from ICEVs to EVs, such as traffic regulation, pollution control, support to domestic OEMs, etc. This can ensure that the adoption of EVs would not worsen the ongoing issues within the automotive industry and the current transportation system. In conclusion, an effective policy framework must comprise of a long-term vision that apply practical information and analysis into its contents, to properly guide the stakeholders within the industry towards the adoption of electric vehicles.

After the literature review in this topic, the research question remained the same with regards to discovering appropriate tools or methods to aid in the formulation of public policy that would aim at the development of a cluster. It should be noted that most of the considerations and assumptions regarding the formulation of the framework are also relatively similar despite the change of industry. The focus of this framework is still geared towards many considerations outlined in the previous review chapter e.g., knowledge exchange in an inter-organisational setting, the motivation of cluster's participants, the appropriate structure of the cluster, etc. It was stated before in previous chapters that the policy-mix and contents of the policy plan would largely depend on the set objectives of the cluster. Similarly, since the cluster in this research is set to be a research and manufacturing cluster in the Thai e-bus industry, the framework and subsequent policy recommendation would be highly dependent on the inputs from this cluster. However, it was found later on that the goals for the cluster are constantly moving, especially when the organisational structure of the governing institution is changed. Hence, the research question for this thesis would not be about the proportion of effort between research and development activities and industrial activities, or whether the cluster policy should be based on regional innovation system or national innovation system. In contrast, This thesis aims to provide a flexible framework that could be utilised despite the changes in an underlying assumption of the system. This will be reflected in the upcoming results and discussion chapters.

Chapter 6 The Current State of Electric Bus Industry in Thailand

6.1 The Drivers for Electric Bus Industry

The rationale behind a choice of electric bus industry as a topic of study was introduced and explained in chapter 1 and chapter 5. However, it is also crucial for policy makers and the government to assess the current state of the industry and make a justification on their spending of national resources into an effort to develop this industry. The first section of this chapter attempts to explore all the drivers that represent the urgency to develop an electric vehicle industry by the analysis of the external environment surrounding the industry. These drivers are extracted from the primary data through the in-depth interviews that were conducted by the researcher, and from existing literature and industrial reports. They are summarised and categorised into the following four sections.

6.1.1 Environment and Pollution Issues

The perception of general public towards the global warming phenomenon and the deterioration of the world environment is increasingly dramatic (Abeles *et al.*, 2019). Electric vehicles are one of the most popularised technological solutions to the issue for many developed and developing countries, including Thailand (Faisal, 2017;Küfeoğlu and Hong, 2020). Electricity is considered a cleaner energy source for a vehicle in comparison to gasoline because of the higher efficiency in electrical engine compared to internal combustion engine (Hofman and Dai, 2010). Additionally, approximately 70% of natural gas and 15% of coal are utilised in generation of electricity in Thailand ('*Proportion of energy types used in the generation of electricity of the country*', 2020). Therefore, the change towards electric vehicles would substantially benefit the environmental condition in Thailand.

The focal point of the recent environmental problem in Thailand originated in urban areas and their vicinity such as Bangkok, Chiang Mai, and Nakhon Ratchasima. The major cause of the problems is utilisation of diesel engine vehicles, especially the vehicles that are below certified emission standard. This led to a multitude of pollution problems including excessive amounts of photochemical smog, carbon dioxide emission, and fine particulate matter ($PM_{2.5}$), which are hazardous to physical health. The seriousness of this hazard is amplified by the fact that all problematic areas are considered highly populated. This issue was recently declared as one of the primary national agendas by the government.

Outside city areas, Thailand also faces an additional air pollution problem arising from crop burning and forest fires, which contribute 35% towards total air pollution in Thailand (ChooChuay *et al.*, 2020). However, this problem is difficult to control due to the wider area and randomness of the occurrences. Crop burning could be discouraged via government policies to reduce the occurrences, but the issues would not be completely solved since most farmers in Thailand does not have any other effective means to manage the crop residual (Kumar *et al.*, 2020). On the other hands, forest fire in Thailand is highly likely to happen due to the exposure of strong sunlight coupled with the extremely dry climate (Kaushal and Prashar, 2021).

Approximately 50-60% of air pollution in Thailand originates from vehicles emission. In Bangkok, diesel engine’s emission from buses and trucks contribute to the largest proportion of road-based pollution (ChooChuay *et al.*, 2020). Since a large proportion of public service buses in Bangkok are public owned, the shift towards electric buses in public transportation is considered as the most feasible solution that the government could supervise. Moreover, the development of an electric vehicles ecosystem could also lead to the initiation of a vehicles and vehicle’s components disposal and recycling industry, which could further mitigate the overall environmental issues from poorly managed waste disposal in Thailand.

6.1.2 Industrial Economy and Global Technological Change

Another primary driver for the development of electric vehicle industry in Thailand is rooted in the current market value of the automotive industry in Thailand. The automotive industry constitutes a large portion of the Thai economy. There are currently 19 assembly plants and 2,200 OEMs factories in Thailand. In 2019 they contributed 850,000 employees, with the annual value of all manufactured vehicles totalling 61.856 billion USD (Massamadon, 2020a). Global trends towards electric vehicles threaten the stability of the traditional automotive industry, which is still lacking in electric vehicles research and development. If the preferred model of road-based transportation will be based on electric vehicles in the future, the Thai automotive industry would be forced to comply to this disruption. Several restructuring policies aimed at the automotive industry were recently adopted towards the mitigation of foreseeable struggle among Thai stakeholders during this potential revolution.

There are several key potential problems within the Thai automotive industry that could happen in the future. Firstly, following the lower global demand for gasoline vehicles, Thailand's export value in internal combustion engine vehicles might drop significantly. Additionally, if Thai industry could not embed itself into the global supply chain of electric vehicles manufacturing, Thailand would have a choice between importing electric vehicles from other countries or continue using ICE vehicles. The first choice would lead to potentially large international trade deficit to the country. In contrast, the second choice is also risky, considering the high level of reliance on foreign multinational corporations (MNCs) within the automotive industry. If these corporations discontinue their support for ICE vehicles or shift the production base to other countries, the situation will result in a large amount of job losses for the Thai population. Therefore, the development of a domestic automotive industry to compensate for this potential economic deficiency should be planned. According to the recent global trends in electric vehicles, Thai government considers the development of this market segments as one of the most significant prospects for its automotive industry.

From several types of electric vehicles, battery electric vehicles (BEVs) have gained a lot of momentum in the world market lately. This is due to the reported progress in battery technology, which accelerate both in term of lower production cost and higher performance (Nykvist, Sprei and Nilsson, 2019). Several technology experts predict that BEV's performance could catch up with internal combustion engine vehicles (ICEVs) within a decade (Burd *et al.*, 2021). This scenario puts ICEVs at risk of being an obsolete product. Additionally, the development of other relating vehicle-based technologies namely, autonomous vehicles, vehicle connectivity, and vehicle sharing business models are more complementary to the development and manufacturing of electric vehicles in comparison to the internal combustion engine vehicles.

In Thailand, the electric bus manufacturing industry is less technological reliant on foreign companies in comparison to the passenger or commercial cars manufacturing industry (Wongdeethai, 2019). Thus, it is ideal as a starting point to obtain domestic capabilities to develop necessary technologies that could be utilised in the manufacturing of electric vehicles. Some components of an electric bus such as the vehicle control unit (VCU) or converter does not need any new development or manufacturing specifications to be used in other class of electric vehicles such as passenger cars. Therefore, the success of electric bus cluster would also be partially beneficial to the development of electric vehicles industry in Thailand as a whole. If consistent collaborative networks between original equipment manufacturers (OEMs) and bus assemblers could be created, it would allow many OEMs in the automotive industry to sustain their business during the industrial transition to electric vehicles.

6.1.3 Society and User's Acceptance of Electric Vehicles

Social drivers are arguably less directly intimate to the cause for electric vehicles adoption. Most of societal motivating factors are derived from drivers in other categories. For example, the reduction of pollution would lead to increasing health and welfare of urban citizens, or the better safety features of electric vehicles might reduce the frequency of traffic accidents. Nevertheless, these social drivers are also important because they are closely linked with potential sizable amount of demand for electric vehicles to facilitate growth of the industry. It is asserted that Thai drivers are expected to gain more confidence in EVs after they are being exposed to their practical usage, which is likely to stimulate their willingness to purchase the vehicles (Laoonual, 2020) .

There are still a lot of doubts on the functionality of electric vehicles among the public. The concerns mostly associate with the economic value and usability of electric vehicles (Narakornpaijitr, 2020). This is also true for electric buses. From the data that were collected in this research, most bus operators expressed concerns that electric buses would be worse than gasoline or natural gas buses in terms of business value due to their lower driving range, longer time to recharge, and higher price. It would be the responsibility of the policy makers and the government to ensure the confidence of potential buyers and establish a sustainable market for electric bus industry.

To cultivate adequate social drivers for the electric vehicles industry, there are two essential topics that should be investigated. The first topic is the settlement of electricity cost, which would be the main factor in customer's buying decision of electric vehicles. In the case of passenger cars, this plan should also be developed concurrently with the logistical planning for the installation of charging stations. The low price of fuel coupled with the availability of charging station would be fundamental to sway people who make business or economic decisions (Brinkmann and Bhatiasevi, 2021).

The second topic is public knowledge and awareness regarding electric vehicles, including electric buses. There are two types that the government should considered. Firstly, policy awareness is not high enough among stakeholders to create an impact within the industry. Second, public perception towards electric vehicles among Thai citizens is unclear. The government should promote the public image of electric vehicles by publicising their positive attributes such as convenience, comfort, and reliability. False premises such as safety issues also need to be dispelled. Currently, these public relation activities were engaged by the Electric Vehicles Association of Thailand (EVAT). However, additional efforts from other organisations might be necessary for full scale adoption of electric vehicles in the country.

6.1.4 Legal and Political Climate within the Industry

Finally, the success of the electric vehicles industry will be tied with legal and political agenda, both within the industry and at the national scope. It was explicitly stated that electric vehicles would be promoted by the government. A committee which supported and monitored public policies relating to the development of the electric vehicle industry and the public adoption of electric vehicles was formed. In fact, there were several policy plans related to the preparation for the shift of the global automotive industry towards electric vehicles since 2014 (Massamadon, 2020a). This initiative represented continuity of public support towards the industry. However, since clear results and progress were not established within the industry, it can be criticized that the government did not implement these policies effectively. This could be due to the uncertainties of global trends in electric vehicles technologies in the past.

The Thai government has made previous attempts to stimulate the industry by providing incentives for potential start-ups and existing enterprises in the electric bus sector (Massamadon, 2020a). However, electric buses were categorised into the group of large logistic and service vehicles, together with electric boats and electric trucks. These vehicles are normally used in commercial transits or public transportation activities rather than for private transits or leisure activities. Public policies that were previously adopted are not specialised for each sub-group despite the difference in industrial properties in each type of vehicles. Further attempts should be made to classify the electric bus into its own industry cluster because there are several key differences that set the e-bus apart from the other EV market such as passenger cars. The examples of differences are the technological specification of the component, different set of safety and performance standard, etc. This would simplify the perspective towards a complicated political agenda that are exclusive to the bus manufacturing and services industry, which might enable policy makers to easily identify and solve the outstanding issues in the cluster.

A large portion of policy initiatives that could be utilised can be a pre-emptive effort to setup incentives for stakeholders. The Board of Investment of Thailand (BOI) will be heavily involved in the provision of business investment incentives to both old and new business owners in the electric vehicles industry. This includes charging infrastructure providers, manufacturers, and independent researchers. Currently, there were already several incentives designed for the future investment that are related to the growth of the EV market. This includes a wide array of subsidised programmes aimed toward EV research, EV manufacturing, and EV adoption which has been increasing every year from 2016 to 2020 (Kurovart *et al.*, 2020). In addition, the government has been attempting to alter the tax structure to promote the purchase of electric vehicles. In the electric bus industry, this method could be used to facilitate the acquisition of crucial components for domestic assemblers.

Other legislative policy includes the enforcement of the adoption of electric vehicles in public organisations. Going forward, state-owned transportation fleets will be exclusively limited to electric buses (Massamadon *et al.*, 2020). Moreover, the reduction of regulatory costs such as registration and insurance would encourage private organisation to purchase electric buses as their corporate fleets. Other future legislative policies might be the allowance of free passage on the expressway or the designation of special lanes for public electric bus services, both of which were adopted before in the attempts to promote the uses of ICE-buses among Thai commuters. Nonetheless, government should also make sure that there would be no extreme public backlash to this legal administration.

Table 6-1 Examples of interview quotes regarding the drivers for the Thai electric bus industry

Participant	Theme	Quotes
NN	Economic value of the Thai automotive industry.	"Theoretically, if we convert all of our cars to be EVs, 30% of our value in automotive industry would be lost. There would be no exhaust pipe or transmission system."
NN	Environmental issue in Thailand.	"EV is the platform for next-generation vehicles. Because fossil fuel vehicles create a lot of pollution to the environment, many countries adopt strategies to reduce them. So, the main driver for EV industry are environment and energy."
TW	Impact of global technological progression.	"They might also do not want to risk investing on the current specification of battery and charging station while there are very fast technological improvement approaching."
TW	The importance of taxation and fiscal policies.	"Chinese has economy of scale and fully integrated supply chain which help drive their cost down. Moreover, there are a lot of parts for EV that we need to import, and the import tax policy is still not reduced to promote this activity."
SW	Social awareness of electric vehicles.	"Especially with bus operators, they need to be convinced that e-buses are more than just a replacement for older model, otherwise it is shown that they still don't understand its limitations and the utilization of EVs technology."
AJ	Volatility of political situation.	"There was a lot of questions on the longevity of Food Innopolis at first, because it was founded in the time of political crisis."

In conclusion, external drivers for electric vehicles and the electric bus industry could be either organic drivers i.e., response and reaction to the circumstances, or inorganic drivers i.e., drivers that are reinforced by certain organisations to stimulate the industry. The impact from each driver could be arranged as follow:

1. *Economic* – In long-term, the loss of economic value to the automotive industry would be severe to the Thai economy. The global market expansion of electric vehicles will threaten the Thai automotive industry, but also provide new industrial opportunities.
2. *Environmental* – The electric vehicles committee put environmental factors as the most urgent issue in Bangkok. The adoption of electric vehicles, especially in the public transportation sector, was expected to be the most impactful method to mitigate urban pollution problems.
3. *Technological* – Technological drivers for Thailand are mostly external, which mean they depend on global technological changes rather than domestic technological development. Nevertheless, it is a driving factor that would shift the manufacturing industry towards electric vehicles.
4. *Legal* – Legal drivers could be highly impactful towards the transition to electric vehicles. The most important decision would be the regulation of several forms of tax to manipulate the demand and supply in the electric vehicles market.
5. *Social* – Social drivers are not strong because the influence of society is rather low for the research and manufacturing processes. Nevertheless, public opinions could affect the direction of policy making by the government when the EV's demand is required for market growth.
6. *Political* – Currently, positive effects from political drivers are not apparent. In contrast, volatile political situation in Thailand might be detrimental to the progress in the development of domestic electric vehicles industry.

6.2 Stakeholders Analysis

6.2.1 Stakeholders Identification

To formulate a convincing plan for the industry, the first task was to make a compilation of all current stakeholders within the Thai electric bus Industry. This includes stakeholders from the government, research and development sector, manufacturing sector, service provider, and end users. This task is the first step of the process in stakeholder's analysis which investigated the status of stakeholders and estimated their future contribution and influence towards electric bus industry. All of stakeholders are identified and categorised according to their characteristics (Table 6-2).

Table 6-2 Categorisation of stakeholders in Thai electric bus industry

	Category	Responsibility / Stakeholder
Government		Electric bus manufacturing
		Charging infrastructure
		Policy budgeting
		Traffic regulation and control
		Pollution control
		Research funding
Research and Development	Universities	Chulalongkorn University
		Chiangmai University
	Technology Institutes	KMUTNB
		SUT
		RMUTT
		KMUTT
		KMITL
	Enterprises	Panthong
		Sabai Motor
		Cherdchai
		Sakun C
Manufacturer	Foreign	Skywell
		BYD

	Domestic Conversion	Sakun C EV Now (Energy Absolute+TEV) Panthong Sabai Motor
Distributor	Importer	Skywell Loxley (BYD) Sunlong
	Thai	EVT TEV Mine bus (Energy Absolute) Sakun C
	Other business model	Sub-contractor Rental Agency
Service Provider	Public Operator	Bangkok Mass Transit Authority Provincial Authority
	Private Operator	Concession Independent
	Fleet	Public organisation Privately-owned
	Others	Maintenance garage Charging Station
End User	Citizens	Bus passenger Pedestrian
	Employees	Driver Conductor Mechanic

(Source: Based on the data collected)

For the government, six important ministries were identified as significant contributors to the adoption of public policy regarding e-bus research, manufacturing, and usage in public transport. The Ministry of Industry oversees the regulation and act to incentivise the manufacturing of e-bus components and assembling process. This includes the continuation of the e-bus conversion industry, in the case that it is proved to be feasibly commercialised. The Ministry of Energy is responsible for all infrastructural preparation both regarding the electricity network and charging stations installation. The Ministry of Transportation deals with road regulations and the potential exclusivity of electric bus public services. The Ministry of Finance manages the budget that is used to fund public policy in other ministries. The Ministry of Science oversees research and development policies for various technologies in electric vehicle manufacturing. Lastly, The Ministry of Environment will have several tasks regarding pollution control and measurement, and to provide feedback regarding environmental benefits of electric buses.

The research and development sector include two main types of research organisations. The first type is universities and technology institutions. The second type is commercial enterprises who are involved in the process of research and development, in addition to the manufacturing of e-buses. According to the National Science and Technology Development Agency (NSTDA), different research topics were assigned to different researchers based on their current expertise. In this case, management and policy research are mostly delegated to the universities, while manufacturing-based research topics are the focus for technological institutes throughout Thailand. In addition, process and product development in different components or systems in electric buses are separately pursued by different bus manufacturers. For example, Choknumchai would focus on Chassis development while EVT would do more research on smaller e-bus components.

The categorisation of manufacturers is a little more complex than the other sections, since some assemblers could produce their own bus components, while the others require part's suppliers. Nevertheless, considering there are many hundreds of original equipment manufacturers (OEMs) in the Thai automotive industry, this categorisation omitted them and purely focused on the big assemblers who have the most potential to produce electric bus components by themselves, or be able to independently assemble e-buses. This also included manufacturers who have started the research on the conversion from ICE-bus to e-bus. Another category are foreign manufacturers who planned to establish their assembly plant in Thailand according to the data at the time they were collected.

Distributors can be categorised into 3 categories. The first one is importers who import bus components for domestic assembling, including both as a supplier to Thai company or as a seller of their own products. The second category is Thai assemblers who planned to develop and manufacture their own brand of buses. The last category is considered as an opportunity for new service ventures dealing with electric bus procurement and rental for both public and private operators who have interest in e-bus but are short on financial funds.

Service providers can also be categorised into 3 main grouping. The first one is the operators which include both public operators, mainly Bangkok Mass Transit Authority (BMTA) if the scope of initial adoption is in Bangkok and private operators. The second one is those who provide transport fleets as a service on a rental basis, or a public organisation who own and utilise the fleets to internally transport their employees. According to the current scheme of the government, this group could be considered as the most probable group of initial buyers for electric buses. The operating range for their buses would be considerably lower than the scheduled bus services, which partially negate two of the most prominent drawbacks of e-buses i.e., range anxiety and battery life. Nevertheless, the upfront cost for e-buses will still be a barrier and the government might need to provide some financial incentives for this group of potential buyers. The last group is the other related business to electric buses and electric vehicles. This consists of start-ups in charging station business, software developers for vehicle's features and traffic system, etc.

For the end users, there are the Thai citizens as both passengers and pedestrians. Despite that air pollution arguably had more effect on pedestrians in urban areas, the negative effect of air pollution is also applicable to passengers in public bus because most services are still open-air buses. Electric buses will be a more attractive option for employees in this public service sector since they will improve the working conditions for both the bus drivers and conductors. Additionally, e-buses will have different processes for the repair and the maintenance, which would influence garage businesses as well.

6.2.2 Stakeholders Mapping

After the categorisation, each grouping of stakeholders was rearranged on the mapping that estimated their power, interest, and influence towards the development of electric bus industry (Figure 6-1). The origin of information that was used in stakeholders mapping and engagement model are explained in table 4-4 in chapter 4 which listed the interview questions and the response that were utilised. In this case, the responses that are related to the status and relationship among important group of stakeholders in Thailand were used to plot figure 6-1. Additionally, this information was summarised in the following paragraph of this section and some of the related actual quotes are presented in table 6-4. It should be noted this is based on qualitative analysis; thus, the dimension of the figure is subject to some inaccuracy. The main objective for this analytical representation is to illustrate the importance of each group of stakeholders in a comprehensive method that can capture these characteristics in one single diagram. To clarify the labels in this diagram; power is the amount of enforcement that the entity could exert upon other entities in the system. Interest is the predicted intention of the entity to collaborate in the shared goals of the system. Influence is the magnitude of effect towards the whole system when the entity shifts its strategic direction. For instance, a group of e-bus users are somewhat influential towards the adoption of electric buses policy by the government. However, they don't have any power to affect other parts of the system, despite being very eager to see this transition of public services come to pass.

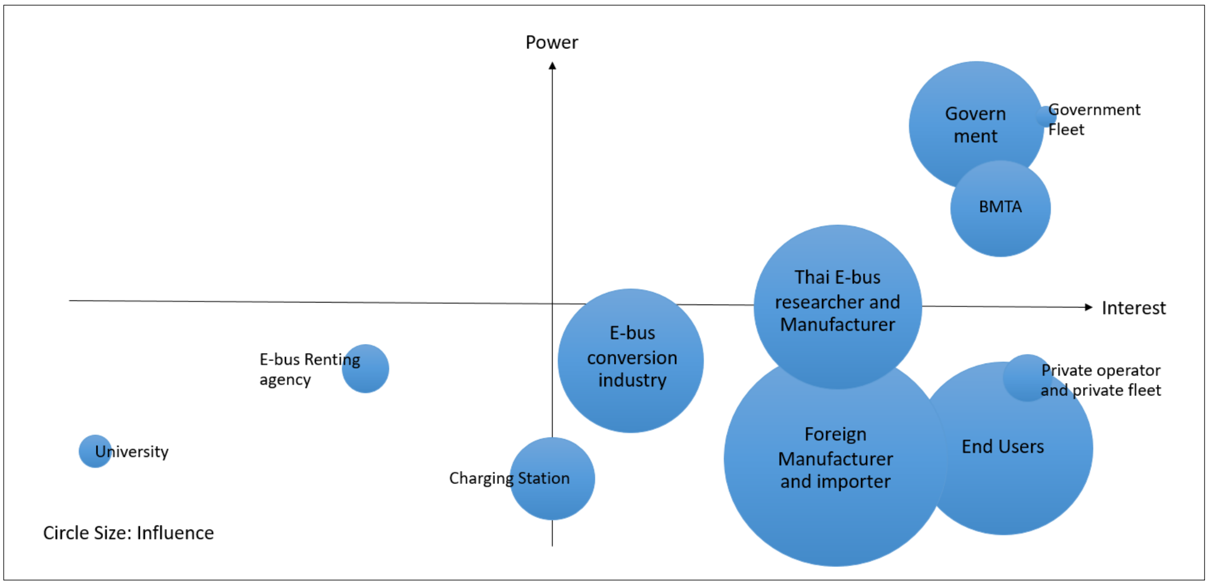

Figure 6-1 Stakeholders Mapping for Thai stakeholders in Thai electric bus industry
(Source: Adapted from (Newcombe, 2003)

According to this figure, there are some important implications for each group of stakeholders. Firstly, the universities would need more engagement in the industry to cultivate more interest in conducting research. Nonetheless, it is still unclear whether the current research will be strongly beneficial to the industry at this initial stage due to the lack of actual manufacturing. Charging station infrastructure would not be as important when compared to the passenger car segment of electric vehicles. However, the success of charging infrastructure installations might have positive effects on the confidence of private bus operators. There is a significant promotion of electric bus conversion research, but many experts have concerns in the economic value of the programme. As mentioned before, most of users are very willing to support the adoption of e-buses in public transportation system if the vehicle's price and fare is acceptable. The main public operator (BMTA) has high interest and high power due to the potential demand they could generate for the industry. On the contrary, private operators and service fleet segment were not currently seen as sufficiently influential to the change in public policy. Government and Thai e-bus manufacturers need to be more empowered by the public policy that could be adopted in the future, especially when the government comparatively has less totalitarian power compared to the countries that are considered to be quite successful in e-bus adoption like Singapore or China (Welfens *et al.*, 2018). Lastly, it can be implied that foreign manufacturers, especially from China, are very influential towards the development of the Thai electric bus industry. The Government should not let them have higher bargaining power than domestic enterprises if they hope to grow this industry further.

An additional implication that could be conceptualised from the diagram is the non-existence of stakeholders in the upper-left (high power/low interest) quadrant. This essentially means that all the stakeholders who possess the power to drive the industry forward have showed at least some interest in this transition. Therefore, if the adopted policies are not in conflict with these stakeholders, the transition towards e-bus industry would be smooth with regards to potential political conflicts within the industry. The most discernible element that could cause friction in the development of the electric bus industry is the group of manufacturers that originally produce components for ICE-bus that would not be transferable to the new supply chain of electric bus manufacturing. Hence, this element should be taken in consideration in the design of the other section of this policy plan. Lastly, it is important to note that this diagram is an observation of the stakeholders who exclusively reside in electric bus industry and did not factor other stakeholders in adjacent industry into the analysis.

6.2.3 Stakeholder Engagement

After the position of each group were analysed, it would be easier to make a proper policy plan for the electric bus cluster. However, the question remains regarding the intensity of policy instruments that should be applied towards each segment of the industry. This lingering question led to the preparation of another tool to assess the amount of effort policy makers should exert on each segment of stakeholders according to the main goal of the national policy. In this case, the main goal was set to be the transition of bus manufacturing industry towards the electric bus and the adoption of electric buses as public services in Thailand. The stakeholder engagement matrix (table 6-2) assessed 12 groups of stakeholders based on their current level of engagement with the cluster and the target level of engagement set by the government. This matrix illustrated the gaps of stakeholder's active engagement in comparison to the desired level of collaboration within the electric bus research and manufacturing cluster. The scale of engagement was divided into 5 sub-groups. Unaware means that the stakeholder have no information regarding this policy. Resistant means that the stakeholder actively resist this policy. Neutral means that the stakeholder is indifferent towards this policy. Supportive means that the stakeholder is supportive of this policy. Lastly, Leading means that the stakeholder plays essential roles in the adoption of this policy.

Table 6-3 The current and desired engagement of stakeholders in electric bus Industry

Stakeholders	Unaware	Resistant	Neutral	Supportive	Leading
Government					C → D
University			C →	D	
Enterprise R&D			C →	D	
Importer				C →	D
Thai assembler				C →	D
E-bus conversion				C → D	
Part manufacturer		C →			D
Rental service			C →	D	
Public operator			C →		D
Private operator		C →			D
Charging station			C → D		
End user				C → D	

C: Current Engagement / D: Desired Engagement

(Source: Adapted from Project Management Body of Knowledge (PMBOK))

According to the table, there were 4 groups of stakeholders that does not require significant effort to increase their engagement: government, e-bus conversion, charging station, and end user. In contrast, 8 groups of stakeholders are decidedly in need of more engagement in the development of an electric bus cluster and associated industry. Despite that the former 4 groups would require less effort to increase their engagement, it does not mean that they should be ignored by the government. Naturally, the engagement level of stakeholders in the system could drop over time if the perceived benefits of their participation in the cluster is lacking (Laoonual, 2020). Therefore, it is better for the government to be vigilant by making sure that they generate sufficient motivating factors for stakeholders to cooperate. This engagement plan could also be used in conjunction with the mapping from previous section. It can be presumed that the parties with higher interest are more likely to be persuaded when compared to the parties with lower interest. This effort could also be prioritised towards the more powerful and influential parties because their commitment is expected to be more impactful towards the industry.

E-bus related research should earn more engagement from the universities, especially the research that focuses on the aspect of electric bus commercialisation. There are some collaborative efforts between local technology institutes and assemblers in its vicinity but most of these activities need to be reinforced by a clearer policy direction (Cherdchai, 2020). Similarly, the research and development team within private enterprises would strongly benefit from a clear strategic direction from the government, so they could become more supportive towards the transition. Importers currently have higher leverage compared to domestic manufacturers in term of e-buses pricing and perceived quality. Their market growth could promote user's confident in e-buses among operators, but their growth should be deftly limited by government policies (Wongdeethai, 2019). Thai assemblers are actively engaging with the cluster in their effort to manufacture functional e-buses. In contrast, most original equipment manufacturers (OEMs) that might have sufficient capabilities to supply e-bus components to the assemblers are not actively engaged with the cluster and are scattered due to the large number of OEMs. Bangkok Mass Transit Authority (BMTA), as the main administrative body of bus-based public transportation in Bangkok (It owns a fleet of 3,005 buses, in addition to 3,485 privately-owned contract buses in 2021). should be the leader in the procurement and usage of e-buses. However, the transformation is slow because the lack of financial liquidity and overcapacity of the ICE bus (Wongdeethai, 2019). This is one of the uncertainties within this industry that could lead to the birth of e-bus rental services as a new business model. These agencies could mitigate the risk of operators, especially for BMTA who would be burdened with a significant amount of ICE bus turnover. However, there are very few stakeholders currently in this segment. Finally, most private operators currently lack assurance in the shift to electric buses because of bad prior experience with natural gas buses when the government decided not to regulate the pricing of natural gas after many private operators shift to NGV buses. This circumstance, couple with the major concern over profitability of running an electric bus service led to the most critical problem that should be addressed by the government.

Table 6-4 Examples of interview quotes regarding the stakeholders in the Thai electric bus industry

Participant	Theme	Quotes
PN	The low power of private operators.	"I don't know what to say first. There are so many things that need to be improved. Sadly, we will not be able to influence their decision in any ways."
SW	Indicator of high influence of Thai researchers.	"For e-bus, we could easily dictate the direction of market because it is owned mostly by the government. We could also influence the industry to some certain extent because bus manufacturers in Thailand are different from car manufacturers in Thailand."
PS	Indicate higher influence of foreign company in relation to Thai enterprises	"There are two problems for Thailand, first is labor market efficiency and second is the lack of domestic market development. All of our manufacturing power and products sales are highly dependent on other countries."
NN	Indicator of high interest in manufacturers.	"Many stakeholders interested in manufacturing electric vehicles, but they lack knowledge on how to design EVs platform systems based on the available components."
SC	The manufacturers are lacking behind because of the lack of confident in infrastructure.	"I think there would be more management problem with regards to the shift towards electric vehicles. What about charging station, electric demand spike, or readiness of maintenance garage? It is not only about the vehicle."
SW	Show that conversion industry is close to fulfilling its objective.	"What we expected was not to initiate bus conversion industry, but to open up opportunity to recycle 700-800 units of old BMTA's buses into EVs if the project is financially feasible."

6.3 Competitors Analysis

In this section of the thesis, the main competitors in the Thai electric bus industry were analysed. The competitors were categorised into 4 groups: Thai manufacturers, foreign manufacturers, importers, and e-bus converters based on the previous part regarding the stakeholder's identification (table 6-2) and the response from the interview explaining the current state of the Thai e-bus industry. Each of these grouping included all the processes that are required to completely manufacture an electric bus. Therefore, this analysis integrated both component's manufacturers and assemblers of e-bus in their respective grouping. The analysis of stakeholder's competitive advantages and disadvantages were compiled in SWOT analysis, which is an approach to present four dimensions of each main competitor; strengths, weaknesses, opportunities, and threats (Stait, 1972).

6.3.1 Thai Manufacturers

For Thai manufacturers, their most significant strengths are the existing connections to domestic suppliers and customers, which could be their potential partners in the new supply chain of electric bus manufacturing. This circumstance could provide them with many benefits such as lower investment costs towards the establishment of product distribution channels. Most importantly, they have existing experience of the Thai market which allows them to have greater insights into customer market and better familiarity with automotive industry regulations in Thailand. These factors would accelerate their business manoeuvre outside the development and manufacturing of the electric bus.

The largest obstacle for Thai manufacturers is the lack in economies of scale in the domestic market. Domestic demand for electric buses was reportedly not large enough for many enterprises to maintain their profitability in production due to high fixed cost of setting up a production line (Thuntiwiroon, 2020). This weakness will result in less competitive pricing of electric buses until some export market is established. In addition, their missing technological capabilities in the manufacturing process would lead to longer time to market, unstable production volume, and the initial products that are not widely proven in term of quality.

Generally, there is a good opportunity for Thai electric bus manufacturers because the global demand for electric buses is expected to continuously rise (IEA, 2020). They would also receive more support from the government compared to foreign enterprises if industry growth is the main objective for the nation. This might include the direct procurement order of electric buses from the government, and the free provision of testing facilities. Furthermore, domestic market share for electric buses is still relatively vacant, so this might be an attractive opportunity for new investors.

The main threats to Thai manufacturers consist of inferior perceptive image towards Thai buyers of an advanced technological product that is domestically manufactured. This circumstance existed for most products even outside the automotive industry (Sone, 2019). Moreover, there is a lack of product differentiation among Thai manufacturers. This problem might lead to a corporate decision to let the foreign company take over their operations in the electric bus segment, to improve their product image and expand their export potential. Finally, domestic demand for electric buses might be lower in the future due to the declining popularity of public bus as a method of public transportation in Bangkok.

Table 6-5 SWOT Analysis of Thai electric bus manufacturers

	Thai Manufacturers
Strengths	• Existing connection to potential suppliers and customers. • Existing connection to government and research sector. • Insightful towards customer needs. • Familiarity to industry and transportation law and regulations. • Already have product distribution channels
Weaknesses	• Have no economies of scale in production.

	• Lacking technological capabilities. • Product quality was not proven to the public. • Longer expected time to market. • Low capital investment. • Potentially high price.
Opportunities	• Policy supports from the government. • Potential order from public organisations. • Free testing facilities. • Rising global demand for electric bus. • Unoccupied market share in Thailand.
Threats	• Low brand image of the product. • No product differentiation from other company. • Strong overseas competitors might limit export capacity. • Potential acquisition by foreign enterprises. • Declining popularity of bus as the mode of public transport in Bangkok.

(Source: Summarised from the data collected.)

6.3.2 Foreign Manufacturers

Several strengths of foreign manufacturers are the opposite of domestic manufacturers. Their biggest strength derives from the higher readiness in electric vehicle's manufacturing technology, which enables them to offer superior or comparable product at a lower price and adopt a wide variety of sales promotion (Wongdeethai, 2019). Additionally, they have production support from their parent company. This is especially true for Chinese manufacturers since their parent company would likely have a surplus in production capacity. As a result, they have a greater capability to maintain sales and services level in a fluctuate demand environment.

The weaknesses of foreign manufacturers include the requirement of time and money investment to initiate their production cycle in Thailand, primarily in the establishment of their new factory and distribution channels. Furthermore, they would require extra marketing efforts to create and maintain a new customer base in Thailand since they would likely to have less connection to the stakeholders in the industry. This fixed cost could contribute to the unusually high price of the initial offering that might be very close to the offering price of domestically manufactured electric buses. Nevertheless, they could still utilise the heavy discount strategy if their parent companies are willing to grant additional budget for overseas market investment (Thuntiwiroon, 2020).

Many of their opportunities in the Thai market are the same as the opportunity for Thai manufacturers, such as the large amount of unoccupied market share in the electric bus sector especially in public services segment. After the penetration into the supply chain in Thailand, they could also use their factories as a production base to distribute the product to neighbouring countries in south-east Asia. Finally, their technological expertise in electric vehicles might be a good bargaining chip for them to exchange information and knowledge with Thai OEMs and use them as suppliers (Thuntiwiroon, 2020). This could be done when Thai assemblers are weaker in term of technological capabilities.

The most apparent threat to their business conduct in Thailand would be the industrial and commercial policy of Thai government. This depends on the level of their commitment to develop an electric bus industry independently from foreign enterprises. The policy could be made to hinder the progress of foreign companies. Nonetheless, policies that would promote the growth of foreign manufacturers also exist, for example the tax reduction of raw materials transaction between domestic and overseas OEMs (Kurovart *et al.*, 2020). Other additional threats included uncertain demand, rising labour cost compared to neighbouring countries, and the lack of existing suppliers for electric bus components in Thailand.

Table 6-6 SWOT Analysis of foreign electric bus manufacturers

	Foreign Manufacturers
Strengths	• Readiness to manufacture electric buses. • Higher perceived product quality. • Access to lower price and variety of sales promotion. • Financial and capacity support from parent company. • Capability to maintain sales volume in fluctuating demand.
Weaknesses	• Require large investment in time and money. • Require new distribution channels and customer's base. • Less existing connection to Thai suppliers and stakeholders. • Possible mismatched corporate culture to Thai industry. • High initial fixed cost.
Opportunities	• The product has better customer perception than Thai brand. • Thailand is a good hub for shipment of e-bus to southeast Asian countries. • Possess high bargaining power via technological knowledge. • Existence of policy that promote cross-country supply chain. • Unoccupied market share in Thailand.
Threats	• Less support from Thai government. • Uncertainty of demand could complicate corporate strategy. • Rising labour cost in Thailand compared to neighbouring countries. • The lack of existing suppliers for electric bus components in Thailand. • Risk of incompatible e-bus components from the suppliers.

(Source: Summarised from the data collected.)

6.3.3 Electric Bus Importers

Aside from being completely manufactured inside Thailand, the imports of electric buses would be another choice for domestic business venture. The primary strength of this business model is the minimal number of infrastructural activities needed to start a business. Moreover, several bus manufacturers from overseas already have multiple Thai operators as their former customers. As a result, their products would be more readily available for purchase. If the whole electric bus is imported instead of major components to be assembled in Thailand, their product would then be perceived as more reliable and possess better quality.

Importers will have unique weaknesses that their products will not be tested in the actual environment in Thailand prior to the shipping. It would also take longer time to deliver products to the customers when compared to domestic manufacturers. Thus, it is possible that their product would encounter technical issues in the real setting (Wongdeethai, 2019). This weakness would be amplified by the lack of brand-specific maintenance options in Thailand, which could frustrate their customers. Most importantly, they must deal with higher logistical cost and import taxes, which could heighten their products price beyond the market price of domestic manufacturer's product (Laoonual, 2020).

When compared to other categories of competitors, their opportunities are somewhat limited because Thailand is not the most attractive market compared to other countries. Most of the opportunities would relate to the improvement of their production efficiency. The small surplus of their production output could be offloaded to Thailand. This does not have to be in high-volume because the Thai government is not likely to take a risk and order a large batch of electric buses without properly testing them first (*Ministry approve the procurement of 2,511 units of e-bus for BMTA*, 2020). Nevertheless, pollution problems in Bangkok and other urban areas in Thailand might encourage the government to settle with the quickest import solution.

In contrast to opportunities, there will be several threats to electric bus importers. These threats consist of low support from Thai government, a large number of competitors in overseas importer segment, and unstable economic and political situation in Thailand. The Thai government is very likely to adopt an industrial development policy to prepare automotive industry towards the disruption of electric vehicle. This might include putting a limit on the volume of electric vehicle imports (Laoonual, 2020). Furthermore, there is a possibility of price war among overseas competitors in Thailand especially among Chinese enterprises, which will reduce potential profitability even further in an already scarce e-bus market in Thailand.

Table 6-7 SWOT Analysis of electric bus importers

	E-Bus Importers
Strengths	• Minimal requirement to start a business. • Can exploit old customer base in normal bus market. • Readily available product for purchase. • Higher product reliability and quality standard. • Product delivery is guaranteed.
Weaknesses	• Products are untested in Thai environment. • Longer time to deliver compared to a running domestic manufacturer. • Lower after-sales services and maintenance options. • Higher logistical costs and subjected to import taxes. • Less connection with other stakeholders in Thailand.
Opportunities	• Surplus of local production could be export to Thailand. • Small sales volume match with the current level of demand. • Pollution problems could encourage the imports. • Existence of policy that promote international trade.
Threats	• Lowest support from Thai government. • Several competitors in imports market segment. • Instability of economic and political situation in Thailand. • Negative impact from industry development policy. • Possibility of price war with other companies. • Thai market is less attractive compared to other countries.

(Source: Summarised from the data collected.)

6.3.4 Internal Combustion to Electric Bus Conversion

Being able to completely convert an internal combustion engine bus into an electric bus would allow manufacturers to save a large portion of raw material costs in the manufacturing process. Therefore, the pricing of a converted electric bus could be made significantly lower than their freshly manufactured counterparts. A bus conversion initiative is considered as experimental and still not applicable in mass production (Wanichanukul, 2020). This experimental programme requires less technological leap for manufacturers. In addition to this unique strength, since bus conversion would also rely on Thai manufacturers, it would also receive the same type of benefits such as connection to stakeholders and familiarity with Thai law and regulations.

According to some industry experts, the conversion of ICE to e-bus is still have concerning issues in high operating costs and possible technical problems in manufactured buses. The products that would come out of this programme were predicted to be poorer in term of quality compared to newly manufactured bus. This resulted in the unlikelihood of product warranty and the promise of mass production. Furthermore, the conversion process would take a longer time to manufacture, in addition to standard vehicles testing. In summary, a converted e-bus would have very limited usability and the production output would not be optimal for commercialisation (Wanichanukul, 2020).

Despite being not suited for commercialisation, a conversion programme could be viewed as a sandbox for Thai manufacturers to develop their technological capabilities. The non-commercialised nature of the programme would make it easier for enterprises to form partnerships. Buses that are converted could be distributed to various organisations, to operate as internal public transport for minimal price or even free of charge. This new market for this pilot production could be independently created regardless of the state in commercialised e-bus industry. Additionally, this programme would reduce waste from the wreckage of retired ICE bus and open new opportunities for recycling-based businesses (Massamadon *et al.*, 2020).

Electric buses that use aged components of ICE buses are predicted to be badly perceived by the bus operators to the point that they might not consider spending any money to purchase them at all. Hence, free testing schemes might be required for converted e-buses. According to the NSTDA, this conversion programme would not be supported by government funding beyond experimental state (Wanichanukul, 2020). As a result, the biggest threat will be the current inability to scale up manufacturing process into a viable and economical mass production, in the case that the products are well-received by the public. It would also be difficult to compete with manufacturers of new bus in the long run.

Table 6-8 SWOT Analysis of the conversion from internal combustion bus to electric bus

	ICE to E-Bus Conversion
Strengths	• Lower raw materials cost. • Existing connection to potential suppliers and customers. • Existing connection to government and research sector. • Familiarity to industry and transportation law and regulations. • Require less technological leap of manufacturers.
Weaknesses	• Higher operating cost per unit manufactured. • Batch or mass production is still not viable. • Unlikely to have product warranty. • Slower manufacturing process. • High possibility of technical issues in products. • Highly dependent to external suppliers.
Opportunities	• Sandbox for technology development in Thai companies. • Stakeholders are more likely to form partnerships. • Low financial burden in research and development process. • Might exist in a different market segment to new e-bus. • New opportunities in bus salvage ventures.
Threats	• Very bad perception from customers. • Inability to scale up the production output. • Lack of viable options as sustainable business. • Strong competition from new buses in the long run.

(Source: Summarised from the data collected.)

Foreign manufacturers were very indecisive regarding the full investment because of the downturn of the global economy due to the pandemic in 2020-2021 and the volatility of political situation in Thailand. On the flip side, e-bus conversion was condemned by some experts as inappropriate for commercialisation (Suebsupanand, 2020). As a result, there are currently more opportunities for Thai manufacturers and importers for the investment in the electric bus industry, in comparison to foreign manufacturers and e-bus conversion. The important hurdle for Thai manufacturers would be the improvement of technical capabilities. While the regulations on imports and taxes would be a key success factor for e-bus importers.

6.4 Issues in the current E-Bus cluster

According to the literature review covered in chapter 2 to chapter 5, important issues regarding the innovation cluster and the global electric vehicle industry were identified and these are summarised in figure 6-2. These gaps were utilised as a benchmarking tool to extrapolate important features that should be studied in the Thai electric vehicle and electric bus industry and subsequently to design an effective policy framework for an effective operation of the Thai electric bus research and manufacturing cluster. Hence, actual drivers and industrial goals for the Thai e-bus industry were investigated in section 6.1, and the major competitor types in the market of electric bus were analysed for their current and future competitive advantages in section 6.3. The results from these two topics which originated from the collected data were used to conclude the possible gaps within the electric bus research and manufacturing cluster in Thailand. These gaps are categorised into 4 groups according to their relative position within the system (figure 6-3). Additionally, some of the interview quotes indicating the gaps between the Thai e-bus industry and global EV industry are included in table 6-9.

Table 6-9 Examples of interview quotes regarding the gaps in the Thai electric bus industry

Participant	Theme	Quotes
NN	Not sufficient research incubators.	"After they could produce minor or small parts for EVs, they could develop their capabilities to develop a bigger part or the whole electric vehicles. The important part is to provide them a research incubator."
NN	No technological diversification.	"It is the trends for OEM to bargain for cheaper old parts from suppliers, but for the new tech where they don't have capability to produce, they need to source big technological company which drive their cost up."
SW	Lack of local content policy.	"Not in national policy level, but there were some organisational level policies such as BMTA who declared new term of reference (TOR) to purchase 2,000 units of e-bus in the future."
PS	Not sufficient communication to public.	"We need to disseminate more knowledge and make them see the actual uses of EVs. The problem is electric vehicles are still too expensive in Thailand which limited their exposure."
SW	Price barrier of EV.	"If we only think about economic value of EVs, there is no way it would be worth the investment. The price of EVs is very high because of battery component, maintenance management, investment of charging station"
PS	Technological lock-in of ICEVs.	"Yes, if EGAT decide to charge high cost for electricity in car-charging, EV industry would not progress. With no economy surplus, we would revert back to diesel engine industry."

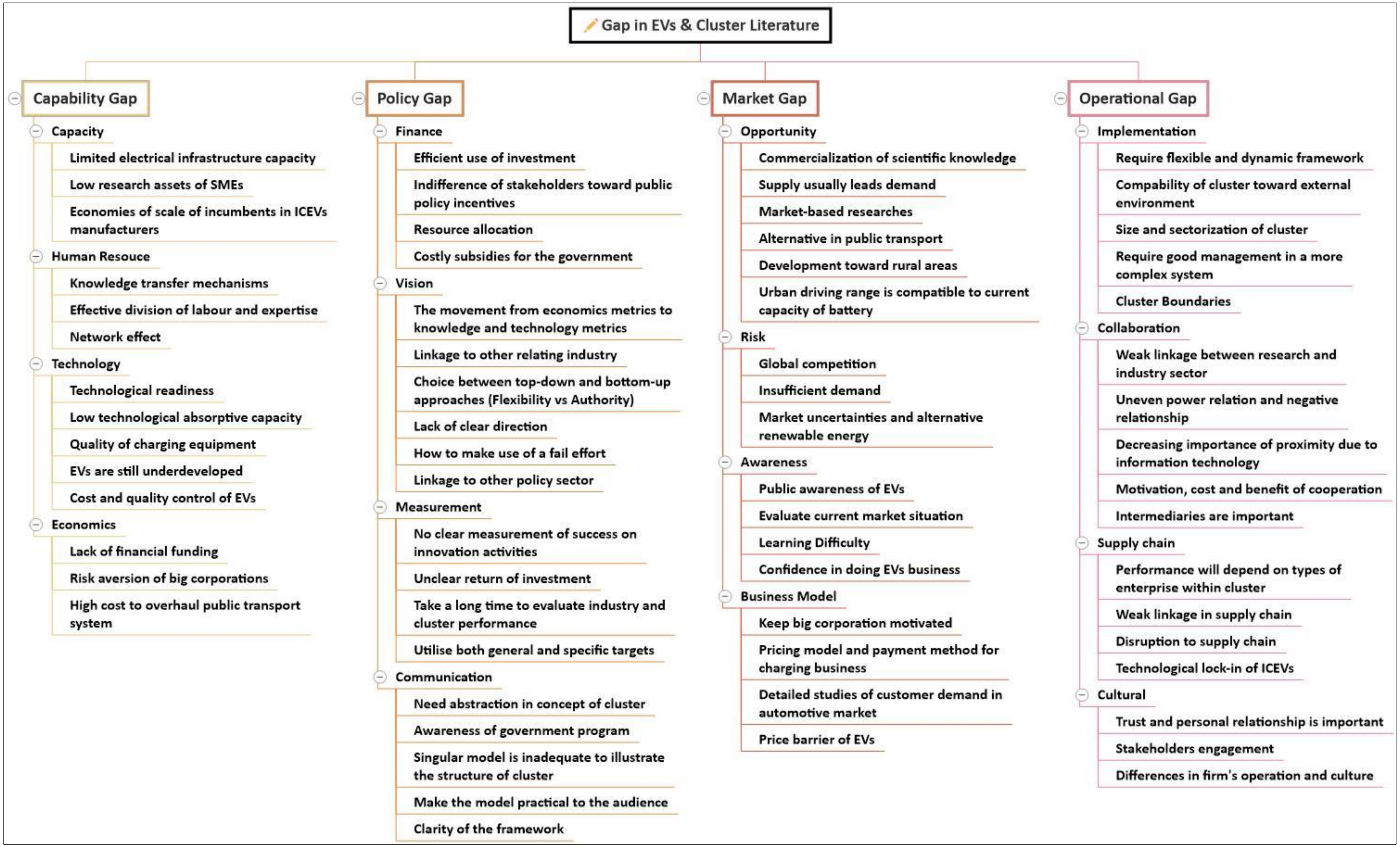

Figure 6-2 Historical gaps and issues in innovation cluster and global electric vehicle industry

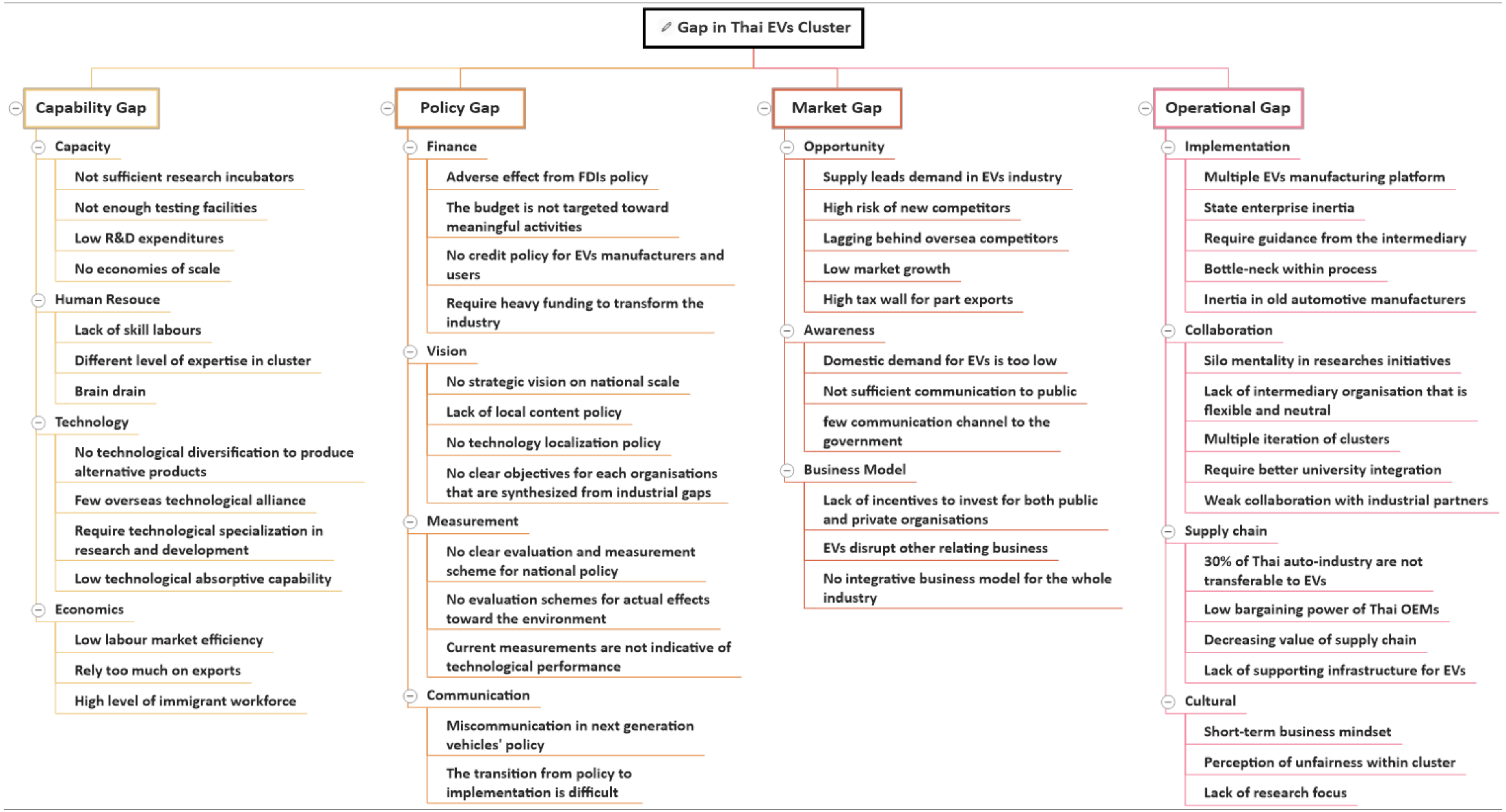

Figure 6-3 Current gaps and issues in Thailand electric bus research and manufacturing cluster
(Source: Summarised from the data collected.)

6.4.1 Capability Gaps

The first category of issues is categorised as capability gap. This category referred to industry's capabilities in research and manufacturing process. This includes 4 sub-groups: capacity, human resource, technology, and economics. Gaps in capacity are the discrepancies between available resources and the ideal number of resources. Since the cluster is still in the initial formation period, a lack of resources is expected. For example, there are not sufficient testing facilities and research incubators specifically dedicated to the electric bus industry despite the intention of technological development. This is connected to the low amount of research and development expenditure that each stakeholder is currently willing to spend. The absence of economies of scale discourages enterprises from investing heavily on the development in manufacturing process.

In term of human resources, Thailand is faced with the problem of skilled labour shortage. There is a pocket of skilled employees scattered within the automotive industry. However, without effective knowledge transfer mechanisms or proper training methods, personnel with deeper understanding of electric vehicles technologies will be too scarce for gradual development at national scale. Amplified by a lower premium salary for technology experts, Thailand is regularly losing knowledgeable human capital to foreign countries. The most important gaps in human resources that should be emphasised are different levels of expertise within the cluster. The current formation of the cluster lacks representatives from different sectors in the industry that communicate with the same level of understanding in the topic of electric vehicle. This feature is considered essential for the effective communication between stakeholders with different background and business focus.

Technological capabilities will be the largest obstacle for the development of the electric bus and electric vehicle industry in Thailand. Thailand still lacks research and development specialisation that could take them into global supply chain. They are currently unable to develop an electric vehicle battery and motor independently from foreign companies. Moreover, the lack of skilled labour and trustworthy technological alliances prevent Thai companies to fully absorb technological expertise from foreign partners. Additionally, the current level of technologies in domestic original equipment manufacturers (OEMs) are not sufficient for them to break away from the controllers, which are mostly multinational corporation (MNCs). To do so, these OEMs would require technological diversification to manufacture alternative products or deliver the products to different markets.

Economic issues related to large scale inefficient resources usage of the industry. Firstly, the Thai automotive industry relies too heavily on automobile exports. As a result, there will be significant struggle when the industry is moving towards a new type of product because domestic demand would be insufficient to sustain the industry. Another cause of instability of the industry is the large quantity of immigrant workforce. There low-wages workers constitute operational risk when they are dismissed because it would be difficult for manufacturers to find replacements from local people. Lastly, the Thai automotive industry has below average market efficiency. It was asserted that many employees were put into positions that were not matched with their qualification (Noomwong and Sutheejaruwat, 2019).

6.4.2 Policy Gaps

The second category of issues is policy gap, which directly relates to the adoption of public policy. This category is separated into 4 sub-group: finance, vision, measurement, and communication. The most urgent topic in financing policy is that the budget was not targeted towards meaningful activities. Some portion of government financial resources were put away in initiatives that could not produce substantial results for the industry. Furthermore, there is still no credit policy for electric buses manufacturers, which discourage them to fully invest in this new venture. Lastly, there are also some adverse effects from the current foreign investment and free trade policies that could impede the development of the domestic EV industry.

Many actors in the electric vehicles industry agreed that the hesitation of stakeholders to invest in electric vehicles is due to the lack of clear strategic direction from the government (Prateep *et al.*, 2008;Cherdchai, 2020). It could be implied that this strategic direction does not just refer to the formulation of national strategy, but also the activation of practical policy initiatives. There are still no activity-based objectives for each actor, which should be derived from industrial gaps. The examples of these objectives could be in the form of a technology localisation plan to support e-bus manufacturers, or local content policy to expand the market for domestic OEMs. This problem will be addressed in the next chapter, which is specifically about the goal setting in electric bus industry.

The current evaluation schemes that were used in the industry are mostly factor driven instead of efficiency or innovation driven, despite that Thailand automotive industry is in the second stage of economic development (efficiency driven economy) and looking to move forward to the third stage (innovation driven economy) (Rostami, Khyareh and Mazhari, 2019). The absence of clear strategic goals led to the lack of meaningful evaluation procedures that capture the development in the second or third stage of the industry. This actual performance of the industry before and after policy adoption would be a crucial set of indicators to reflect the effectiveness of the policies. Therefore, the guidelines to create this evaluation tool are formulated in chapter 9 by utilising industrial gaps that were found in this analysis. It includes important properties that were previously omitted in the measurement such as actual effects to the environment from the implementation of electric buses or technological readiness scale of the Thai electric bus industry.

The communication of government strategies and public policies to stakeholders were often incomplete in the current cluster, due to the clutter of information surrounding each specific branches of the industry that were not systematically segregated. Consequentially, there were miscommunications that resulted in the misunderstanding of some public policies regarding electric vehicles. It was admitted that precise transition from national level public policy to organisational-level action plans was difficult to implement. This framework is formulated with the core idea aimed to solve this specific issue by gathering completed information from every segment within the industry and transform this information into general and accessible policy plan.

6.4.3 Market Gaps

The third category of issues is classified as market gap, which involve market related topics. This category included 3 sub-groups: opportunity, awareness, and business model. The first sub-group, which was named opportunity, covered both opportunities and risks in the electric bus industry. The missing link for business opportunities was uncovered. For instance, the disparity between preparations in the supply side with research and manufacturing plan, and the lack of demand in the electric bus market. This disparity limits the electric bus industry to achieve it fullest market potential. The growth of domestic market needs to be stimulated for Thai manufacturers to have sustainable profitability.

On the other hand, the risks in overseas market for electric buses are high because of several strong competitors who currently have better product offerings, both in term of quality and price. The movement of the Thai electric bus industry towards global market might not happen during the initial stage. However, there is a big potential for improvement in the future, especially if Thailand can secure technological supports from smaller overseas firms. Alternatively, domestic manufacturers could attempt to replicate a certain degree of best practices in manufacturing and distribution process from overseas companies. This topic will be covered in chapter 8, which entails some of the best practises from overseas organisations.

The issues of public awareness to electric vehicles were briefly elaborated in the first section of this chapter. The lack of awareness and confident among end users including bus passengers would negatively affect the demand for electric buses. Prior to the decision of transforming public bus services and enforcing electrical-powered fleets, government should make sure that target customers for this market are aware of the intention. In addition, there should be more communication channels between stakeholders and policy makers to facilitate information sharing. This information should focus on the feedback of stakeholders towards certain policies adopted by the government, to streamline the decision-making processes during the formulation of public policy.

The last gap in this category consists of the concern among stakeholders in their business conduct. Most stakeholders, ranging from manufacturers, assemblers, to bus operators have similar doubt in potential profit of the new business model that would be driven by electric bus. The fact that this industry is still in its initial stage further dampens confidence of the stakeholders in this regard. To relieve this issue, a collection of business models for each group of stakeholders were designed in the next chapter. There are three important features of these model to counter each of the corresponding gaps. First, the model must consider the whole situation of the industry. Second, it should clearly emphasise the prospect of business incentives to the stakeholders. Finally, the disruption in business that could occurred because of electric vehicles should be clearly stated, to make stakeholders aware of their individual risk.

6.4.4 Operational Gaps

The last category of issues in the cluster is operational gaps. This category comprises of action, decision, and behaviour of stakeholders in organisational scale. This category consists of 4 sub-groups: implementation, collaboration, supply chain, and culture. The problem in the implementation of activities relating to the transformation towards electric vehicles manufacturing mostly stems from the slowness of decision-making due to an uncertain environment in the market. This uncertainty obscures the clarity of expected outcomes in entrepreneurial decisions and results in split opinions among stakeholders within the cluster. This circumstance non-uniformly affects state and private enterprises in different sectors and generates bottleneck in the supply chain. The advice from industry experts might be required to facilitate this decision-making. Section 7.1 in this thesis create an approach to alleviate this issue by providing an overall vision for a potential electric bus supply chain in Thailand.

As mentioned in the introduction of this thesis, the solution to the collaborative gap in the cluster will be a primary objective for this framework. The current problems included silo mentality in research initiatives, where multiple research institutes set the same goal but take different and independent approaches to accomplish it. This stems from the lack of a singular entity that could control and direct overall efforts in electric bus research. By having an intermediary organisation, industrial enterprises would have more frequent collaboration among each other through this actor. Moreover, this organisation could also manage the connection between industrial enterprises and universities to improve industry-universities linkage. The concept of intermediaries will be fully explored in final section of the next chapter.

In contrast to implementation gaps, supply chain gaps are less about individual strategies and more about collective transformation of the whole automotive supply chain. They are among the largest gap for Thai industry to overcome, since 30 percent of current Thai automotive industry is not adaptable towards an electric vehicles economy (Massamadon, 2020b). For electric buses, despite being in an easier position compared to passenger cars, they still face a decreasing value of their product offering to the global supply chain. This reduces their bargaining power to technological companies who will be capable of manufacturing key components such as batteries and electronic parts. It is essential for the Thai government to quickly establish supporting infrastructure or platform to facilitate the development and manufacturing of electric buses and electric bus components.

Lastly, the current corporate culture and business mindset in Thailand’s automotive industry is not suitable to the abrupt changes within the system that could be brought about by electric vehicles. Most automotive enterprises still orientate towards short-term goals for internal combustion engine vehicles. As a result, it was predicted that large numbers of manufacturers, especially small size original equipment manufacturers (OEMs) would collapse in the case that global automotive industry have fully transformed itself into the industry for electric vehicles. Another reason that made the current cluster initiatives for e-bus not as successful as originally intended is the perception of unfairness within the cluster. Many stakeholders still believe that a certain degree of foul play exists inside the formulation of public policy. Unfortunately, there are very few instances that this framework could address this precariousness, aside from maintaining the transparency of the newly established intermediary organisation.

Chapter 7 Organisation and Vision for the Electric Bus Industry

7.1 Supply Chain Revision

7.1.1 Potential Supply Chain for the Industry

In the previous chapter, the stakeholders in the Thai electric bus industry were analysed based on their types. The strategic vision for each of the groups was presented in the section that showed current and target engagement for each stakeholder. In this section, instead of analysing individual stakeholders, the supply chain of the electric bus industry will be analysed based on the flow of physical product in the supply chain. The structure of future supply chain that was predicted by the government is shown in figure 7-1. This diagram presents the supply chain in the electric vehicle industry as a single chain which consist of 8 main activities: energy infrastructure, battery, charging facility, components, assembly, service, asset management, and digital platform. According to Thailand electric vehicle committee, the focus of supply chain development for electric vehicles in Thailand will start with the development of core activities in manufacturing, assembling and service operation (Massamadon, 2020b). As a sub-industry for electric vehicle, the existing policies for the electric bus industry was also adopted in accordance with this plan.

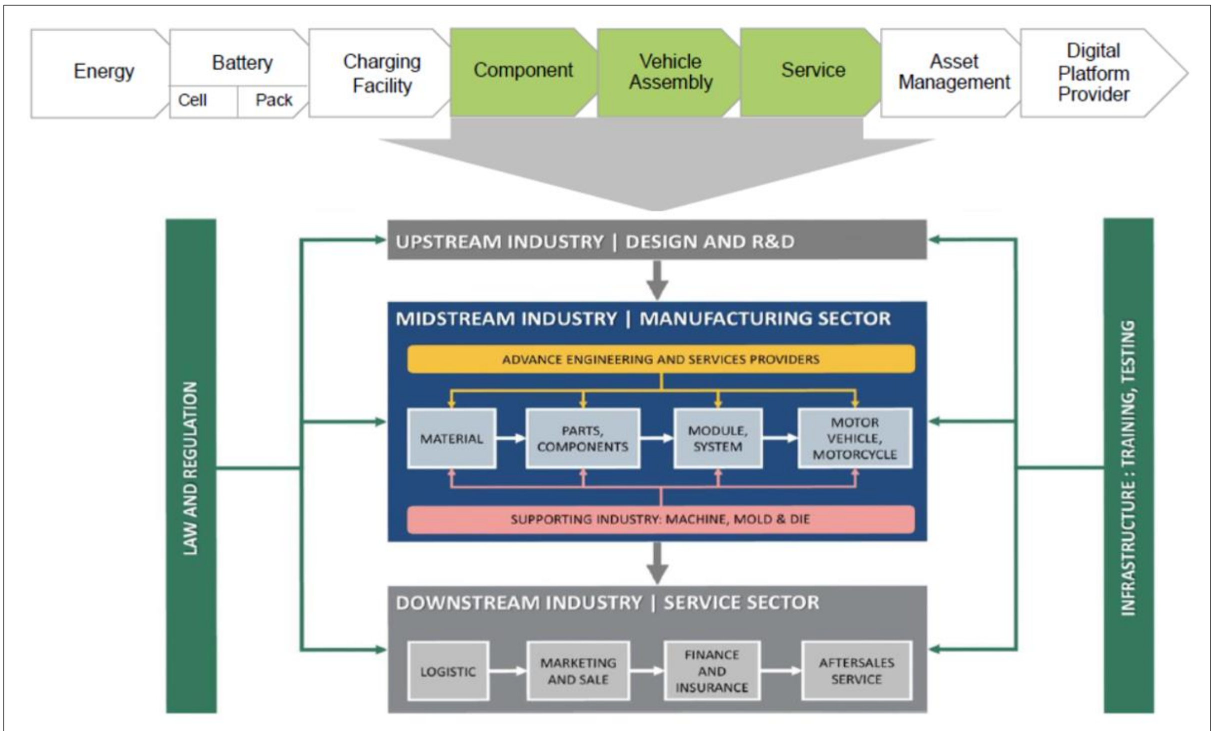

Figure 7-1 Potential supply chain for electric vehicle industry in Thailand
(Source: Thailand Electric Vehicle Committee, Ministry of Energy, 2020)

The first core activities consist of the manufacturing of every major component that are required to assemble an electric bus. However, the battery and energy storage components are excluded from this core activity. They are separated into another group because of the level of significance that EV battery contributes to the total cost of electric vehicles. Consequently, battery research and manufacturing industry also contribute to a large portion of the value chain within the electric vehicle industry. This is especially true for the electric bus since its operation relies on significantly higher amount of battery capacity, due to the greater weight of the vehicles. In addition, it was concluded that the development and manufacturing of electric vehicle batteries in Thailand will be arduous to accomplish (Wanichanukul, 2020). The quality of end products is expected to be at the level that could not compete in the current global market, and the development costs are not economically viable due to the lack of raw materials, enabling technologies, and existing human resources. Thus, Thailand will mainly focus on the manufacturing of other components and the development of e-bus assembly process.

In this specific section of the thesis, the midstream section of the supply chain will be analysed. Upstream section such as the design and research process, and downstream section in the service sector will be momentarily excluded. Nevertheless, they will be explored later in the next section of this chapter. The midstream section of the e-bus supply chain includes the manufacturing process of electric bus components. The manufacturers in the analysis of this chapter included only domestic companies. This exclusivity also extends to the whole chapter i.e., only domestic researchers will be considered in the design of a technology roadmap, and only domestic assemblers and operators will be considered in the formation of business model canvas. However, this circumstance is not applicable for chapter 8, where overseas stakeholders will be considered in the design of public policy implementation scenario. In many cases, certain components will also be manufactured by the assemblers. This is even more frequent in bus manufacturing in comparison to passenger car manufacturing in Thailand since the sales volume is lower and quality control is not as strict as personal vehicles market (Wongdeethai, 2019). Lower costs can be achieved if bus assemblers could manufacture some components on their own instead of outsourcing them via other suppliers.

In this segment, all major components in an electric bus were categorised based on their main system. In addition, they were also allocated in groups according to the current capabilities of bus manufacturing industry in Thailand (Table 7-1). All components are grouped into 4 levels of capabilities for their potential in domestic development. High capabilities refer to a group of components that Thai manufacturers have expertise and are competitive in the global market. Additionally, there are some components that would belong to this group after a minor modification, since their functionality in electric bus is different from the ICE bus. In contrast, some components are considered as having a good potential for domestic production but require a moderate level of research and development process. Next, components that are lacking capabilities are the most difficult to develop. Finally, the last grouping of components is obsolete in electric bus and can be excluded from the supply chain of e-bus manufacturing.

Table 7-1 Potential of major bus components in electric bus supply chain

	Powertrain	Energy Storage	Controller	Electronics	Chassis	Body
High Capabilities					Frame Suspension Handling Tyre	Bumper Seat Mirror Roof Door Accessories
Require Minor Modification				Wiring Lighting	Braking	Air condition
Potential for Development	Inverter	Battery pack	VCU Converter	Devices		
Lacking Capabilities	Electric motor	Battery cell BMS		Charging system		
Obsolete	Engine Cooling system Exhaustion Fuel system Transmission					

Components in the same category of system are noticeably gathering in the same or adjacent level of capabilities. This is because the manufacturing of components in the same system are connected and utilise many similar technologies. Most components in the powertrain system will be obsoleted since the evolution towards electrical driving system will mostly affect the engine components and the powertrain system of electric vehicles is significantly less complicated than ICE vehicles. Components that have potential for development are mostly smaller parts in an electric bus, which require less technological capabilities. Moreover, many of these parts such as converters, use similar principles to be manufactured as their applications in other industries. The chassis and its relating system can be categorised as a high potential group, but not as much as the body parts of a vehicle. Some systems still need additional modification to function with electric powertrain, such as braking system, but the technology requirement is not that high. Body parts manufacturing is the longstanding competence for many manufacturers in the Thai automotive industry (Wanichanukul, 2020). Unfortunately, these types of products will command the least value among other components in e-buses.

7.1.2 The Transition from ICE bus to E-Bus Manufacturing

After the mapping of a potential supply chain, it would be beneficial for policy makers to gather information from the stakeholders to assess their current level of manufacturing capabilities and their predicted position in the new e-bus supply chain. Major changes and important considerations for stakeholders in specific activities within the supply chain are collected (Table 7-2). The discussion will be made regarding the shift towards electric bus supply chain and its implication to other areas of industry, apart from two core activities: components manufacturing and assembly. These two segments would be exclusively discussed later in the next section, which contains information regarding government strategic vision for domestic and foreign parts suppliers and assemblers.

Table 7-2 Major changes and important considerations for electric bus supply chain

Activities	Major changes and important considerations	Stakeholders
Energy Infrastructure	• Small amount of impact, electricity usage is not exceedingly high in e-bus industry. • Electrical spike might be high based on charging behavior, especially in smaller cities. • Initial stage should be closely monitored.	Electricity generation authority of Thailand Metropolitan electricity authority
Battery and Energy Storage	• Battery for vehicles will be of significantly higher capacity and require deep-tech development. • Imports are the most feasible options. • Several producers to choose from.	Overseas producers
Charging Infrastructure	• Small amount of impact, charging will be done in garage by the charger provided by assemblers. • Public charging spot provided by government. • Locations might be provided by gas station firms.	Government start-up Gas station New private venture
Components manufacturing	• Several obsolete components, most of them are in powertrain system. • Not sufficient technology to produce battery. • Decreasing value in body parts and chassis. • Increasing value in electronics and controller.	Small OEMs Assemblers
Electric Bus Assembly	• Conglomeration of multiple enterprises to jointly improve production capabilities. • Likely to be supported and directed by government in the initial stage. • Close collaboration with OEMs.	Sakun C EV Now EVT
Service and Maintenance	• No new business because most services would be provided by manufacturers. • Requirement of more testing facilities.	Manufacturers Assemblers

Asset Management	• New format of schedule for public bus service due to different refueling capacity of e-bus. • Imbursement from the government. • New opportunity for rental agency.	Rental agency BMTA
Digital Platform	• Platform for public bus services. • New ventures for software developer. • Spillover to vehicle's digital platform.	Government Software enterprises

(Source: Summarised from the data collected.)

Energy infrastructure is one of the most important preparations for national-scale adoption of electric vehicles. However, the current power grid and energy plan were expected to be lightly affected by the implementation of electric buses. This is due to the fewer number of buses compared to passenger cars. Additionally, the excess of electricity capacity is reported by The Electricity Generation Authority of Thailand (EGAT). This excess capacity provides additional electricity usage for the charging of electric buses and will not result in the increase of electricity pricing. In fact, the price of electricity will be lower because of the load sharing between users. Nevertheless, this circumstance might change with the rising numbers of electric vehicles that are charging in the same instance.

As mentioned in the previous section, the most feasible option to procure batteries in the electric bus manufacturing industry will be overseas imports. Instead of R&D problems, the main issues for battery acquisition will be the procurement and assembly process. There are several brands of battery manufacturers to choose from. This also depends on the specification of electric buses that will be assembled. Alternatively, battery cells might be imported and packed in Thailand. This option will provide new business opportunity for assemblers and manufacturers because the packing of batteries is not as technological intensive as the manufacture of the battery cell.

The development of charging station infrastructure is also considered to be an essential activity for the adoption of electric vehicles on the national scale. In the electric bus industry, it is not required as much effort as the passenger car industry to designate the new location for vehicle charging stations. There are two main reasons for this assumption. Firstly, electric buses normally operate routinely, which mean they will mostly be charged at rest at the predetermined locations. This is especially true for electric buses in public service. Secondly, charging equipment and facilities will be provided and installed by bus manufacturers, which decreases the workload for the government. Nevertheless, it would be sensible to prepare charging infrastructure for private fleets and other type of electric vehicles.

A similar situation will be presented in the group of service and maintenance activities. A large portion of maintenance services are expected to be delivered on-site by technicians from manufacturing companies. This service model is feasible because of lesser complications in the electric bus system, which is boosted by the development of information technology into electronics platform of e-bus. On the contrary, vehicles standard testing and components testing are short in supply. These activities will be essential if Thailand intends to put a focus on domestic manufacturing of electric buses.

Asset management of stakeholders in the supply chain will be drastically different from before. Manufacturers must deal with new types of components, forcing them to realign their business model. Bus operators must restructure their service plan according to different properties of electric buses, especially the lower active driving range and longer refuelling time (*Opinions of operators on E-Bus compared to ICE-Bus or NGV-Bus*, 2020). Both groups also must put extra efforts to train their workforce in the topics regarding electric bus. Since the high cost of electric bus would incur financial burden to many operators, it will be a good opportunity for new ventures that could mitigate this risk for them. This might give rise to new business models in bus-based transport services.

The last position in this model of a supply chain is occupied by actors who create or manage digital platforms that could be integrated into the electric bus industry. This includes software that can be used in the manufacturing process, service operations, and traffic regulation. The software industry is another industry that was heavily promoted by the government for the last decade (Jones and Pimdee, 2017). With the right business opportunity and proper connection to stakeholders in the electric bus industry, domestic software developers might be able to provide complementary products that would promote the growth of electric vehicles. However, this industry would not be deeply investigated since they're considered to be beyond the intended scope of this thesis.

7.1.3 Supplier's Assessment

In this segment, the supply chain of bus manufacturing was investigated. The scope of this investigation is from the manufacturing of smaller parts that are required for the manufacturing of bus components to the assembly of final product in the form of an electric bus. This part of the supply chain was simplified into 4 levels according to the former value chain in the manufacturing of ICE-bus. The name of stakeholders was put in the table which shows their respective position in the value chain (Figure 7-2). To clarify, finished components in this case refer to independent functional items such as motor, battery cell, steering wheel, etc. While component parts refer to smaller elements that will be assembled into functional components. For example, induction motor's components would include several smaller parts such as frame, rotor, shaft, electrical connections, etc. Major system is a combination of finished components that contribute to vehicle's performance. For example, powertrain system would include motor and electric inverter with the connection to energy generation and storage system. These 4 tiers of manufacturers are ranked by the economic value of their products in descending order from the top to the bottom of a pyramid. The top tier consists of manufacturers with larger size but fewer in numbers, while the bottom tier consists of larger numbers of smaller enterprises.

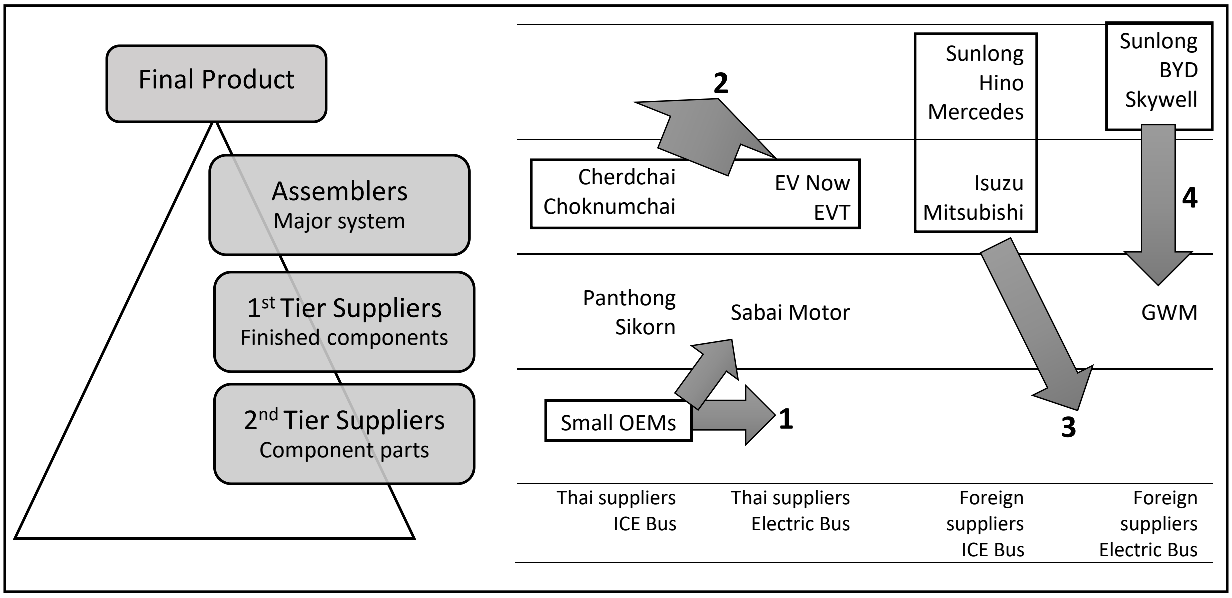

Figure 7-2 Ideal movement of suppliers in electric bus value chain

The large amount of original equipment manufacturers (OEMs) highly contributes to the industrial economy of automotive manufacturing industry in Thailand (Noomwong and Sutheejaruwat, 2019). In the transition towards electric vehicle technology, these OEMs would be unevenly impacted i.e., some components will still be usable while some components will be incompatible in the manufacturing of e-buses. There are two available options for OEMs who produced obsolete components. First, they could start to develop new products that will be applicable in electric bus. Second, they could improve their manufacturing capabilities, so they can move upward in the value chain or diversify their offerings into other applications. Essentially, the supply chain in the new economy of electric bus and electric vehicles might not be in hierarchical structure. The relationship among electric bus suppliers in the future is expected to be more unilateral where several component's manufacturers exist on the same level. This structure should be governed by a single manufacturing platform which deftly allocate manufacturing responsibilities to actors in the supply chain (Wongdeethai, 2019).

The assignment of roles and responsibilities in the supply chain according to different expertise was tested before by the National Science and Technology Development Agency (NSTDA) to develop a converted electric bus from an ICE bus. Research and development projects and funding of major components and system for the electric bus were separately delegated to bus manufacturers in Thailand (Wanichanukul, 2020). For example, low weight material development was assigned to Sakun C, due to their former experience in manufacturing the body of buses from aluminium-based materials. This model could be applied in the first stage of e-bus industrial development to reduce inefficiency and silo problems within the industry. The programme should be designed with the objective of helping bus manufacturers to overcome the lack of individual expertise in the manufacturing of electric bus.

The movement within the bus manufacturing industry that the Thai government has envisioned is the upgrading of Thai domestic assemblers to the top level of the value chain (Massamadon, 2020b). The biggest obstacle for this ambition is the poor customer's perception of Thai brands. From the interview, it can be asserted that most Thai people are more sceptical towards Thai branding of an advance technological products. Since the electric bus is normally categorised into this category, negative reception of the electric bus from domestic buyers was expected by the stakeholders. This issue was also prevalent in ICE-bus industry. Even though the bus was almost completely manufactured by domestic assembler and Thai OEMs, they usually struggle with low sales with the exception when overseas brand was applied to the bus (Cherdchai, 2020). This viewpoint will be a challenge for Thai stakeholders not only in the manufacturing process, but also in marketing activities.

Another action that the Thai government has strived to accomplish is to reduce the influence of foreign manufacturers within the automotive supply chain. As mentioned before, the branding and technological capabilities of foreign companies are currently superior to domestic manufacturers (Laoonual, 2020). This state of the industry has negative effects on bargaining power and market share of Thai suppliers. Ideally, it would be beneficial to Thai manufacturers if foreign enterprises are dropped to lower tier in the value chain. However, this could only be achieved after sufficient manufacturing capabilities are reinforced into domestic manufacturers. After that, foreign enterprises could be positioned into being the suppliers for essential parts that Thai manufacturers could not produce such as battery cells. Moreover, with fewer business opportunities in the supply chain, they could also be convinced to partner with Thai OEMs in the manufacturing of smaller components. This partnership will be favourable to the development of technological capability of many Thai OEMs.

7.2 Technology Roadmapping

7.2.1 Identification of the Technologies

From the analysis of the collected primary data, research prioritisation and integrative national policy were top issues for the operation of an electric bus research and manufacturing cluster. In this section, a research plan for electric bus industry is designed based on the principle of technology roadmap. Technology roadmapping was described as a planning method to match specific short and long term targets with technological solutions (Bray and Garcia, 1997). The road mapping process created by this thesis will consist of 3 phases: Identification of technologies, prioritisation of research, timeline management and summarisation.

The first step in technology roadmapping is to identify all possible technologies that are related to the manufacturing of an electric bus and the operation of electric buses in the service sector (Table

7-3 to Table 7-6). This compilation of technologies was obtained from the data collection process, especially during the conferences and seminars related to the electric vehicles. Since most of these conferences usually have record and documentation in text format. The extraction of information for the identification of technologies were convenient. Additionally, the analysis of other interview data was also used in this technology identification process. The referral of certain technologies that were not mentioned in the conferences were kept and allocated into the pre-exiting categories. The technologies are defined into 4 main categories based on their application within the industry: physical component, vehicle testing, infrastructure, and support technology (CASE technology).

Table 7-3 List of relating technologies for electric bus manufacturing.

Categories	Areas of Expertise	Technologies
Physical component	Powertrain	Electric motor design Electric inverter and controller Overheat protection system Durability improvement Regenerative braking system Engine performance Magnet based technology
	Energy Storage	Battery capacity improvement Battery recycling and waste management Alternatives other than Lithium-based raw material Solar power panel Portable charger Battery manufacturing Battery management system (BMS) Battery packing Charging system
	Electronics	Vehicle control unit (VCU) Electric current converter Interior wiring Electronics appliance e.g., radio Lighting system Air condition system Driver and passengers' interface
	Body and Chassis	Lightweight materials Heat and corrosion resistance Handling system Tyres manufacturing Braking system Mirror outfitting Seating and interior features Suspension system

(Source: Summarised from the data collected.)

Table 7-4 List of relating technologies for electric bus industry in vehicle testing category.

Vehicle Testing	Lab Testing	Vehicle control e.g., handling Safety features Lighting and reflection Flammability Battery related test Mechanical hazard e.g., vibration Chemical hazard e.g., weathering Environmental hazard e.g., temperature
	Field Testing	Autonomous driving Road comfort Charging efficiency

		Driving range Pollution generation Internal and external noise Vehicle performance e.g., acceleration Crash testing

(Source: Summarised from the data collected.)

Table 7-5 List of relating technologies for electric bus industry in infrastructure category.

Infrastructure	Electricity Grid	Monitoring and measurement tools Smart grid and electricity networking Vehicles to grid electricity transfer Public announcement procedure Electric utility policies renewal Electricity capacity and spike management Pricing model development
	Charging Station	Fast charging cable and plug Safety protector Charger controller Charging platform and user's interface Payment system Site assessment Slow charge technology Fast charge technology
	Services and Public Policy	Charging station and garage availability Safety and emergency protocol in manufacturing Personnel training in manufacturing and services Battery swapping model Battery recycling service Electric bus regulation Public awareness of electric bus

(Source: Summarised from the data collected.)

Table 7-6 List of relating support technologies (CASE) for electric bus industry.

Support (CASE)	Connectivity	Wireless charging Monitoring software Traffic control Service platform Connectivity to external system e.g., other vehicles	
	Autonomous	Basic autonomy	Cruise control Emergency brake Lane keeping Parking assist
		Advance autonomy	Highway pilot City pilot Full auto pilot
	Sharing	Low maintenance chassis Maximization of interior space Minimization of vehicles weight Self-cleaning system Interior workstation Rotatable passenger seats	

(Source: Summarised from the data collected.)

For the most part, technology requirements for the manufacturing of electric bus components are straightforward. Primary technological barriers for manufacturers are the production capability i.e., the ability to fully manufacture the required component. Then, the improvement of the manufacturing process should be considered respectively. After obtaining the capability to efficiently manufacture the product, manufacturers could then expand their skill in research and development towards non-essential activities that could improve their production value. There are several paths for technological development in components manufacturing. For example, there are more than a single type of electric motor that is applicable to electric buses. Motor manufacturers could opt for either direct current motor, induction motor, or permanent magnet motor. However, this roadmap will not dive into a detailed explanation in each branching of technologies. Instead, the identification of technologies is kept at the surface level since this roadmap will focus more on industrial development rather than the manufacturing process.

Vehicle Testing is divided into two groups: laboratory testing and field testing. The majority of laboratory testing are sub-level tests where each component or individual system are assessed for their functionality in several criteria such as the application of mechanical force or the exposure to high temperature. In addition, this type of test also includes vehicle test in indoor location. On the other hand, field testing is a practical set of tests developed for an actual test-drive in the outdoor. The details of this second type of test are mostly identical to ICE vehicles, except for the advance autonomous driving system and charging procedure. In contrast, several lab tests for electric bus require newly developed test protocols. This would include the procurement of new testing equipment and establishment of testing facilities. It was reported that testing facilities are in demand for further development of the Thai electric bus industry, and electric vehicles in general (Wongdeethai, 2019).

The development of infrastructure to support the growth of an electric bus industry will be mainly about the generation of electricity and the installation of charging stations. Nonetheless, these features are not as essential to electric bus industry when compared to the effects they would have on the passenger car industry. This is due to smaller market size and lower number of active vehicles on the road. Thus, the minimal threshold for infrastructural preparation will be lower in the electric bus sector. It should be noted that the development in this certain category would require the largest coverage in a collaborative network. Therefore, this feature should be put in consideration of policy makers during the implementation process.

Despite garnering less interest than electric vehicles, technologies for the development of other CASE elements (connected, autonomous, and shared vehicles) are predicted to be substantial factor towards the growth of electric vehicles market in the later stage. The adoption of electric vehicles might mitigate environmental issues, but it provides less benefits in other areas of urban transportation. Autonomous systems are a better solution for road safety issues, the connectivity of vehicles to the information network is more likely to solve traffic congestion issues, and vehicles sharing model will be the most effective method to reduce land usage in urban areas (Adler, Peer and Sinozic, 2019). Hence, the complete development of CASE technologies will provide a more complete solution for urban transportation than the exclusive development of electric vehicle industry. All these elements are categorised into the last group despite its large technological scope, because of its status as an optional development beyond the realm of electric bus industry.

7.2.2 Prioritisation of Research

Technological progress is a cornerstone of the development of uncharted section within any industry. Similarly, the development of electric bus industry in Thailand would rely on the progress of research and development to a certain degree, depending on the direction of the national research policy. However, since both time and financial capital are limited, the logical step for setting up an effective plan for industrial research is to prioritise technologies based on their benefits that they might contribute to the whole industry. The second step in the design of technology roadmap incorporates this principle by attempting to prioritise the identified technologies into a single analytical matrix. This matrix consists of two parameters: cost and importance. Cost represents the expected research costs to complete the development of a specific technology. This primarily includes monetary and time costs. Hence, the research that are lower in cost parameter should be set to a higher priority. In contrast, the importance of research represents the level of expected positive impact this technology would have towards the industry. Thus, research with high importance should also be set to a high priority. With these two criteria, all of technologies in electric bus industry are plotted into the matrix to illustrate their approximate priority (Figure 7-3).

The limitation of this part of the study is that there is no certain way to systematically compute the two parameters; cost and importance unless a large-scale quantitative survey was conducted. In addition, the accuracy of the quantitative survey results may not be improved by undertaking a larger survey given the calibre and knowledge of those who participated in the original survey. The participants for the survey should be at least required to have an adequate level of knowledge regarding technologies in EV's manufacturing especially e-buses. Such knowledge and insight in such a sector would not be commonly known by most of the Thai population. This alternative research design would overcomplicate the sampling process that could result in a subpar outcome. Hence, this segment and the subsequent formulated technologies roadmap was designed to be a speculative model based on the interview data with the limited number of interviewees who were currently involved in the development of EV and E-bus research and manufacturing cluster in Thailand. Nevertheless, the frequency of the similar themes within the interview responses is partially applicable in the process of plotting the cost and importance matrix for each identified technology.

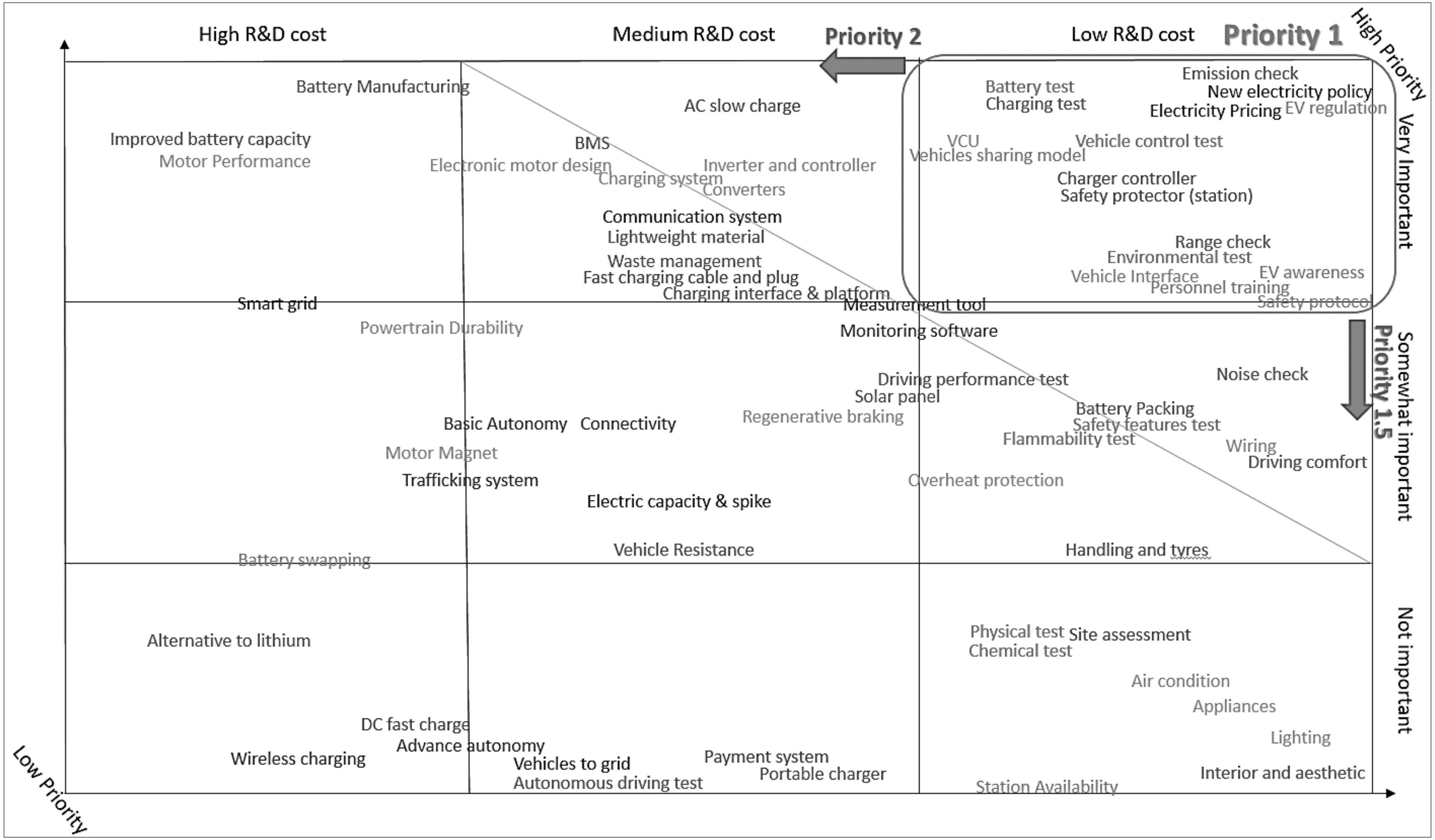

Figure 7-3 Prioritisation of research in electric bus related technologies

(Source: Summarised from the data collected.)

According to figure 7-3, the top-right corner of the matrix consists of the technologies that are relatively low cost and very important to be developed. Hence, the group of technologies in this section are labelled as "priority 1", which mean that they should be among the first choice for the development. If these technologies are individually identified by the categorisation in the previous section, it can be observed that most of them are from the category of additional services and public policy. In addition, field testing and some small-scale lab test also appear in this quadrant. Public awareness policy such as regulation for electric buses can be a low cost to implement and has a potential to generate impactful outcomes because the current level of knowledge in electric vehicles is very low among Thai population (Laoonual, 2020). Most field testing can be shared with the pre-existing location for ICE vehicles, so the cost will not be a large problem.

For bus components, vehicle control unit (VCU) and electronic interface are among the top priority technologies. Electronic interface is a branch of bus components that several domestic manufacturers can handle since there are already some producers who have manufactured these parts for a newer model of an ICE car. Since vehicle control unit is essentially a computer hardware; the industry in which Thailand is very capable (Tan and Leewongcharoen, 2005), the development of VCUs in Thailand is very viable. However, this development requires the condition of having hardware manufacturers fully collaborate with the assemblers who are the model owner of electric bus, which still does not yet exist in Thailand. Alternatively, a joint project between Thai hardware manufacturers and overseas assemblers would be more difficult to arrange.

"Priority 1.5" and "Priority 2" would be the medium to long term target for electric bus research in Thailand. Technologies from the former group are conceived to be more important than the latter group, but also costlier to develop. The order of these two groups of technologies could be swapped, depending on the strategic targets of policy makers. If the situation is more budget-constrained, they might consider pursuing cheaper but less impactful technologies. In this situation, high-cost technologies usually consist of the research in the field that Thailand currently possess low or no capabilities, such as energy storage and powertrain system. This group also include many technologies related to charging infrastructure. In contrast, low-cost grouping of technologies consists of the research and development in bus components in which Thailand already possess sufficient skill in the manufacturing process.

By using this priority matrix as the guideline, policy makers could immediately review the cost and importance of each technology against each other. This diagram would be most useful in its dynamic state where the position of technologies is shifted in accordance with transformation of industrial and technological environment. Additional prioritisation beyond the assessment in this section is also possible. However, they are not designated in this specific case because the assignment of research in priorities 1 and 2 would be ample to cover the design of long-term technology roadmap for the electric bus industry in Thailand that would be presented in the next section.

7.2.3 Technology Roadmapping for Electric Bus Research

A summary of technologies prioritisation is made in the format of technology roadmap that spanned 20 years (Figure 7-4). This roadmap is separated into three continuous phases: short-term plan, mid-term plan, and long-term plan, in accordance to the national agenda to promote the adoption of electric vehicles in Thailand (Massamadon *et al.*, 2020). This national agenda was put together by the electric vehicles committee of Thailand. Its timeline was adjusted in accordance to the public policies regarding the adoption of EVs from other countries around the world. A short-term plan has a period of 3 years from 2021 to 2023, a mid-term plan is for 2024-2030, and a long-term plan will be in 2031-2040. Essentially, technologies in "Priority 1" from the last section are put into short and mid-term plan, and the rest of technologies upward to "Priority 2" are placed in late mid-term to long-term plan. Another important feature of this roadmap is the linkage between industry drivers and the choice in technological development. All technologies in this roadmap could be positioned differently in the timeline, according to primary national objective which translate into the corresponding industry drivers. Furthermore, there would be some overlapping technologies that could be transferred from electric bus to electric vehicle industry. Hence, it might be preferable to prioritise those technologies first, to maximize growth opportunity in Thailand electric vehicle industry. Finally, this roadmap could be further modified by expanding the long-term plan and allocating additional technologies from the last section into the roadmap based on their estimated priority.

In the short-term plan, the initiation of electric bus services within the vicinity of Bangkok and other urban areas would be the main policy agenda. It is essential to set precise targets such as the number of bus routes or the number of public-owned electric buses. During these periods, the focus would be the development of policy research and planning e.g., preparation of the electricity grid and electricity pricing models, the adoption of updated traffic regulations that consider the integration of e-buses, etc. For industry side, the development of testing facilities is recommended over the development of electric bus components. The market for electric buses might take more time to be sufficiently developed and would require a lower pricing point which would largely depend on technological progress of battery manufacturing (Laoonual, 2020). Therefore, it might be more appropriate to develop a smaller component such as vehicle control unit (VCU) before investing into more expensive technological options. The preparation of vehicle's road test programme will be a worthwhile investment, granted that the government has clear procurement targets for the adoption of electric buses as public transports in urban areas. Moreover, smaller components testing could be a new type of venture that domestic manufacturers can position themselves in the global supply chain.

According to this roadmap, public bus transportation in Bangkok is planned to be completely consist of electric buses within 10 years. In addition, the usage of private electric buses would be encouraged or even enforced by the law. Public awareness for electric vehicles must be improved for this vision to become successful. This was to reduce the resistance of possible traffic regulations and enforcement which are expected to be more skewed towards the usage of EVs and e-buses. The larger amount of research tasks will be assigned to researchers and manufacturers in Thailand to support this future growth of an EV market. Thai manufacturers are expected to be able to produce more components that would be in the global electric bus supply chain. The top choice would be electric inverter and controller of the motor (Wanichanukul, 2020). Additionally, testing facilities need to be expanded to cover the expansion of electric vehicles. Within 10 years, Thailand should have sufficient facilities to accommodate the complete standard testing for electric buses. This would include both components test and field test in several areas to reduce the chance of breakdown in public service vehicles.

The focal point for this roadmap is to bridge the gaps and facilitate the start-up process in the electric bus research and manufacturing cluster rather than to support the growth of an electric bus market. As a result, there are fewer details for long-term technological development in this specific roadmap i.e., upward to 20 years. These details could be easily included by utilising prioritisation matrix in the last section. However, there are multiple moving technological factors that could compromise a static and long-running technology roadmap. The roadmap could be invalidated and cease to be relevant. Hence, a long-term technology development plan might be less accurate than a short and mid-term plan in this case. The suggestion for manufacturers is to continuously improve existing capabilities of bus design and manufacturing process for driving performance and comforts. Moreover, Long-term education policies should be made for future Thai workforce, to match this transition in the industry. Nevertheless, new potential development such as battery packing industry should also be considered to sustain the value of domestic industry. It was asserted by several interviewees that governance in public policy and regulation would be extremely important to the progress and long-term sustenance of electric vehicle industry in Thailand (Cherdchai, 2020;Thuntiwiroon, 2020). This technology roadmap might not be adequate for a comprehensive policy plan that is supposed to represent the overall picture of the industrial development. Therefore, the next two sections in this chapter were designed to provide more information on the intermediate and the downstream portions within the supply chain of electric bus industry.

Table 7-7 Examples of interview quotes relating to the designing of technology roadmap.

Participant	Theme	Quotes
PS	The importance of BMS and VCU to the manufacturing of e-bus.	“We lack necessary expertise on electric vehicles. No knowledge on battery management system (BMS), which is a major part of electric vehicles. Vehicle control unit (VCU) is also important, yet we don’t have this kind of knowledge.”
NN	EV is the priority before the development of other C.A.S.E. technologies in next-generation vehicles.	“EV is the platform for next-generation vehicles. Because fossil fuel vehicles create a lot of pollution to the environment, many countries adopt strategies to reduce them. So, the main driver for EV industry are environment and energy, and EV is the development platform for autonomous vehicles and shared-service vehicles.”
PS	The high cost to develop battery technology.	“Battery for large vehicles would be substantially more expensive because they require high power. Department of excise charge high percentage for battery as well.”
SW	The importance of the provision of testing facilities and procedures.	“They only manufacture bus at the minimum requirement of vehicles declared by Department of land transport. That’s why we could help them to increase their standard by providing extra testing procedure for e-bus in both manufacturing process and manufactured components..”
SC	Comment that battery should not be the main priority to be domestically developed.	“For electric bus, most of the cost is in the battery. However, it is mostly material cost rather than engineering cost like chassis. My expectation is that in the future, EV battery would mostly come from the producers who could cheaply acquire raw materials.”
SW	Value, service infrastructure, and confidence are listed as the three primary issues for e-bus adoption.	“Firstly, the initial cost of EVs. For bus operators, there would look at the value in purchasing e-bus. Secondly, the availability of service and maintenance of buses. Thirdly, it would be about confidence in EVs, which could be related to the building of safety standard regulation and public awareness and knowledge on how to properly drive and maintain EVs.”

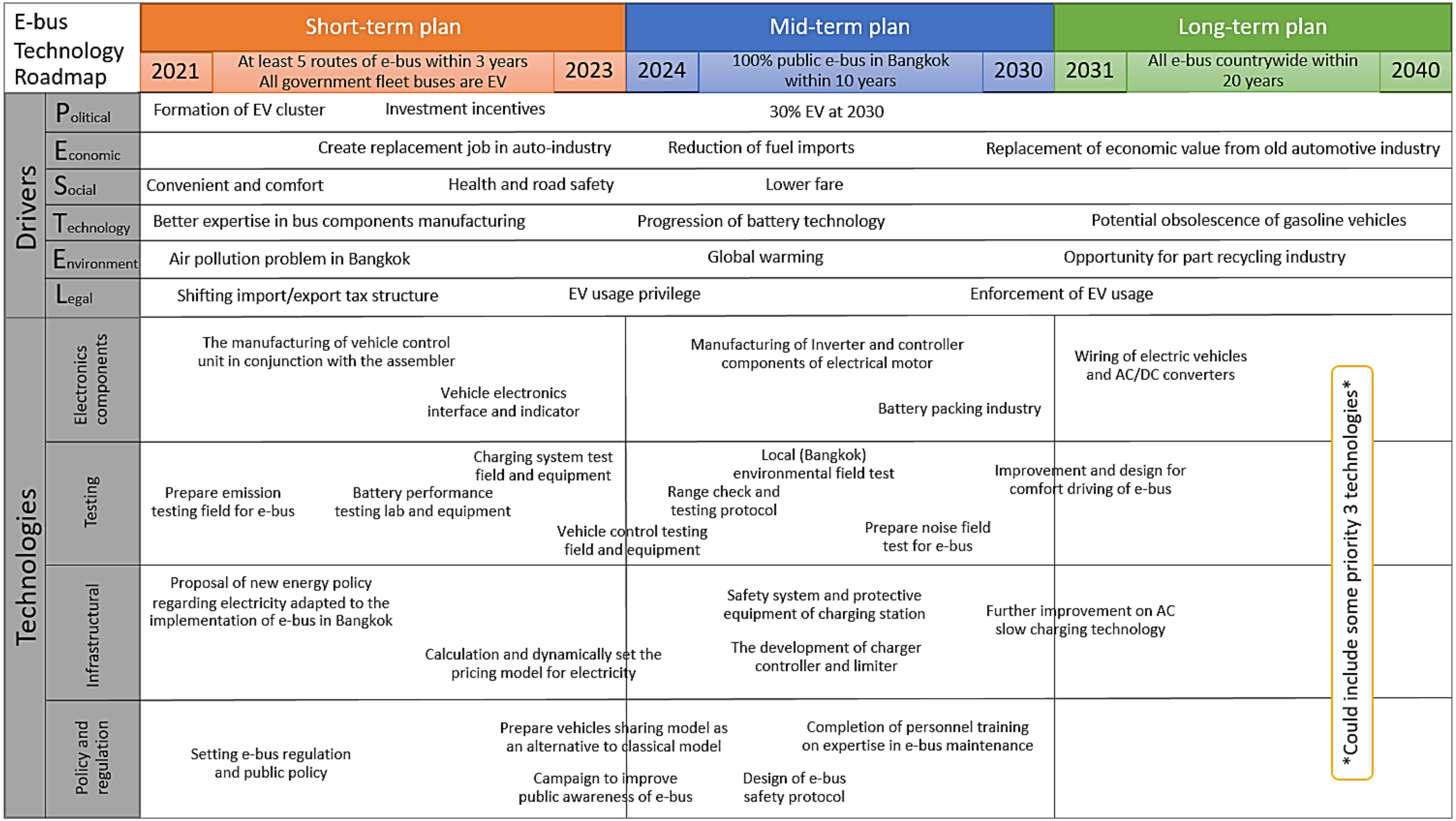

Figure 7-4 Technology Roadmap for electric bus industry in Thailand

7.3 Business Model Canvas

7.3.1 The Conceptualisation of Business Model Canvas

Planning tools for the upstream portion of the supply chain such as the technology roadmap could be accurately created from a verified set of primary data from the researchers within the industry. On the contrary, market demand for electric buses is more volatile and unpredictable than the development of prospective technology capabilities. As a result, a planning tool for the downstream portion of the supply chain would be considerably more difficult to design. From the analysis of primary data, it was concluded that many stakeholders have significant apprehension in the feasibility of electric buses for their business model. This included both the manufacturers and the operators. This section is included as a guideline for stakeholders during the initiation period of their operation to alleviate their business concerns. However, it should be noted that these models are significantly less precise and more susceptible to changes than the other sections in this thesis.

The business model canvas (BMC) is the visual chart that is used to develop a new business model or document existing models of the enterprise (Osterwalder, 2010). In this section of the thesis, it was used to illustrate potential market elements for organisations within three different sectors which are involved in the electric bus industry: national policy, manufacturing, and transport services. There are 9 components in this format of the business model canvas. Their titles and descriptions are explained in the following list.

- *Key Partners*: Suppliers and partners are necessary for efficient organisations. The activities that generate less value should be outsourced to these parties.
- *Key Activities*: Important activities that the organisation is required to do to maintain their operation. They should be directly related to value proposition of the organisation.
- *Key Resources*: Assets to an organisation that are required for its operation. These resources can be financial, human, or physical resources.
- *Value Propositions*: Important elements in the organisation's products and services that would distinguish themselves from competitor's offering.
- *Customer Relationship*: Strategies to maintain business contact with customers. The profiling and management of customers would improve the success rate of business model.
- *Distribution Channels*: The delivery options to distribute products or services to the customer. They should be cost-effective and quick to execute.
- *Customer Segments*: The segmentation of potential customer base. Different group of customers might have different types of preferences and requirements.
- *Cost Structure*: Different sources of costs that would be incurred by the operation of this model.
- *Revenue Streams*: The strategy and method to generate income for the organisation.

This application of business model canvas is a variation that present the details regarding business in a different manner from the original purpose of the model. Firstly, the first model that will be presented in this section is not a canvas for business enterprise. Instead, it was created with a purpose to capture important considerations surrounding the electric bus market through the lens of policy makers. The coverage for this canvas is from e-bus research until the provision of an e-bus in public service sector and treats the e-bus as a form of product that will be delivered to the public. In contrast, the other two canvas are created for business-oriented stakeholders. Nevertheless, they also differ from a traditional business model that is usually designed for private enterprises. Information scale in these two canvases is in broader categorisation, and not aimed towards any single stakeholder. Instead, they are aimed towards the whole sector of the e-bus industry by providing a range of options that are relevant to their business model rather than funnelling several options into a specific business direction. For example, the value proposition in the original format of BMC for a certain manufacturer might be a negotiable price, but it was simply described as the pricing model in this canvas. In summary, BMC in this framework is a less specific proposition for a certain company, but rather a sandbox guideline that any stakeholders within a specific sector could utilise to improve their business model. The information presented in these business model canvas in the following section was designed by utilising analysed interview data in appendix B: dataset 7 which are the re-theming of interview responses from stakeholders regarding their views on several topics that they deemed vital in each component of the canvas. The example of applicable interview quotes is presented in table 7-8.

Table 7-8 Examples of interview quotes regarding the business model in the Thai electric bus industry

Participant	Theme	Quotes
PS	Government BMC – Maintenance and creation of jobs in the automotive industry.	"The country needs to provide new jobs that provide better income for its population. On the other hands, the countries that became the new manufacturing hub must absorb the knowledge and capabilities of the process to upgrade their domestic labor's skill and develop their own products."
AJ	Government BMC – The usage of policy framework to guide stakeholders.	"We always investigate to find bottleneck of the process and think of how to smoothen that specific area. We made a database of researchers and experts. We made a decision tree for stakeholders to guide them through the process."
SC	Manufacturer BMC – The importance of battery and motor suppliers.	"There are only 2-3 components left that we won't manufacture for sure. Those are electrical motor which normally includes inverter, battery which normally includes BMS."
TW	Manufacturer BMC – Indication of high investment for new entrants.	"Our food sector is easier to develop because the investment amount is substantially smaller. The fixed-cost for start up the manufacturing line is high, so sales volumn need to be big to cover the cost."
O1	Operator BMC – The requirement of different and diverse leasing/selling plan.	"We don't want to procure a big lot of electric buses, instead we plan to gradually convert our buses into the new one over time."
PS	Operator BMC – The value of services that passengers are looking for.	"For some public transportation, saving time is their main value proposition to the customers. Thus, their focus would be only on service availability, not on maintenance or comfortability."

7.3.2 Government Canvas

The first business model canvas is designed by using the government as a proxy enterprise with an electric bus industry as its main product offering to Thai citizens and automotive industry. The information that are presented in this section have a focus on industrial drivers for the development of an electric bus manufacturing cluster from multiple points of view, from both industry stakeholders and normal citizens. It serves a similar purpose to the first section of this thesis, albeit in a wider scope by not solely putting emphasis on the government. Therefore, the market mechanisms of the whole supply chain are expected to be investigated along with the creation of this BMC (Figure 7-5).

The main benefit that the electric buses would bring to Thai citizens is the improvement in public welfare. These positive effects are expected to be stronger in the crowded urban areas where the pollution level is high. It was predicted that people will be content with the change towards electric bus because of the higher service quality compared to the current format of public bus services ('The emission of diesel vehicles and PM2.5', 2020). However, it was also predicted that the higher fare of electric bus will not be welcomed by the public (*Opinions of operators on E-Bus compared to ICE-Bus or NGV-Bus*, 2020). Therefore, the government and bus operators should design a sustainable pricing model for the services. The transactional cost is expected to be high for the government and the stakeholders, especially during the initial development phase. This would likely make the pricing of public services less affordable for population with lower income. This problem also relates to several other factors outside the bus industry itself. For instance, it would be difficult to completely bypass the issues of social inequality and income gap that could affect the number of passengers on e-buses. As a result, electric buses are likely to be considered as a complementary service that would have positive effects on other sectors such as tourism and logistics, rather than providing the government with direct financial gains.

On the supply side, electric buses would be a risky proposition for stakeholders, considering that the technology trajectory for electric vehicles is not yet stabilised. There are many competing technological alternatives for a cleaner public transport. Nevertheless, due to the sheer size of Thailand's automotive industry, the wait for the movement in the global market might not be the best solution because the whole industry would take a long time to adapt towards the new economy. On the other hand, the current domestic production capacity could be utilised in a format of a regional manufacturing hub for part manufacturing or vehicle assembly for the export activities to other countries. These export activities might be essential during the first stage of the industry growth since there is not sufficient demand in the domestic market. As mentioned in the previous chapter, the cultivation of demand will be substantial to the initial stage of an electric bus manufacturing industry. Without an adequate amount of orders for bus assemblers, their projected income would not be at the break-even point with their production cost. This circumstance would discourage a domestic bus manufacturing business. Potential overseas exports of e-buses could bring additional demand to the industry. Neighbouring countries such as Indonesia or Vietnam are considerably larger markets with a lot of potential that Thai manufacturers could utilise to improve their manufacturing efficiency.

Key Partners

NSTDA – Organization of researches
- E-bus conversion program
- Battery & motor research
- Lightweight material
- Chassis and suspension
- Charging technology

NXPO – Policy and collaboration
- Parts suppliers contact
- Collaboration of Ministries
- Activation plan
- Design incentives package

Universities – Research and development
- Spec testing research
- Market research
- EV components research
- Electronics & software

Private Enterprise – Manufacturing and workforce
- Workforce Training
- Business plan
- Transition plan

Key Activities

Battery and motor
- Create alternatives or scenarios for acquiring

Other components
- Manufacturers assignment and market segmentation

Policy readiness
- More public reinforcement
- Encourage communication and exchange within cluster

Key Resources

Battery and Motor
- Little to no capabilities
- Agreeable pricing of Chinese product's import

Other components
- Excellence production capacity and readiness

Policy readiness
- Good progress but little awareness and coordination

Value Propositions

Commuter
- Reduction of travelling cost
- Convenience
- Adequate services
- Passengers comfort
- Better work condition
- Alleviate traffic congestion

Pedestrian
- Reduce emission
- Reduce noise pollution
- Increase road safety
- Positive impact on health
- Reduction of air pollution

Auto Industry
- Creation of jobs
- Lower fuel cost
- Add value to supply chain

Others
- Boost tourism
- Increase carbon credit
- Improve city image

Customer Relationships

Population
- Total acceptance if e-bus performance and reliability is proven to be similar

Private operator
- Consist of largest market share but would be difficult to convince

Private fleet
- More willing to purchase
- less costly to incentivize

Channels

Public bus line
- High volume, require total agreement and imbursement

Public fleet
- Low volume, first segment

Private bus line
- Industry maturity

Private fleet
- Good potential for growth, but cost need to be justified

Customer Segments

Population
- Pedestrian
- Passenger
- Driver
- Commuter
- Operator

Auto Industry
- Parts manufacturer
- Assembler
- Body-maker
- Importer
- Exporter
- Distributor

Country
- Finance
- Tourism
- Environment
- Labor
- Transportation
- Industry
- Research and innovation

Cost Structure

Research, development and testing
- Research: low, considering our normal research output
- Development: very high for areas with low expertise
- Testing: high one-time fixed cost with some maintenance

Components manufacturing
- Battery and motor: 60-70% of total cost
- Body, chassis, and electronics: lower cost with the current expertise

Electric and charging infrastructure
- Incremental to the growth of industry

Policy support
- Investment and usage incentives has the potential to be high cost activities

Revenue Streams

E-bus components and E-bus
- Non-profitable in short term but could have potential in the future especially with exports

Digital and support software or platform
- Good profit potential in accordance to EV industry growth

Bus service
- Negligible, mainly provided as the improved public service for citizen
- Low financial gains, but provide reduction in cost for other industry such as transportation and long-term sustainability
- Benefits for other areas such as citizen welfare, environment, tourism, etc.

Figure 7-5 Business model canvas for the government: Thailand electric bus industry
(Source: Adapted from Osterwalder, 2010)

7.3.3 Assemblers and Manufacturers Canvas

The second business model canvas is designed for assemblers and manufacturers in the Thai electric bus industry (Figure 7-6). It is expected that several motivating factors for business in electric bus and e-bus component's manufacturing could be extracted from this BMC. These factors might be pivotal to investment decisions in electric buses for this group of stakeholders. The existence of these factors would also reduce the chance of interruption in an existing business model for the manufacturing and sales of electric buses. The detailed business view of this industry provided in this BMC is purposefully made to encourage more enterprises to attain some confidence for the investment in electric bus production.

As mentioned in the previous section, only domestic demand for electric buses might be insufficient for an efficient production in the manufacturing process. As a result, manufacturers might need to put in additional marketing efforts to increase electric bus sales in the wider regional market. They will need a more convincing value proposition for potential users to purchase their product. Additionally, current customer perception for an alternative energy source for buses among bus operators in Thailand is not very positive. The previous type of energy that was strongly promoted by the government was the natural gas for natural gas vehicles (NGVs). The NGV-bus is regarded as a disappointing product by several bus operators. They pointed out that the reduction of fuel costs for them are negligible despite the benefit of cost-saving was being heavily advertised by the government (*Opinions of operators on E-Bus compared to ICE-Bus or NGV-Bus*, 2020). When the customer base among private operators is being overly cautious, the most probable option for the initial stage of market diffusion would be public-owned vehicles. Since the government is adamant on solving the problem regarding urban air pollution, they are expected to adopt procurement policies for new electric buses. The largest target market should be orders from public bus services in Bangkok that are regulated by the Bangkok Mass Transit Authority (BMTA), which periodically procures a considerable number of new buses in replacement of old buses that must be retired. After the widespread uses of electric buses in the public sector, additional private enterprises might be more confident towards the usability and economic feasibility of electric buses.

To sell electric buses to private buyers, manufacturers need to be more concerned about their value proposition. From the interviews with private operators, it seemed that their purchasing decision will be heavily influenced by the reduction in maintenance and fuel costs. For both two criteria, electric buses almost guarantee a less frequent breakdown and fuel cost in comparison to ICE bus (Suebsupanand, 2020). However, a single unit of an electric bus is currently priced at upward of two-times the price of an ICE or NGV bus. Even with lower maintenance and fuel costs, many operators concluded that they could not make a profit from an electric bus due to their high selling price (*Opinions of operators on E-Bus compared to ICE-Bus or NGV-Bus*, 2020). This high unit price for an electric bus is mainly contributed by the high price of battery. The acquisition strategy of battery and motor will be the key success factor in the business model of any manufacturers since the whole supply chain for electric bus manufacturing is highly driven by costs. Batteries and motors alone would constitute approximately 60-70% of the vehicle's total value. Any manufacturer who acquires the expertise to manufacture these components would gain a tremendous competitive advantage in the market. This situation coupled with the market environment in Thailand that has a surplus of potential suppliers also raises the barrier to entry for new entrants in the manufacturing business of e-bus components.

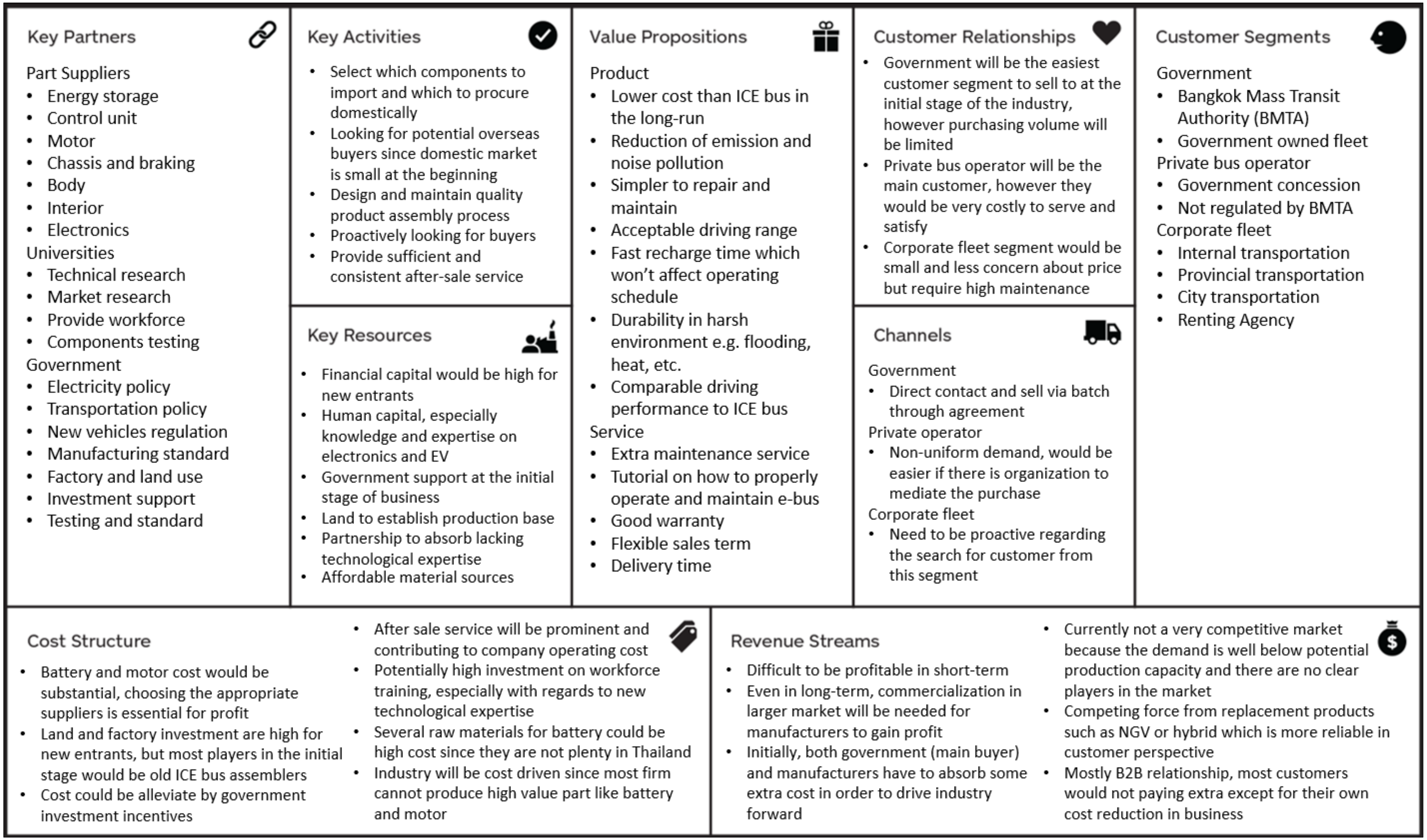

Figure 7-6 Business model canvas for the manufacturers: Electric bus manufacturing and sales
(Source: Adapted from Osterwalder, 2010)

7.3.4 Bus Operators Canvas

The third business model canvas illustrates business opportunities and business features for electric bus operators in the transportation sector (Figure 7-7). The purpose of this diagram is the same as the previous part. It was made as a guideline for the current and potential stakeholders in the transport service sector. There are still a lot of doubt regarding the profitability of an electric bus operational model among bus operators, especially private enterprises. By providing a thorough market information via this canvas, the operators will be aware of several implications surrounding the electric bus industry and could hasten their decision-making process. Even though there is a chance for the rejection of the model for electric bus services from multiple bus operators, the rapid and informed decisions by several stakeholders would still benefit the policy-making process within the e-bus industry.

There are three segments of operators that are expected to be in the supply chain. The first segment is routine public transport service, which would be the majority of bus operators in Thailand. The second segment is taxi fleets which provide the transport service in a provisional format. Potentially, there might be a third segment of electric bus leasers. These leasers might exist because of the high pricing of electric buses which could limit the willingness to purchase e-buses among private operators. Bus leasing might be a new type of venture that could foster the growth of the electric bus industry in the initial stage since it would mitigate some financial constraint in the service operators. For existing private operators that provide services with ICE bus in the past, the acquisition of electric buses must be in concert with the turnover of their old buses (Sintavacheeva, 2020). This practise is essential to the maintenance of economic efficiency within the enterprise. Unfortunately, an e-bus service business might not be profitable at this stage because the price of electric buses is still too high for the current pricing model of the service. The change in pricing model of bus services need to be made for both public and private operators. Alternatively, the Thai government could compensate the stakeholders with initial funding to support the growth of this business.

The pricing model is expected to be difficult to alter since buses are normally considered as a fundamental mode of public transport in Bangkok. The fares for bus services are relatively cheap, which incurs heavy financial losses for the BMTA each year (Laoonual, 2020). Charging for higher fares for electric bus is possible, but only when they are treated as an additional segment to the normal bus service. The preservation of the ICE bus might be mandatory in the initial stages of e-bus adoption to provide Bangkok's population with varying levels of service fares. The services of electric bus should be of higher quality to justify their price. This situation requires a major overhaul of the public transportation system in Bangkok that could possibly take several years. Nevertheless, it will be a necessary preparation if Thailand intends to fully adopt electric buses for public transportation services. The pricing of electric buses is found to be the main driver for the purchasing decision of operators, thus the events in field-testing and demonstration of electric buses should be able to cultivate the demand for e-buses. It is also a good opportunity for new parties beyond the existing bus operators to design a novel business model based on the operation of the electric bus. These parties will have less inertia in doing business because they don't have any concerns regarding inventory of old ICE buses, unlike the former bus operators. However, they also need extra work in terms of operation scheduling, communication with government agencies, and customer segmentation.

Key Partners

Manufacturers
- Provide information
- Pricing strategy
- Distribution channel
- Sales promotion
- Product development
- Inventory management
- Testing events

Service Garage
- Repair and maintenance
- Labor training
- Knowledge exchange
- E-bus conversion
- Parts recycling
- Scheduling

Government
- Manage concession (BMTA)
- Public relation
- Provide knowledge
- Coordination
- Create incentive schemes
- Investment support
- Policy and regulation

Key Activities
- Actively comparing choices and alternatives of e-bus
- Develop services or sales support digital platform
- Maintain constant communication with partners
- Bargain for more incentives or discount to reduce financial risk
- Create multiple leasing schemes / clear operating schedule in accordance to e-bus characteristics
- Workforce training

Key Resources
- Financial capital for both e-bus purchase and employee's wages
- General knowledge and expertise on electric buses
- Human capital for services business
- Connection with manufacturers
- Garage and transport hub
- Efficient charging system
- Management and scheduling
- Communication with BMTA
- Sufficient service staff

Value Propositions

Transport service
- Reliability
- Comfort
- Timely
- Cheap
- Low pollution
- Clear schedule
- Communication
- Sufficient volume

Taxis fleet
- Reliability
- Comfort
- Cheap
- Communication
- Promotion
- Luxury add-on
- Good driver

Bus leasing
- Flexible selling schemes
- After sales service
- Low risk to customers
- Product variety
- Lower price in bulk
- Acceptable warranty

Customer Relationships
- Public opinions on bus services have been largely negative, e-bus might reverse this with superior services.
- There would be stronger competition from substitute products since perceive benefits of e-bus would be lower compare to alternatives in this segment
- Bus leasing business might not be feasible in long-run when e-bus cost is lower which enable operators to easily procure the product

Channels

Individual passengers
- Require good scheduling and effective public communication from the government (BMTA)

Group passengers
- Intensive marketing communication, especially on social media platforms

Operators
- Government could mediate the initial stage of market diffusion since majority of customers would be related to government

Customer Segments

Individual passengers
- Elders
- Monk
- Children
- Normal people
- Low income

Group passengers
- Corporation
- Government
- Family
- Other organization

Operators
- Lease (more than 1 year)
- Lease with maintenance
- Rental
- For sale

Cost Structure
- Fixed cost from vehicle purchase is the main concern for operators since the reduction of operating cost and reliability of e-buses are not yet proven
- This risk aversion behavior leads to opportunities of the new venture based around shared vehicles or leasing model of e-buses which help mitigate risk for operators
- For bus leasing business, there will be large land cost for establishing garages or hubs
- Most operators already have their own bus hub and garage, so there won't be additional cost except the installation of charging station
- Might have to outsource the design of digital platform to aid their communication with partners and customers
- Requirement of extra workforce training in e-buses knowledge might incurred minor cost

Revenue Streams

Bus leasing
- Require flexible leasing or selling plan since purchasing power of operators would be different based on their number of buses
- Should keep the price competitive and monitoring on shifting strategy of bus manufacturers in order to maintain the profit from bulk purchase and sales volume

Operators
- Fleet rental would be more likely to meet with strong competition. As a result, revenue might not be able to cover the cost in short-run, except that there would be discounts provided by the government to promote E-bus industrial growth.
- Individual passengers should be willing to pay an extra for superior services, however the price spread should not be too much

Figure 7-7 Business model canvas for the service operators: Public transport service via electric buses
(Source: Adapted from Osterwalder, 2010)

7.4 Intermediary Organisation

7.4.1 Concept and Creation

From the amount of policy planning that was suggested in the previous sections of this chapter, there will be a heavy workload for those who will be responsible for the implementation of this set of public policies. To maintain good governance and control on the policy implementation process, it might be prudent to assign policy tasks encompassing the development of the electric bus research and manufacturing cluster to a newly formed intermediary organisation. This intermediary, however, need to have a certain degree of self-organisation and internal control to minimise the level of bureaucracy in the process of policy implementation. Food Innopolis is a well-established example of self-sustainable public organisation that could act independently to the larger portion of the Thai government (Jangbua, 2019). This section contains the discussion regarding the possible formation of this intermediary organisation within the electric bus cluster. The first topic will be the rationality and justification behind the creation of an intermediary within the cluster. Then, the characteristics of possible candidates who should be assigned as the intermediary will be discussed. After that, the positioning of the intermediary within the potential supply chain of the electric bus industry will be illustrated. This will be made simultaneously with the positioning of the intermediary along the timeline within the technology roadmap that was designed in the previous section. Finally, the last part of this chapter will be a discussion about the envisioned responsibilities and the example of mechanisms that could be utilised in their operation.

The expected amount of workload is not the only reason for the creation of an intermediary organisation within the cluster. There are many other logical reasonings behind this idea. One of the major topics is the concern of unfairness within the adopted policies among different groups of stakeholders. This concern could stem from different motivations behind their participation in the cluster. Therefore, it is mandatory that the party that would be assigned as the intermediary acts with significant degree of fairness, transparency, and impartiality. This characteristic would assist the assignments of responsibilities according to policy programmes to the stakeholders. If these tasks are assigned based on stakeholders' expertise, budget, and willingness, there would be less disagreement within the cluster. Moreover, the intermediary can also serve as a liaison and negotiator between each stakeholder, in the case that a conflict of interest cannot be avoided. This responsibility would facilitate collaborative networks within the industry and prevent the slow-down of the development.

Another main reason for the existence of an intermediary organisation is the facilitation of activities within the cluster. As a cluster grows larger with respect to the size of the automotive industry, every element within the cluster would be more complex and more difficult to properly manage. The rate of information exchange and decision-making in policy related issues are expected to be slower. By having the intermediary as a coordinator of policy plan, accurate and timely communication could be maintained despite the expanding breadth of stakeholders. They could also act as a conduit or a point of contact in the knowledge exchange between universities, research institutes, and industrial enterprises. The hierarchical structure of the intermediary organisation should be flat, with few members to maximize organisational flexibility. This flexibility is more needed in an environment that requires quick decision-making. Hence, the intermediary should also be empowered to make some decisions on its own if the decision is related to the overall target of the organisation i.e., the development of the electric bus industry. Optionally, they should also be able to mitigate or absorb some operational risks in lieu of some stakeholders who are unable to weather such risks by having a mechanism to transfer the risks towards other actors within the cluster.

The formation of the intermediary organisation should consist of representatives from all sectors of stakeholders within the cluster. The members of this consortium should have sufficient level of knowledge in the electric bus industry. Experts in diverse field within the industry including electric bus research, manufacturing, sales, and service operation are recommended to be recruited into the organisation. Furthermore, they should be ready to dedicate substantial effort to the implementation process of electric bus related policy and maintain communication channels with other stakeholders. Ideally, the activities of the intermediary organisation should be treated as a high priority task, which requires full cooperation from the members. As a result, they might have to be specifically compensated by the government. Lastly, the members should be elected fairly and not be rejected by any parties within the industry. It is utmost important that these groups of people would prioritise the development of the electric bus industry in national level, rather than serve the best interest of a single group or a single organisation.

7.4.2 Positioning of the Intermediary

Because the intermediary will exist as a small group of people that originated from several sector, it is not expected that they would put their efforts in every segment of the industry. The positioning plan for intermediary (Figure 7-8) provides a specific perspective on this regard. The position within the electric bus supply chain is assigned as their limited field of operation. This position would also vary in a different stage of developmental plan that was designed in the previous section, as illustrated in the diagram. The intermediary is expected to focus its efforts in a specific sector within the supply chain, which is predicted to be the most contributory to the progress of the electric bus industry at a certain time.

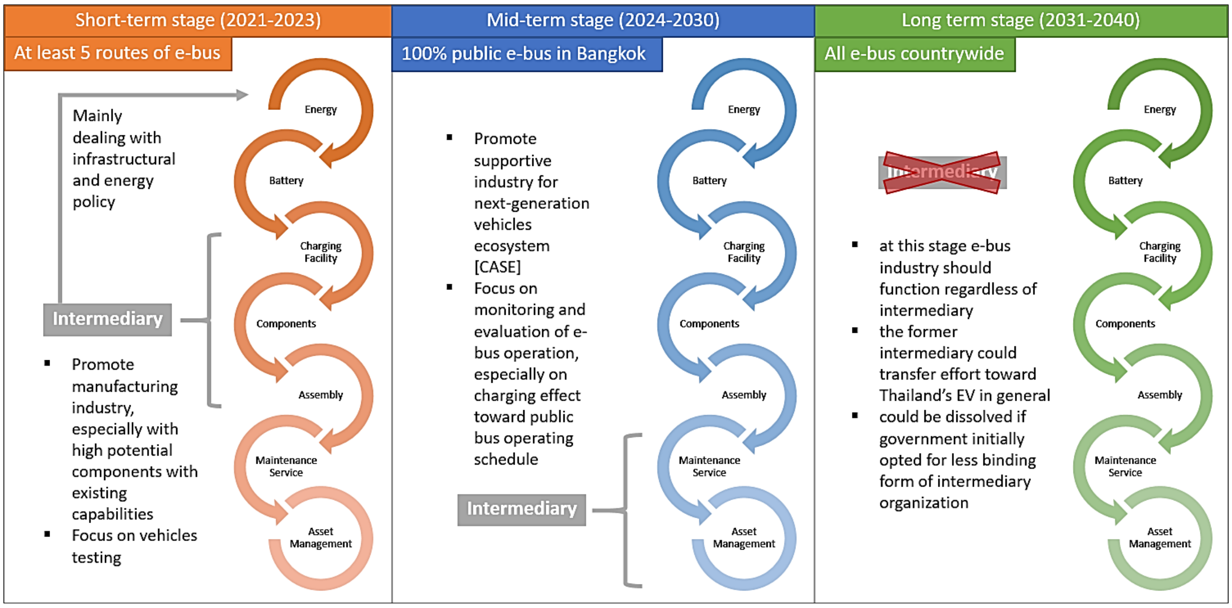

Figure 7-8 The positioning of intermediary within the supply chain of electric bus industry

In the initial formation of the electric bus cluster and during the short-term plan period, the coverage of the intermediary within the e-bus supply chain would be at its largest. This coverage is expected to mainly include infrastructural policies and capability development in the manufacturing process of the electric bus. In addition, the degree of regulations in testing and vehicle's standard would also be the key activities for the intermediary during this stage. Primarily, the intermediary will not actively engage in any core activities in the research and manufacturing. They will only act as an overseer to the overall progress of the initial phase of cluster building, and the operation of an e-bus cluster in a later stage. Their key task will be about solving emerging cluster-based issues which involve conflicting opinions among members of the cluster that could make it difficult to make any collective decision. By delegating this process to a smaller group of people, it would be easier to reach a conclusion that would please most members within the system. Nevertheless, dissenting feedbacks might be unavoidable, and some mechanisms should be placed by the intermediary to prevent the decrease of goodwill within the cluster.

The key task of the intermediary will be the same in the mid-term period of industry development. Nonetheless, the coverage of responsibilities would be smaller and shifted towards bus service operations and asset management of the electric bus within the supply chain. In this phase, the development in other features of new generation vehicles i.e., autonomous, connected, and shared vehicles model will also be promoted along with the development of an electric bus. This full integration would provide substantial benefits to the future of the transportation ecosystem in Thailand, especially in urban areas. However, the focal point should still be about an electric bus cluster to prevent scope creep of the intermediary. The most essential task for the intermediary in this phase will be the creation of a monitoring and evaluation mechanism for the operation of e-bus as a new mode of public services. The incremental changes in the reliability and the reduction in pollution should be a focus of this evaluation process since they could be considered as the main driving force behind the adoption of electric buses in a public service sector.

It can be shortly summarised that the positioning of an intermediary in the supply chain should be adapted based on its main activities. This repositioning would likely to occur during the transition between a short-term stage and a mid-term stage. Apparently, there will be a higher amount of ongoing regulatory tasks in the downstream part of the supply chain during the range of a mid-term plan. In contrast, the activities surrounding the upstream portion of the supply chain will take precedent in the initial stage. However, this does not mean that the whole electric bus industry should focus on the upstream portion in the initial stage, and downstream portion in the middle stage. For the industry to be constantly developed, every segment within the supply chain needs to be moving in conjunction. The positioning of intermediary in this section is just a reference to the appropriate focal point for the intermediary organisation. This interpretation of position need not to apply to every organisation within the cluster.

In theory, the existence of an intermediary organisation should not be the requirement for the electric bus industry to propagate in the long-term. The original purpose of the intermediary is the provision of support activities to hasten the formation of the industry cluster and improve the effectiveness in cluster-related activities. This purpose will ultimately be conceived as being of less importance when the state of the electric bus industry is increasingly stabilised. After 10 years, the electric bus industry in Thailand is expected to gain a certain level of automation across all parties within the cluster. It should be able to form free market mechanisms regardless of heavy regulatory processes from the mediator. At that point, there will be two options for the former intermediary of the electric bus cluster. Firstly, they could transfer their responsibilities into an adjacent industry that requires similar development. The most appropriate candidate would be a passenger cars segment of the electric vehicles industry, or the overall development of the electric vehicles industry in Thailand. Alternatively, this intermediary could be dismissed if the government opt for a different format of an intermediary due to potential differences in industrial environments. The dismissal process could be easily completed if the intermediary was loosely formed, akin to the characteristics that were elaborated in the previous section.

7.4.3 Responsibilities of the Intermediary

In this section, the possible roles and responsibilities of intermediary are briefly explained. The collection of strategic objectives of the organisation (Table 7-9) was compiled based on the categorisation of industry gaps that were presented in chapter 6. Nonetheless, all these objectives are not expected to be completely fulfilled by the intermediary. The sheer amount of workload to complete all activities would be too large for a small and non-structured organisation to handle. The intermediary is expected to only follow some of the objectives that were deemed to be especially important to the developmental state of the electric bus cluster at a certain moment. For example, if the analysis from the industry showed that most Thai manufacturers are incapable of developing technological capabilities on their own, the technology transfer and localisation between Thai firms and overseas enterprises might be a highly prioritised strategic objective for the intermediary. To summarise, this diagram presents the possible list of objectives for the intermediary, not a complete goal's checklist for their operating lifetime.

Table 7-9 Possible strategic objectives of intermediary organisation categorised by industry gaps.

Industry Gaps	Possible Strategic Objectives
Policy	• Set industry and market targets. • Establish collaborative network of e-bus manufacturers. • Monitoring and evaluation plan. • Technology roadmap. • Commercialization roadmap. • Scenario design of public policy.
Capabilities	• Technology development platform. • Development of C.A.S.E technology. • ICE to E-bus conversion. • Technology transfer and localization. • Human resources training. • Scale-up plan for e-bus manufacturing. • Provide matching grants. • System integration development.
Market	• Industrial aids and subsidies. • Promotion of e-bus fleet in public organizations. • Tax incentives for e-bus manufacturing and/or imports. • Allowance for private energy enterprises. • Management of public procurement plan. • Regulate product categories based on operating condition. • Promote EV usage and awareness.
Operation	• Designate demonstration zone for electric buses. • Assessment of citizen's feedback. • Research in battery swapping model. • Preparing charging infrastructure. • Preparing standard and facilities for testing. • Reduction in production cost by partnering with MNCs. • Shared manufacturing platform.

(Source: Summarised from the data collected.)

Before the listing of possible strategic objectives was created, responsibilities of an intermediary organisation are more limited in the previous iteration. The previous set of responsibilities were more straightforward and focused. In the non-final design of this policy plan, the intermediary organisation was exclusively assigned to the policy-related problem. Later, after the analysis of primary data, it is apparent that the troubleshooting of policy gaps might not be sufficient for the electric bus industry to move forward. There should also be some form of additional implementation plans to support the adoption of public policies. The implementation strategy should be aligned with a national strategic direction to improve the cohesiveness of the whole policy plan. In the final iteration of this chapter, the responsibility of the intermediary was altered into the format of a listing which contain possible activities in all areas rather than a set of static objectives to accomplish (Table 7-9). There might be some questions regarding the overwhelming scope of responsibilities that are assigned to the intermediary. It is possible to criticise that the scope is being overextended beyond an appropriate boundary of a single organisation. Hence, it is very important that the problems within the cluster are accurately identified. A precise analysis and unambiguous communication within the e-bus cluster could improve the efficiency of intermediary's problem-solving process and complementary to this circumstantial model of organisational responsibilities.

Despite being mostly circumstantial to the objective of the cluster, there are some responsibilities of the intermediary that could be considered as essential to each of the development stages of the electric bus cluster. The first responsibility that should be assigned to the intermediary in the initial stage of development is the setting of national level targets for the electric bus industry. These targets should be derived directly from the strategic direction of the national public policy, which should be formulated beforehand. The example of this task will be explained in more detail within the next chapter. Another responsibility that has a similar level of importance is the cultivation of market demand for electric buses by utilising policy instruments such as taxation policy, subsidies, and financial incentives. This topic was predicted to be predominant in a general market of electric vehicles but less so in the electric bus industry (Laoonual, 2020). Nevertheless, market development will be the main driving force for the progress of most manufacturers. This can be concluded from the analysis of the interviews, since the most recurring themes among manufacturers are the concern over the profitability of the production line. Without sufficient demand in the market, the manufacturing process of electric buses would not be economically sustainable. It is imperative that sizable market for electric bus is prepared for the potential growth of the industry.

After the main responsibility was determined, the next logical step for the intermediary is to create an implementation plan that could lead to the fulfilment of the objectives. There are several ways to accomplish this task. The choice on how to approach the objectives depend on the scale and scope of the objectives itself. It should be noted that most responsibilities presented in Table 7-9 are very broad in scope. These listed responsibilities could be segmented into a smaller piece of objectives in an actual planning process of the intermediary organisation. For example, the development of C.A.S.E technology could be narrowing down to the development of a single process within the autonomous system in vehicles. Smaller objectives might require less top-down level administration and could be essentially accomplished in a shorter duration. On the other hand, responsibilities that have a larger scope would require an overarching plan that add multiple factors into equation and might take a long duration to yield significant results. To manage this complexity, the diagram could be designed to illustrate internal mechanisms of the initiative (Figure 7-9). This diagram shows government support mechanisms for technology localisation of domestic enterprises. The details included identification of sub-objectives for each group of stakeholders, the timeline for development, and the connection between each sector. In the next chapter, the implementation plan for electric bus policy will be presented in a format that could accommodate both small and large targets of the e-bus industry in Thailand.

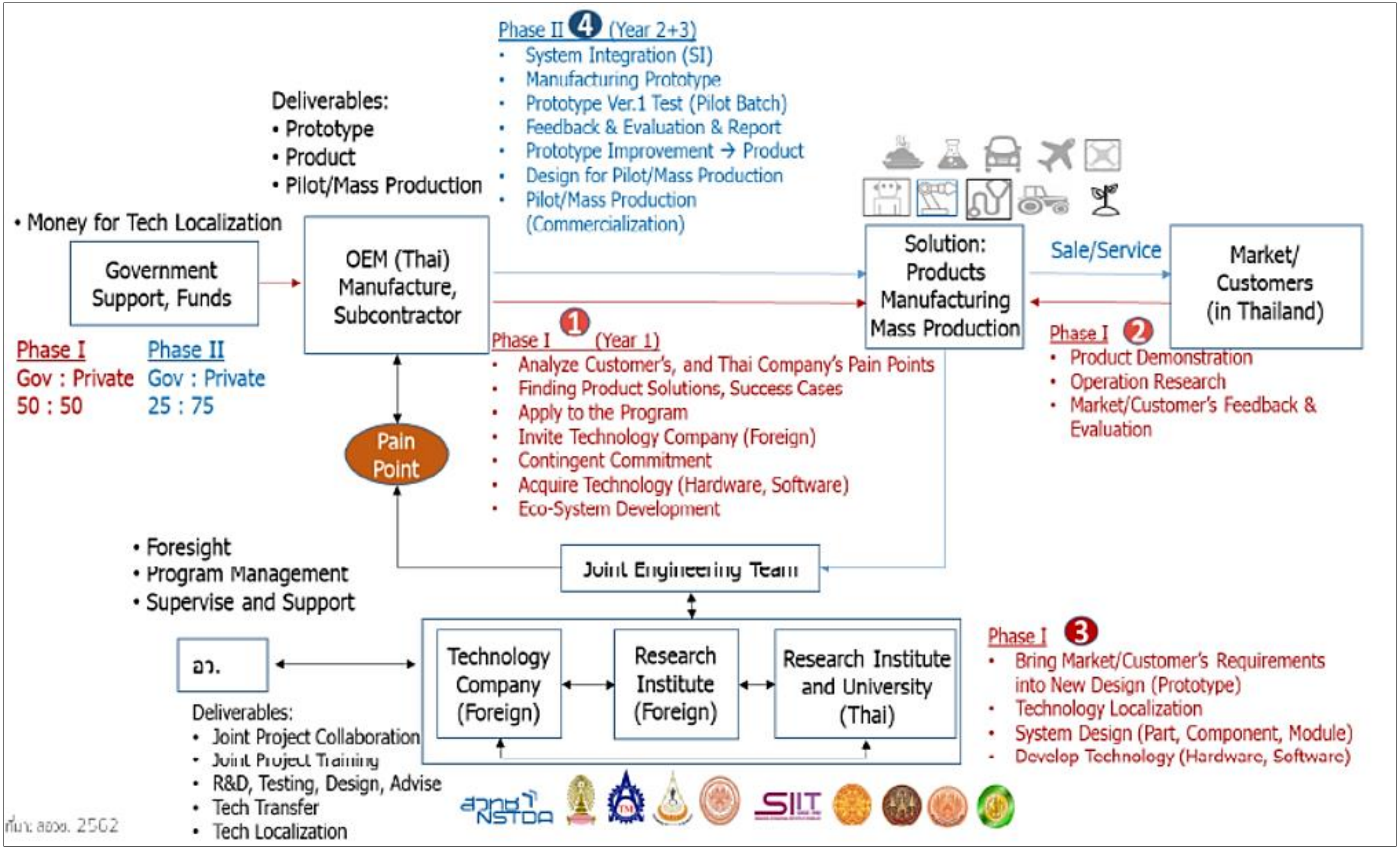

Figure 7-9 Government support mechanisms for the localisation of overseas technology
(Source: (*Next-Generation Automotive : Promotion and Development*, 2019)

Chapter 8 The Implementation of Public Policy

8.1 IDEF0: Scenario Design for the Thai E-Bus Industry

After the strategic direction for the e-bus cluster was devised in the previous chapter, the next step for the formulation of policy plan is a practical implementation of policy initiatives that would support the adoption of electric buses in Thailand. As indicated by the contents in the previous segment, there are many important factors for the accomplishment of this goal. For instance, it is imperative to create clear research objectives for domestic research institutes, but it is also equally important to foster the market demand for electric buses. A comprehensive planning template for these two concepts has been established as a technology roadmap and business model canvases respectively. Additionally, an altered structure of the supply chain was also introduced. This information would be applied in the design process of policy formulation and implementation in this chapter.

From the summary of the previous two chapters, there are several signs which indicate that the strategic path to the adoption of e-buses in Thailand would be more complete when it is viewed as a complex and non-linear pattern. An interviewee commented on this aspect and suggested that multiple scenarios of policy implementation plan should be developed to maximise the impact of the policy framework.

"I think you need to invent some tools such as system dynamics modeling to analyse the situation. You need to think about how overall picture could be observed in a certain scenario, and how to simulate policy effort." -YL

With this assertion, it is justifiable to create several scenarios for the implementation of the policies to promote an e-bus cluster. Four different scenarios were created in this thesis to define different stances that the Thai government could take regarding the development of an e-bus industry. These four scenarios reflect the current uncertainties of the Thai EVs industry by considering the primary interview data regarding the feasibility of a Thai EV industry (figure 8-1). In addition, they can be clearly identified by two dimensions; the degree of involvement and the cost to implement. The degree of involvement represents how much effort is required from the stakeholders to transform the bus manufacturing industry towards electric vehicles. On the other hand, the cost to implement represents monetary and temporal cost for the government to support this transformation.

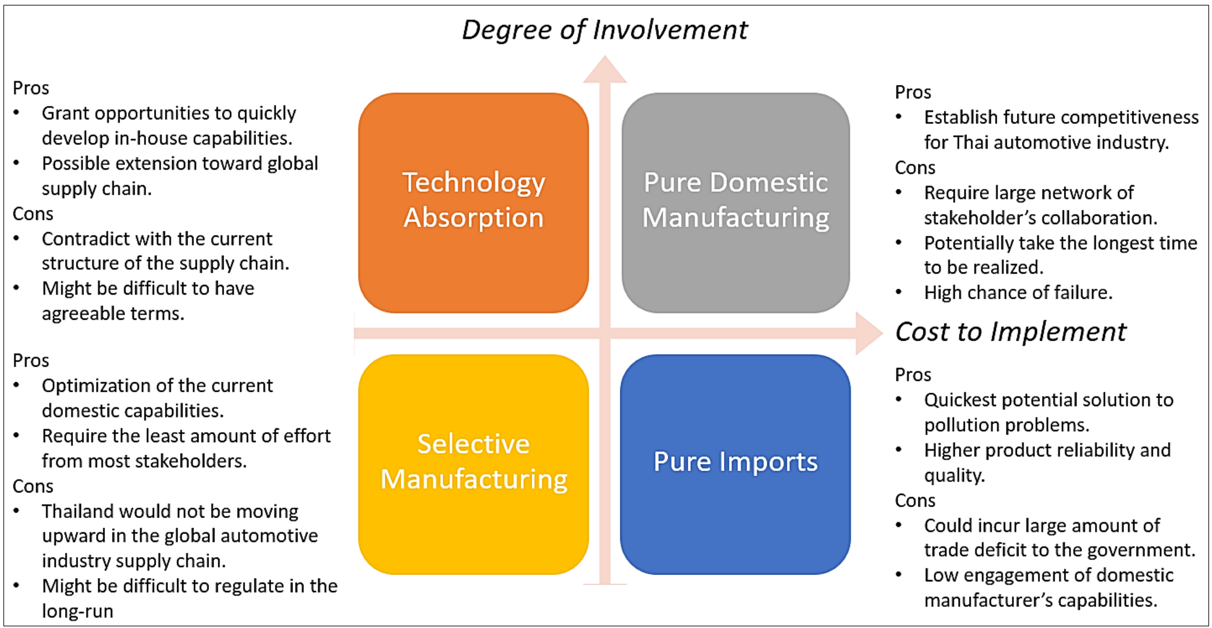

Figure 8-1 Different scenarios for the implementation of electric vehicle policy

In this chapter, the supply chain of each scenario would be visualised by the integrated computer aided manufacturing definition for function modelling (also known as IDEF0) to illustrate the predicted critical product and information flow in each scenario. The main purpose of the IDEF0 modelling method is to provide precise and consistent graphical representation of business or manufacturing operations to any desired level (Lightsey, 2001). There is only a single format of building block for IDEF0 diagram. It is represented by a block that corresponds to a function within the system and four possible placements of arrows (figure 8-2). IDEF0 is utilised in this thesis mainly because of the simplicity and universal syntax that could be easily understood by the general audience who are not the experts on system engineering. Moreover, it could also be expanded or retracted to the desired level of complexity, the feature which might be welcomed in further applications of the diagram.

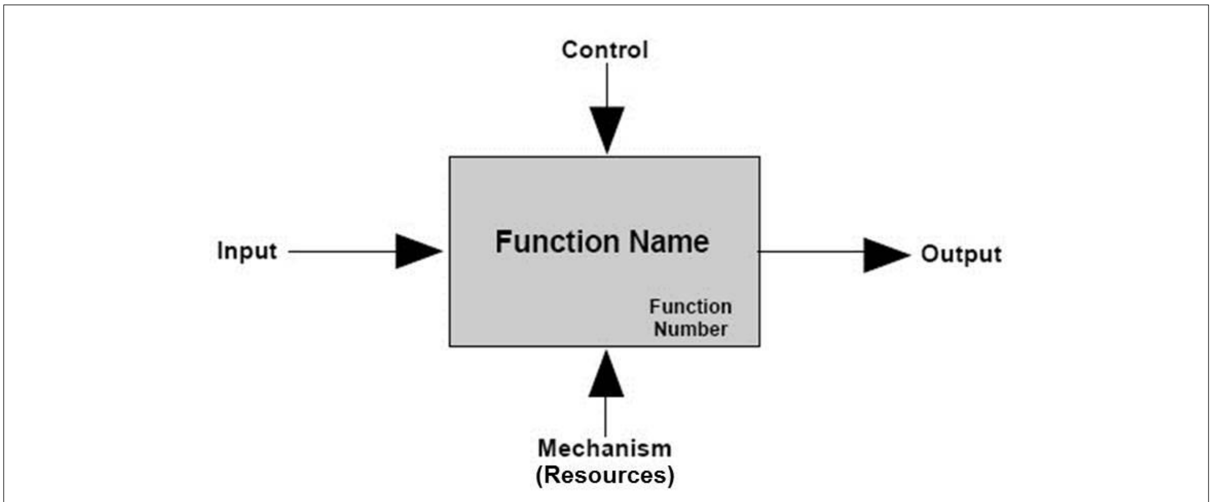

Figure 8-2 Basic building block of IDEF0 system modelling diagram
(Lightsey, 2001)

8.1.1 Scenario 1: Pure Imports

The first scenario is the situation where all electric buses in the country will be imported from overseas manufacturers. This scenario is the simplest to implement and would require minimal policy planning to succeed. The main aim for this scenario should be the rapid mitigation of environmental problems that originated from ICE buses, especially those that are owned by the BMTA ('The emission of diesel vehicles and PM2.5', 2020). The change from ICE buses to e-buses could be completed in a relatively short time span since there are an abundant supply of e-buses that could be imported. Additionally, most of the product offerings from overseas manufacturers currently possess higher reliability and quality compared to the current array of domestically manufactured e-buses. In example, most e-buses from Chinese companies are already proven to be function normally on the standard amount of the service range, while domestically-manufactured e-buses still struggle to achieve the comparable level of reliability (Cherdchai, 2020). The main reason for this might related to the extensive period that Chinese stakeholders and manufacturers have been invested in the process of research and development. This was further supported by the longstanding programme for EV diffusion in China, which provided the point of market entry for manufacturers to develop their manufacturing capabilities (Liu *et al.*, 2020). These are significant factors that led to the disparity of technology commercialisation between Thai and Chinese manufacturers.

In contrast, the pure imports scenario would also contain a multitude of issues. These issues are mostly related to the long-term national economy. The large number of e-bus imports from other countries would likely lead to a national-level trade deficit (Wanichanukul, 2020). Furthermore, this scenario might be harmful to the bus manufacturing industry by removing a significant portion of potential sales from domestic bus manufacturers. The development of domestic manufacturer's technological capabilities would be much slower, due to the lack of policy support. This was indicated in the assertion that public policy support to domestic manufacturers would be the integral part for the initial development of an e-bus industry (Laoonual, 2020). In the worst-case scenario, e-bus manufacturing industry in Thailand might not materialise. The overseas imports of e-bus would likely to affect the financial health of the Thai government since the government currently owns and operates 3,219 units of public bus (BMTA, 2022). Therefore, it can be expected that there would be less governmental support in terms of fiscal policies and subsidies to domestic manufacturers in this scenario. It is more likely that the government would focus its effort on the validation of e-bus quality and the procurement process in this scenario to lessen the risk from imported products. This might include a skewed public policy towards the development of testing facilities and technical standards for actual uses of imported e-buses.

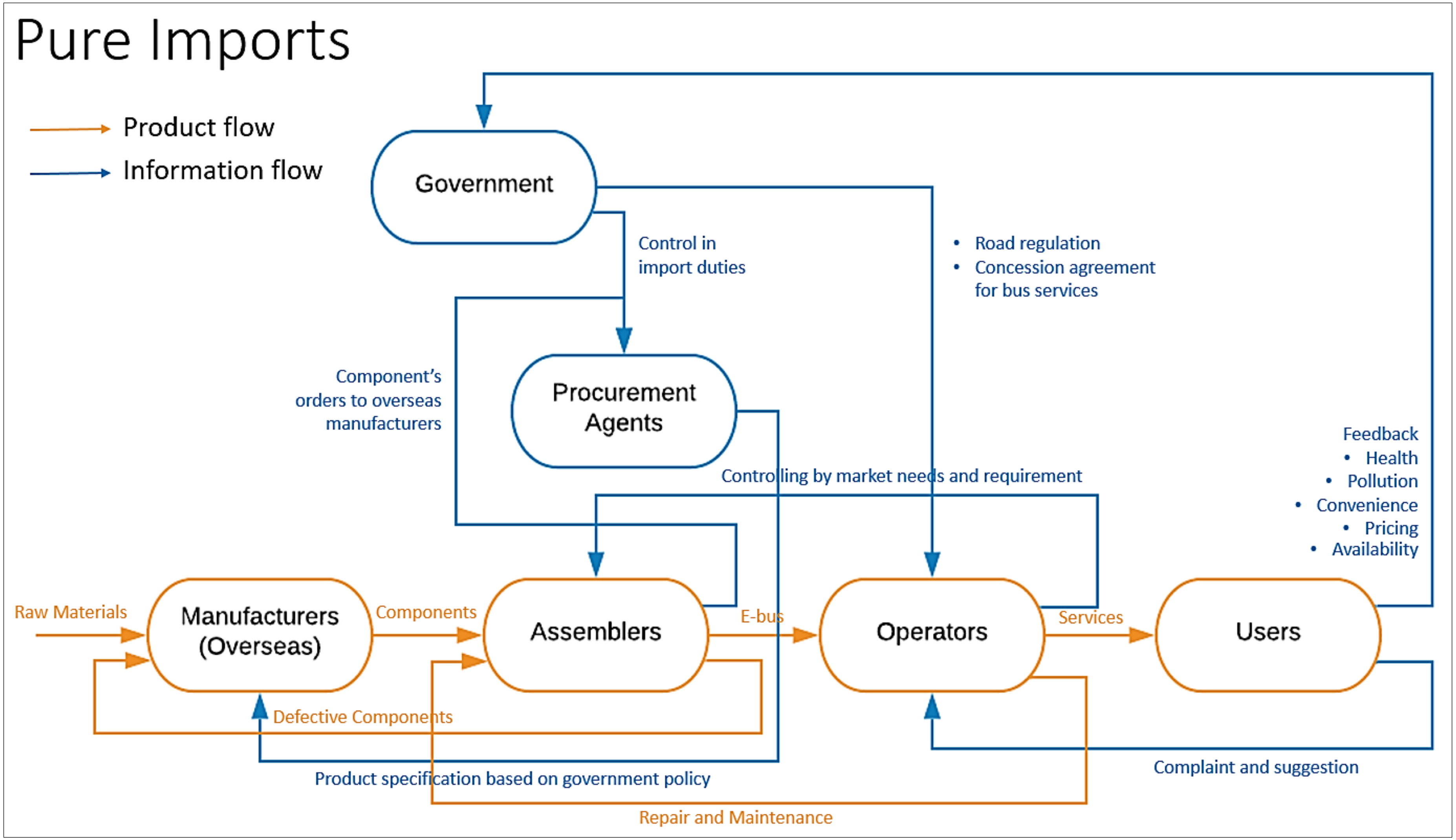

Figure 8-3 IDEF0 diagram for scenario 1: pure imports

8.1.2 Scenario 2: Pure Domestic Manufacturing

Scenario 2 is designed to be on the opposite end of the spectrum when compared to the first scenario. The main objective for this scenario is the complete development of the Thai automotive industry and supply chain and prepare them for the technological disruption of EV on a global scale. This scenario assumed that e-buses and all necessary components can be completely manufactured by using only the domestic expertise of Thai automotive industry. As a result, the corresponding policy plan would require more intense management of collaborative networks between manufacturers and research institutes. The IDEF0 diagram in this scenario is substantially more complicated than any other scenarios. Additionally, the complication of information flow might be underrepresented in this diagram (figure 8-4). It is expected that the linkage between domestic OEMs, assemblers, universities, and researchers will exist in a more complicated sense, based on the predicted diverse and large amount of technological knowledge. According to this scenario, Thailand could become one of the leading manufacturers of e-buses. Since it is asserted that several manufacturing technologies for the manufacturing of e-bus could be applied in other segments of EVs (Dorkmaitead, 2020). The complete integration of the e-bus manufacturing process would potentially create a large amount of technology spill-over to the general research and development within the electric vehicles industry in Thailand.

However, several difficulties are presented in an actual environment, which could prevent this scenario reaching its ideal expectation. Firstly, the National Science and Technology Development Agency (NSTDA) explicitly asserted that there are currently large technological gaps in the research and manufacturing process of electrical motor and battery, which prevents these components to be effectively produced in Thailand (Wanichanukul, 2020). Since it was concluded that both components are very costly to be developed (figure 7-3), it is expected that these two components would spend a long time in research and development process before they can be competitively commercialised. The most apparent flaw of this scenario is the over-reliance on the domestic supply chain. In a modern economy, the optimisation of production through offshoring is supported by the effect of globalization (Farrell, 2005). To reduce production costs, Thai manufacturers could transfer some activities that will not generate high value to the supply chain to other sub-contractors outside the country. However, the reconstruction of manufacturing processes would be required for most companies since the current expertise of Thai manufacturers are mostly associated with the design and manufacturing of external vehicles components such as bus bodies and chassis (Cherdchai, 2020). In conclusion, this scenario is very unlikely to happen considering the current state of the Thai automotive industry. Nevertheless, the policy plan that is created from this idea could be used as a referential point for a more practical implementation scenario.

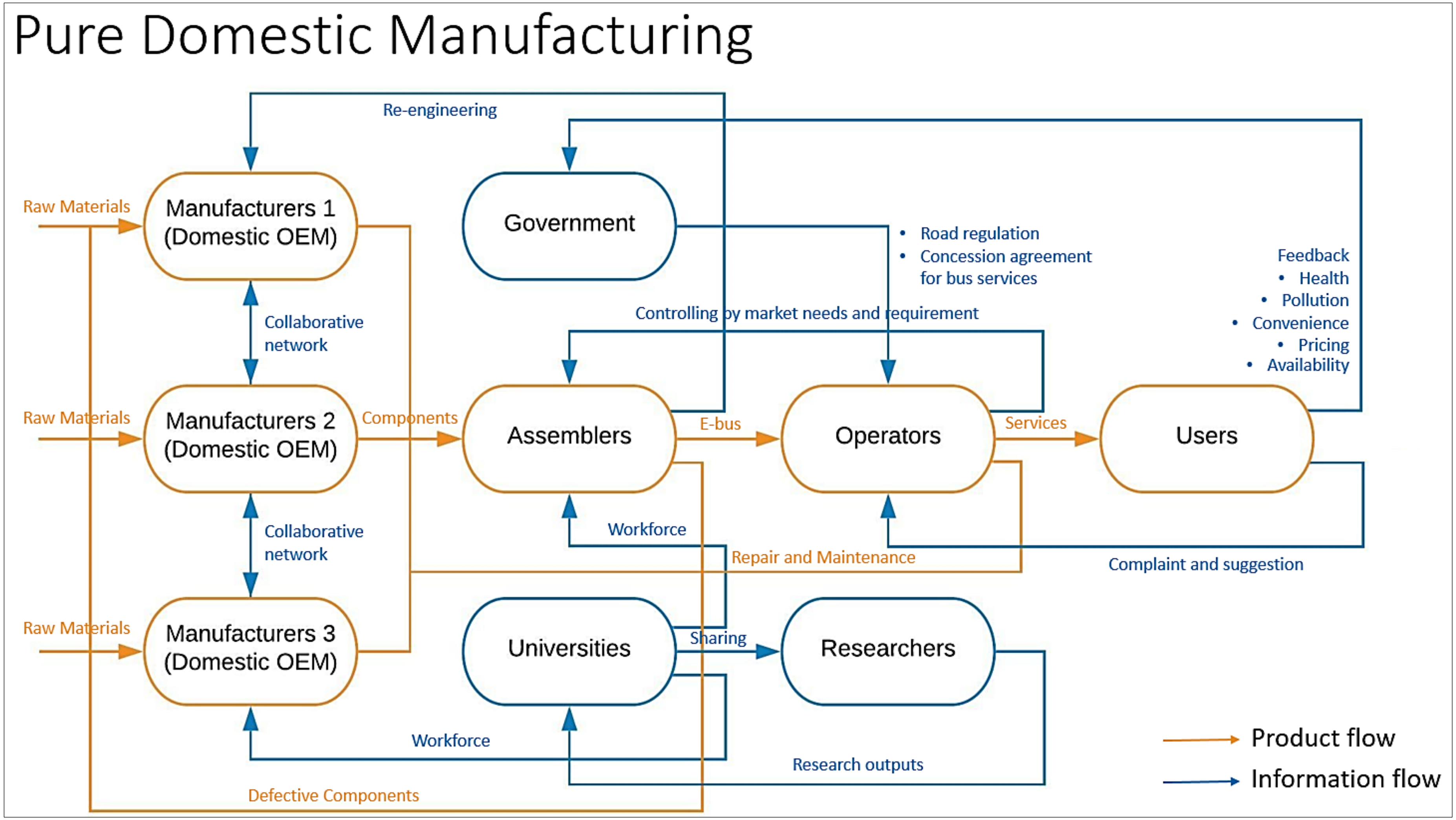

Figure 8-4 IDEF0 diagram for scenario 2: pure domestic manufacturing

8.1.3 Scenario 3: Selective Manufacturing

While scenario 1 and 2 have main constraints in terms of finance and technology respectively, the third scenario was designed to exist at the middle ground between both scenarios. As a result, selective manufacturing should be the most plausible scenario for the government to implement. This scenario would require a minimal number of extra efforts from stakeholders because the industry could focus on their existing capabilities. Nevertheless, further development should be made to increase the value of lower tier components in electric buses. Moreover, it is expected that manufacturers should be able to extend their capabilities into new technological frontiers that is relevant in the manufacturing of electric vehicles. For example, there should be a cooperation in research and development for digital system integration between the bus assembler and information technology firms. This collaboration might be able to cover some weaknesses in term of domestic product value from the lack of capabilities in battery manufacturing. The main objective of this scenario should be the improvement of resource allocation across the supply chain. Both financial and human resources should be properly assigned to value-adding activities. This objective can be aided by the formulation of a technology roadmap or the creation of intermediary organisation, both of which were presented in the previous chapter.

The negative traits of this scenario would be relatively easier to manage when compared to the extreme cases of scenario 1 and 2. While this scenario is not financially or technically taxing, there are some limitations to the benefits it could convey within the Thai automotive industry. Despite the large recorded volume of annual automobiles exports, the Thai auto-industry still has low technological learning capability (Intarakumnerd, 2019). As a result, most of the manufacturers in ICEVs manufacturing industry often overlook the investment in research and development activities, which prevents them from radically improve their designs by advance engineering concepts (Wongdeethai, 2019). This scenario would not improve this situation since the focus would be on the existing capabilities rather than the aspiring quality such as innovation propensity. Moreover, this scenario might have a slight issue of tunnel-vision since it mostly focuses on short term possibilities. It would be easier to execute this policy plan when the industry is relatively smaller in size. It will be more difficult for the government to have total control over manufacturing regulations, which could dictate the direction for the product-mix of domestic manufacturers when the domestic e-bus industry became saturated (Wongdeethai, 2020). Thus, the long-term policy implementation of this scenario should consider this topic in conjunction with the ascension of domestic manufacturers in the global value chain of e-buses. In fact, this consideration would likely make selective manufacturing the most difficult to implement in the long run.

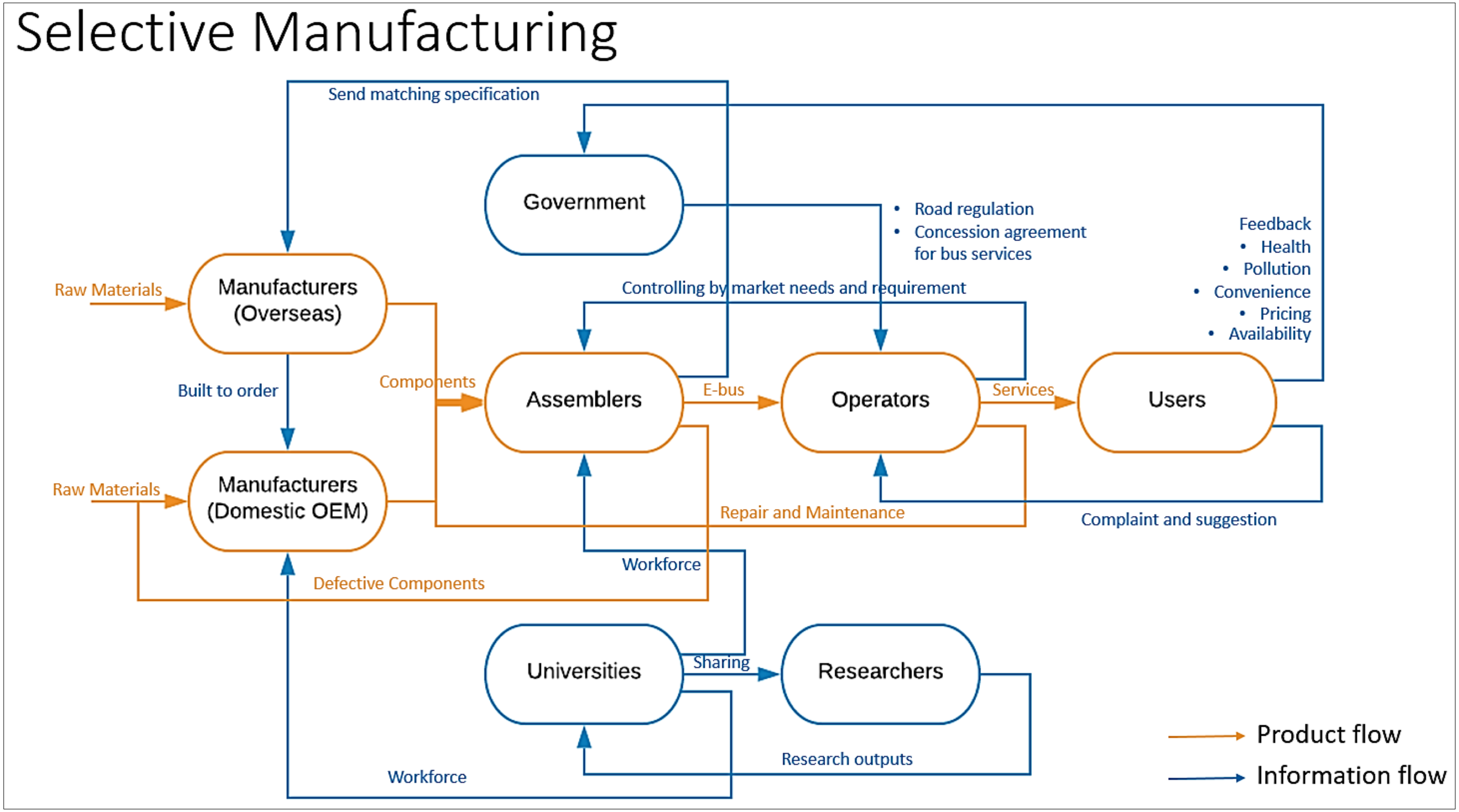

Figure 8-5 IDEF0 diagram for scenario 3: selective manufacturing

8.1.4 Scenario 4: Technology Absorption

Since the general disadvantage of the Thai e-bus manufacturers was identified as the lack of technological learning capability, this issue is used as the main notion to design scenario 4. This scenario primarily focuses on the improvement of technological capabilities among domestic manufacturers. The scope of this improvement should be strictly related to the manufacturing of e-buses, their applicable components, and testing procedures. In fact, there is more technological development that could contribute to positive impacts of e-bus adoption, such as the development of charging infrastructure or the management of the public transport service. However, the current scope of policy plan is limited to research and manufacturing process to maintain the alignment with the previous three scenarios, which focused on the differences in the upstream part of the e-bus supply chain. The main benefits of this scenario is the possibility for Thai manufacturers to quickly obtain technological capabilities from federal organisations with a relatively low upfront cost (Link and Scott, 2019). Alternatively, the connection to foreign corporations could lead to the extension of domestic supply chain towards global supply chain. This might be beneficial to the effort of the Thai industry to promote the demand for e-bus based products, since the potential market size would be significantly larger in a bigger country such as Indonesia or China.

Two types of technology absorption can be categorised in this scenario: technology transfer between domestic actors, and technology transfer from foreign parties. It can be assumed that the former type would be easier and faster to implement. Nevertheless, effective knowledge transfer mechanisms between multiple domestic stakeholders are required to fully capitalise on this opportunity. On the other hand, technology transfer with overseas entities is supposedly more difficult because of the potentially demanding negotiation process. It might be difficult to reach agreeable terms with foreign corporations since the objective of e-bus policy is directly connected with the benefits of the Thai industrial economy and its domestic stakeholders. Overreliance on the success of these agreements could result in a high level of uncertainty, which might be detrimental to the process of policy implementation. Even though the complete local-based technology transfer is possible, it was asserted that the process would be comparatively slow to the predicted global progress of EVs technologies (Suebsupanand, 2020). Therefore, the combination of public policy schemes between overseas and local technology transfer should be adopted. In this case, the progression rate of technology absorption is expected to be faster than the scenario of pure domestic manufacturing.

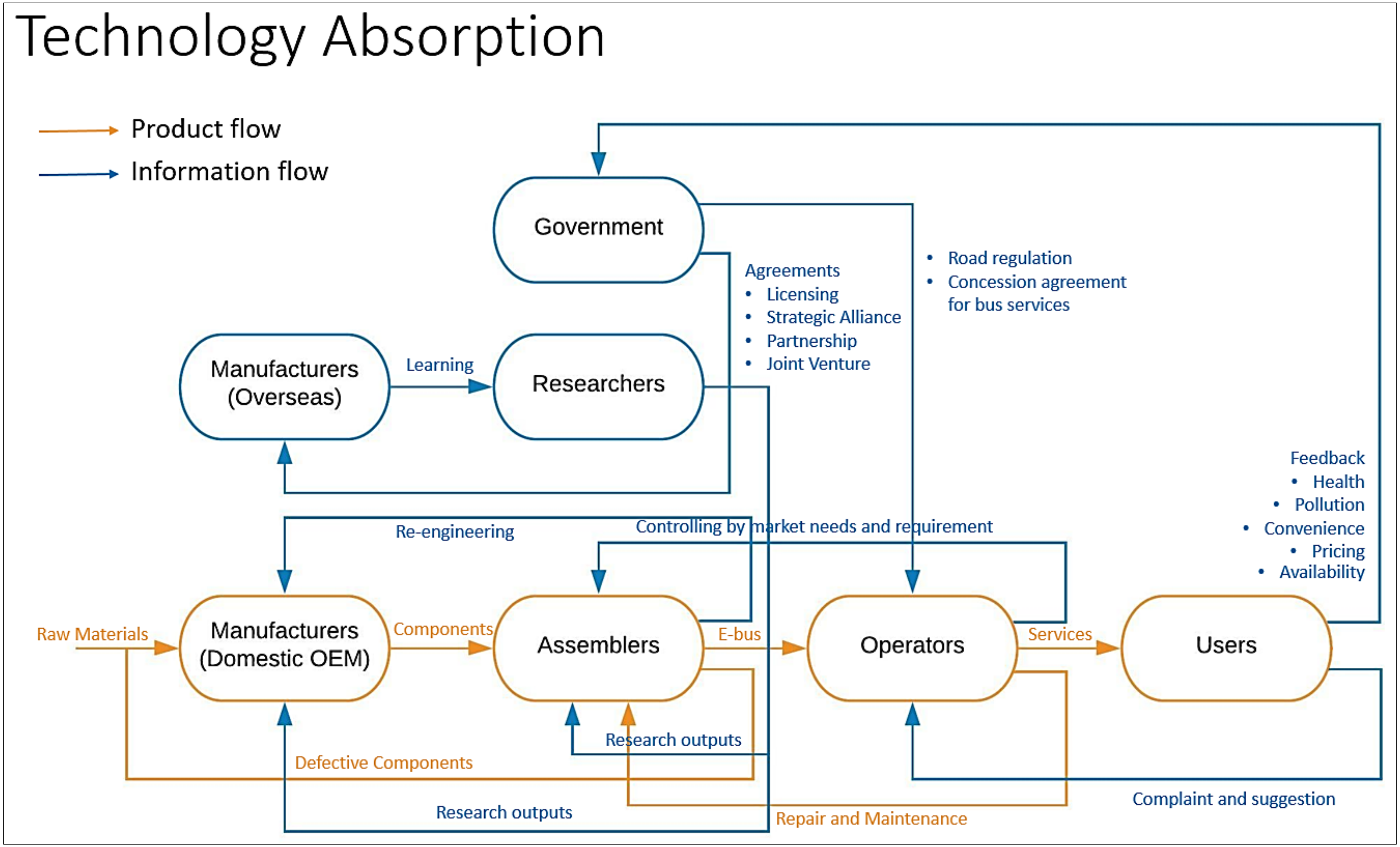

Figure 8-6 IDEF0 diagram for scenario 4: technology absorption

It can be concluded that the physical product flow in the downstream beyond bus assemblers are relatively similar regardless of the scenario. In fact, the main differences in these diagrams are mostly within the flow of information. This highlights the potential importance of policy initiatives to organise the network of collaborations among applicable stakeholders in each scenario. The role of users in each scenario would be relatively the same, which is expected to be mostly about the provision of feedbacks regarding product and services of the e-bus. It could be safely stated that their opinions would not generate a high level of impact that could differently affect policy implementation in each scenario, since it was established that the main differences of each scenario would be within the process of electric bus research and manufacturing.

There are multiple policy plan options that are considered as out of scope for this thesis, for example the selection of battery types and the detailed business model of e-bus services. In this specific chapter, this framework would primarily focus on one of the original objectives of this research, which is the encouragement of collaborative efforts within the e-bus research and manufacturing cluster via an effective organisation of information flow. The information flow of these scenarios might be similarly represented in the diagram, but they have stark differences in a more detailed level. For instance, defective components in pure domestic manufacturing scenario would require a higher level of scrutiny when compared to the pure import scenario. The higher frequency of defective components can be expected in some components that are domestically manufactured, due to the lower level of current technological capabilities.

The different level of focus in each area of the supply chain could lead to different public policy approaches in each scenario. The linkage in this diagram would facilitate the translation of policy plan into tangible targets and corresponding policy initiatives in each scenario. This process would also be used in conjunction with overseas case study that was presented in the literature review. After that, this information would be compiled into the strategic implementation plan which would present a collection of various policy initiatives that should be utilised by the government to accelerate the adoption rate of electric buses in Thailand.

8.2 The Identification of Policy Initiatives

Following the setup of scenario-based objectives for the implementation of the e-bus policies in section 8.1, this section is designed to provide a comprehensive format of the policy implementation plan that would be easily understandable by laypeople who lack technical expertise in the topic of electric transportation. The core concept of this format was modified from the strategic implementation plan, which was originally created to strengthen the synergies between action groups and overarching objectives at the governance level (Bousquet *et al.*, 2017). There are three main layers for this structure: objectives, targets, and actions. To invigorate the synergies between national-level vision and enterprise-level action plans, each initiative should connect with at least one target from the scenario. Likewise, the targets also need to be directly derived from the top level of strategic objectives. In addition to the original design, the information in this version of a strategic implementation plan was also summarised in categories, based on the types of stakeholders that are for each scenario. It should be noted that all information in the strategic policy implementation plan including objectives, targets, and policy initiatives for each scenario were derived from the gathering of primary data from the in-depth interviews. The examples of these information with regards to the interview quotes are summarised in table 8-1.

Strategic implementation plans for the adoption of e-buses in each of the four scenarios are designed based on the ideas explained in the previous paragraph (figure 8-7). The 'objectives' represent the central ideas of each scenario, which were briefly explained at the beginning of this chapter. The 'targets' not only consist of overall goals for the government, but also a discrete target based on the interest of each stakeholder. This ensure that the resulting policy initiatives would be more likely to be accepted by both parties. On the contrary, the 'activities' would be the exclusive machination of public policies, which can be directly induced by the government or policy makers. The reason for this design decision is because this framework is originally developed as the government-centric plan for the implementation of public policy. Therefore, the collection of activities in this strategic implementation plan are only limited to public policy instruments that can be completed by the government. Policy initiatives and activities which are suggested in this section are the culmination of analysed data from the process of data collection in Thailand. In addition, the conclusion from case studies in the literature review would also be applied as benchmarking metrics for the Thai e-bus policy to find proper initiatives that could effectively response to the main concerns in each scenario.

Table 8-1 Examples of interview quotes regarding the suggested targets and policy initiatives

Participant	Topics	Quotes
AT	The need of large-scale manufacturing infrastructure for S2: Pure domestic manufacturing.	"I couldn't tell you at this point. We don't know the exact number yet. For instance, BMTA asked to rent 2,800 units annually. We don't have enough capacity for that because they requested 50% local contents of those buses which mean all these buses need to be assembled in Thailand."
SW	Reroute requirement for e-bus adoption in all scenarios.	"At the same time, they also need to re-route their operation to accommodate extra time needed for charging vehicles."
PS	The necessity of high-quality jobs provision to the population for S1: Pure imports and S3: Selective manufacturing	"Many countries transfer their manufacturing process into other countries where they can have cheaper labour cost but maintain their manufacturing process quality. What happen next is the de-industrialization of the said country. The country needs to provide new jobs that provide better income for its population."
TW	The difficulty for S4: Technology absorption, which indicate that a lot of preparation is required	"We should also do technology localization policy which allow us to absorb technological capabilities of foreign enterprises. The problem is most of Thailand big transportation company are state enterprises, and they are not forced to do what the government want.."
YL	The import taxes for battery should be reduced for domestic manufacturing in S2 and S3	"The battery price difference is high because of 40% import taxes."
AJ	Indicate that the facilitation of businesses might be as important as fiscal policies	"I personally think that government incentive policy is not the main attraction for stakeholders to join Food Innopolis. The main selling point of us is our services that could facilitate their business."

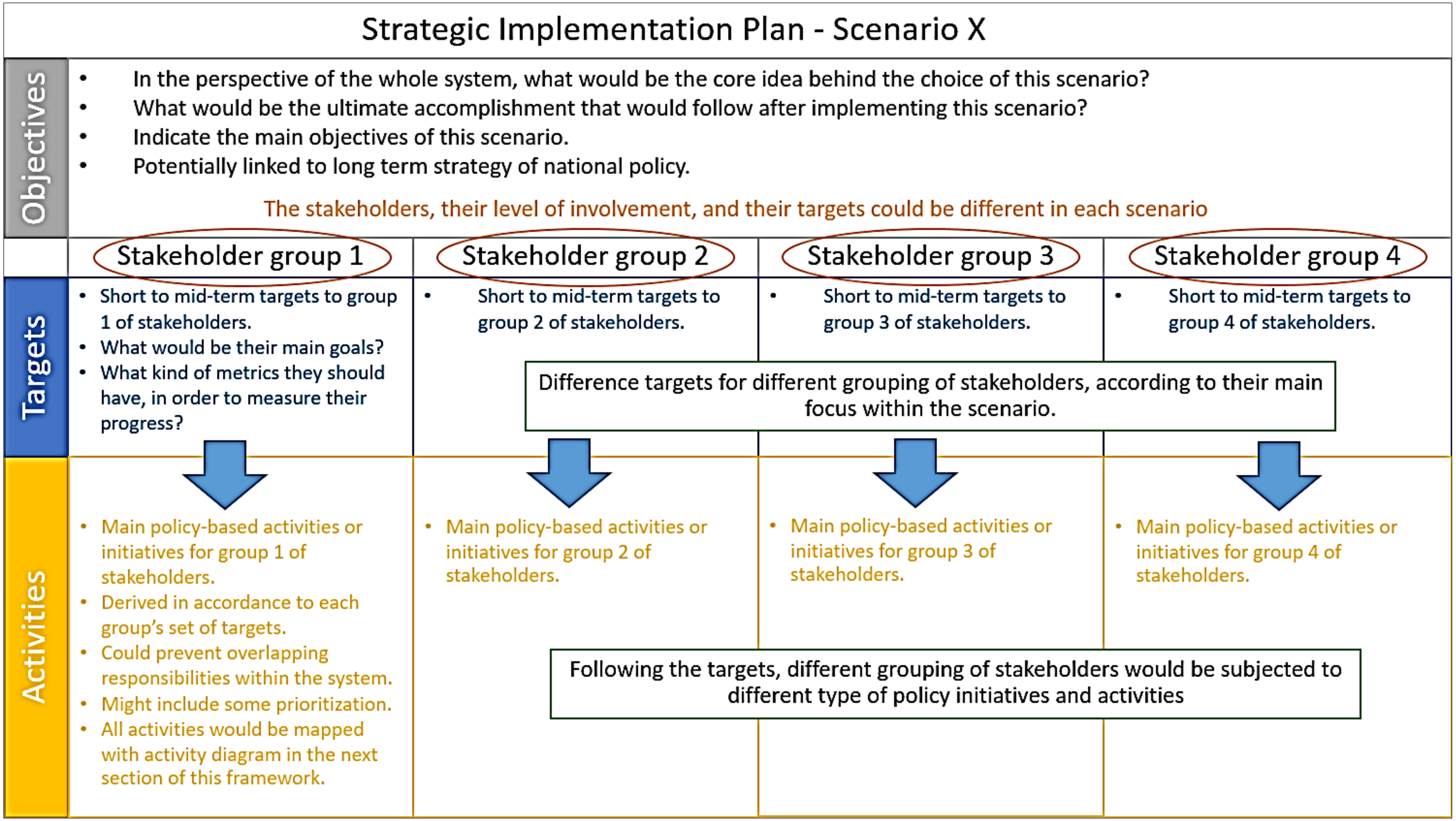

Figure 8-7 general outline of the strategic implementation plan

(Source: Adapted from (Bousquet *et al.*, 2017)

8.2.1 Scenario 1: Pure Imports

The main conceptual idea for this scenario is the rapid adoption of e-buses in actual transportation system, which supposed to quickly mitigate pollution issues in several urban areas in Thailand such as Bangkok, Chiangmai, and Nakhon Ratchasima. This would not only include bus-based public transportation, but also private fleets. Nonetheless, public transportation should be prioritised since the number of vehicles are more numerous. It can be implied that the change to e-buses in the public transport sector would provide a larger positive impact to environmental conditions in cities area and its vicinity (ChooChuay *et al.*, 2020). This plan also provides the quickest hedging option towards the volatility of fossil fuel prices in comparison to the other scenarios (Rentschler, 2013). Other scenarios would be relatively slower in the process of e-buses adoption because it would take time to develop the required technological capabilities for domestic manufacturing. Therefore, the objectives for policy implementation in this scenario are the quickness in the development of the public bus operation model that would be fully compatible with the different usage patterns of e-buses which have innate shorter driving range and longer charging time (Wongdeethai, 2020). In contrast, the development of research and manufacturing parts of the supply chain would be less demanding, and the priority should be on vehicle's standard and testing procedures. However, it was asserted that e-bus importing would also provide the opportunity for domestic manufacturers and assemblers to experiment in the reverse engineering process, which might allow them to properly manufacture some components for e-buses in the future (Suebsupanand, 2020). Domestic manufacturers will be dramatically affected by these pure import policies, especially the OEMs who normally supply vehicle parts that are exclusively used within the manufacturing of ICE buses. As a result, the government must engage in the policy programme that can mitigate potential job losses in this industrial sector.

According to the IDEF0 diagram in figure 8-3, this scenario transfers the importance of the research and manufacturing process to the operation of actors who would be responsible for the procurement process of imported e-buses. The procurement agents of this scenario must set the standard for their purchases. This could include delivery time, low defect rate, responsive communication with the seller, etc. Hence, there would be a smaller number of targets and activities aiming at the e-bus research and manufacturing cluster in Thailand. In the case of components package import which will be assembled in Thailand, they need the linkage to domestic assemblers who can handle the projected volume of assembling tasks. Preferably, domestic assemblers should have some preparation for reverse engineering process. This task could be organised and funded by the NSTDA since they have the best access to the information on each manufacturer's expertise. It is expected that most of the primary imports would be for the conversion of the existing ICE buses of the BMTA into e-buses (Sintavacheeva, 2020). Therefore, many policy efforts in this scenario should be in the management of public transport operation during the first few batches of e-bus imports, especially the improvement of services quality to attract more passengers and the restructuring of public bus routes.

Implementation Plan - Scenario 1: Pure Imports

Objectives

Core Idea - Quick mitigation of pollution problems in Bangkok urban areas.
- Immediate hedging toward the rising of fossil fuel price.

Objectives - Quickly develop operation model of metropolitan electric buses as public services.
- Capture possible chance for domestic development of components in the future via reverse engineering.
- Engage in policy planning that aims to reduce job loss and the break-down of gasoline-based automotive industry.

	Procurement agent	Assemblers	Operators	Users
Targets	• On time delivery • Minimize defective product • Best value for money • Sales promotion • Forward order • Ease of assembly • Responsive communication	• Continuous manufacturing process • Reverse engineering • Job options • Controlled layoff • Quick decision • Procuring agreement • Component and vehicles testing	• Quality of service • Convenient of repair and maintenance • Affordable pricing • Sufficient amount of services • Business confidence • Transparency • Profitability	• Reduced health risk • Traffic congestion • Availability of service • Affordable fare • Application integration + Extra features • On time and reliability • Convenience and comfort • Widespread usage
Activities	• Offer tax rebates or exemption • Negotiate for possible technological exchange or training with buying order • Develop initial stage of imported component's inspection • Provide credit for Thai assemblers • Act as the facilitator of buying process • Create equipment procurement's decision tree for bus assemblers • Create opportunity for insourcing parts or exports in global supply chain network	• Investment intensives • E-bus workshop for Thai assemblers by invitee from overseas • Prepare job creation plan to accommodate employee who might be laid of in the future • Allocate budget for e-bus purchases within BMTA • Assign assembled e-bus to testing fields • Maintain connection between e-bus assembler and other electric vehicles assembler such as e-bike or e-boat	• Special incentives for e-bus operators • Capital imbursement to BMTA • Provide feasible business plan • Manipulate oil and electricity pricing • Framework for quality control in bus services business • Assign intermediary to work among public bus association • Provide free e-bus for a certain period of time as demonstration • Enforce public organization to use e-bus as an internal fleet • Provide government-owned maintenance garage	• Designate exclusive electric buses lane • Build new express electric bus lane • Policy to prohibit the usage of diesel buses in public services • Development of bus service application • Renew of traffic regulation in accordance to the inclusion of e-buses • Initial discount for bus fare • Route planning to connect with other public transportation such as sky-train and underground train • Public relation of electric buses aim toward Bangkok population • Pollution measurement

Figure 8-8 Strategic implementation plan for scenario 1: pure imports
(Source: Adapted from (Bousquet *et al.*, 2017)

8.2.2 Scenario 2: Pure Domestic Manufacturing

In contrast to the first scenario, the second scenario focus on self-learning capabilities of the Thai stakeholders by fully utilising policy supports from the government. The long-term goal is the total transformation of the Thai automotive-manufacturing industry towards the global EVs manufacturing hub. It is envisioned that the minimum target for this pursuit is that Thailand could rely on the export volume of EVs to drive economic growth, similarly to the accomplishment of the ICEV manufacturing industry in the past (Massamadon, 2020a). Additionally, Thailand could capitalise on this disruption to improve their standing in the global supply chain of vehicle's part manufacturers. To fulfil this ambition, extensive development of technological capabilities in several branches of EV-related technologies are required. This should include the extension towards other CASE technologies. It was asserted by the experts in Thailand that this is an essential element towards the sustaining growth of the EV manufacturing industry (Noomwong and Sutheejaruwat, 2019). The precedence for this policy implementation scenario is the creation and development of a transitioning plan for the current bus manufacturing supply chain. The most important aspect is the maintaining of the balance between domestic demand and technological development. It is imperative that most suppliers and assemblers in Thailand need to increase their technological and manufacturing capabilities for their products to be commercially competitive in this new market segment (Laoonual, 2020). Likewise, there will be no incentives for manufacturers to invest in e-bus research and manufacturing if there is not sufficient demand in the market. Overseas markets could be used as the additional driver for these stakeholders. Therefore, the Thai government should proactively search for overseas trade partners that could be potential customers or suppliers for the industry.

The targets of this scenario are designed to be more heavily influenced by the performance of the research and manufacturing sectors, in addition to bus operators and users. Therefore, a lot of policy instruments should be targeted towards the development of the whole supply chain to stimulate the economy of the e-bus manufacturing industry by both supply and demand for e-buses. Overall, it is expected that the achievement of the targets in this specific scenario would require the largest amount of effort in policy implementation. The highlights of these policies include the sustenance of manufacturer's business model, which could be supported by strengthening inter-organisational cooperation between groups of stakeholders within the industry. The government should aim to facilitate the product, knowledge, and information exchange among research and industrial actors. Additionally, it is also important to classify market segments for e-buses and indicate the accurate number of e-buses that will be procured for public uses by the government. Lastly, the most important factor for this scenario to succeed is the development of technological capabilities. These capabilities can be fostered via the restructuring of higher-education programmes, which are related to the manufacturing of automobiles. The updated curriculum for automotive design, manufacture, and engineering that are geared towards electric vehicle technologies would lead to constant provision of a talented workforce which is fundamental for the development of this industry.

Implementation Plan - Scenario 2: Pure Domestic Manufacturing

Objectives

Core Idea - Highest potential to increase economics value in automotive industry in the future.
- Maintain the stability of automotive industry and the position as a leading part manufacturers in Asia.

Objectives - The improvement and transition plan for the current supply chain in bus manufacturing industry.
- Proactively search for trade partners overseas that could be potential customers and suppliers.
- Instigate domestic demand for electric buses and electric vehicles.

	Researchers	Manufacturers	Assemblers	Operators
Targets	• Provide capable workforce • Market-based researches • Target-based researches • Adequate testing facilities • Effective learning process • Relevant engineering curriculum • Research outputs	• Net income maintaining • Proper long-term customers • Supply chain understanding • Industry classification • Interorganisational cooperation • Knowledge exchange • Components reengineering	• Explore domestic and overseas market • Cost-saving process • Quality control • Development time • Knowledge sharing to other industry • Components standard	• Quality of service • Convenient of repair and maintenance • Affordable pricing • Sufficient amount of services • Business confidence • Transparency • Profitability
Activities	• Long-term technology roadmap • Workforce training programs and universities curriculum base on technology roadmap • Exchange student and internship programs to link between research and industrial sector • Provide awards for excellence researches • Improvement of workspace and research environment • Market survey and analysis • Develop large scale questionnaire for stakeholders • Block grants to different technological organizations • Develop control and measurement tools	• Customer segmentation for overseas market • Develop virtual network between manufacturers and researchers • Cross industry development program within relating technologies • Automotive industry transition plan from ICE to electric vehicles • Prepare large volume of testing facilities • Manufacturer's capabilities analysis • Prepare sufficient components testing facilities • Provide clear-cut diagram of prospective e-bus supply chain to stakeholders • Consortium of e-bus OEMs	• Facilitate collaborative network among OEMs and assemblers • Designate physical location for e-bus manufacturing cluster • Develop virtual network to connect between assemblers and manufacturers • Adopt clear and continuous e-bus procurement policy • Develop E-bus rental business model as an alternatives • ICE bus salvage and recycling policy • Prepare large-scale infrastructure for full adoption of EV • Prepare field testing facilities • Time-based incentives to reduce development time	• Special incentives for e-bus operators • Capital imbursement to BMTA • Provide feasible business plan • Manipulate oil and electricity pricing • Framework for quality control in bus services business • Assign intermediary to work among public bus association • Provide free e-bus for a certain period of time as demonstration • Enforce public organization to use e-bus as an internal fleet • Provide government-owned maintenance garage

Figure 8-9 Strategic implementation plan for scenario 2: pure domestic manufacturing
(Source: Adapted from (Bousquet *et al.*, 2017)

8.2.3 Scenario 3: Selective Domestic Manufacturing

Scenario 3 is labelled as selective domestic manufacturing. It focuses on the exploitation of existing capabilities to maximise the potential value of the bus manufacturing industry. It can be considered as the most viable option for the current level of technological capabilities in electric vehicles of the Thai automotive industry. The core concept for this scenario is the sustenance of the value within the domestic supply chain amidst the disruption of EVs. Since batteries and electrical motors for e-buses would contribute to a large proportion of e-bus production value and Thailand still currently has significant technology gaps in these areas (Wanichanukul, 2020), it is essential for the economy of bus manufacturing industry to develop new products that could be applied to the e-bus manufacturing process. These products might be able to counter-balance the net loss from batteries and motors, which are very likely to be imported by most of the existing bus manufacturers in Thailand (Cherdchai, 2020). Nevertheless, it was asserted that some new ventures such as Energy Absolute Corporation (EA) have claimed that they have enough expertise to manufacture these components (Wongdeethai, 2020). As a result, the most important aspect of policy implementation in this scenario would be the clear strategic direction for the bus manufacturing industry. The segmentation of the market should be clearly designated to prevent conflicting interests and repetitiveness of technological investments among several stakeholders. These problematic issues might be augmented by the growth of market share, which will require more production output from all bus manufacturers in Thailand. Additionally, extra effort should be spent in the process of quality assurance and system integration because of the mixed origins of the bus components. It is vital that the assembly process for e-buses could run smoothly despite this drawback.

Policy targets for scenario 3 could be arbitrary, depending on the settled proportion of e-bus components to be manufactured in Thailand. If a high proportion of components are expected to be domestically manufactured, the targets would be like scenario 2. Conversely, if most components are planned to be imported from overseas, they will have more in common with the first scenario. The proportion of locally manufactured components can be regulated by local content policy, which would pre-emptively specify how much of the components would be manufactured in Thailand. Currently, it is expected that 45% local content policy would be viable for policy implementation, assuming that batteries and motor are both not manufactured in Thailand. Conversely, 75% local content will be possible if batteries and motors are domestically manufactured (Kumfoy, 2020). Other targets are mostly the mixture of recurring topics from previous two scenarios However, since the scope of this scenario will cover both domestic development and overseas purchase, it is obligatory for the government to have effective task management. Policy-based activities should be evaluated and prioritised accordingly, based on their urgency and connection to the main objective of the scenario. The creation of an intermediary organisation that was introduced in the previous chapter would be a good option for policy makers to delegate the increasingly complex policy implementation plan to a more flexible and fully dedicated party.

Implementation Plan - Scenario 3: Selective Manufacturing

Objectives

Core Idea - Current most viable option that required the least persuasion or incentives toward stakeholders.
- Generate sufficient value in the supply chain that would not drastically affect economical position of the country.

Objectives - Finding new venture to counter-balance net loss in supply chain value from higher value of imported components.
- Clear policy direction and regulation, including long-term market division and stakeholder's assignment.
- Make sure that assembly process run smoothly despite the usage of components from assorted origins.

	Researchers	Manufacturers	Assemblers	Operators
Targets	• Provide capable workforce • Target-based researches • Initial testing facilities • Effective learning process • Research quality • Supply chain value researches	• Increase value added components • Develop extra features of vehicles • Supply chain understanding • Components reengineering • Net income maintaining • Controlled layoff	• Reverse engineering • Components compatibility testing • Study components procurement options • Capture domestic market • Cost-saving process • Quality control • Components standard • Knowledge sharing to other industry	• Quality of service • Convenient of repair and maintenance • Affordable pricing • Sufficient amount of services • Business confidence • Transparency • Profitability
Activities	• Value-based researches, focusing on pricing and future prospect of each components in e-bus • Prioritization of research topics • Policy plan to gradually transform education institution toward modernized automotive industry • Brief technology roadmap • Small funding to establish demonstration center and testing lab • Develop control and measurement tools • Improvement of workspace and research environment	• Development of new value-adding venture, especially in digital and electronics appliances and features • Plan to leverage existing capabilities to maximize their gains • Develop strict regulation, standard, and quality control process for domestically manufactured e-bus components • Provide clear-cut diagram of prospective e-bus supply chain to stakeholders • Prepare job creation plan to accommodate employee who might be laid of in the future • Intensify domestic market research	• Segmentation of market for domestic e-bus assemblers • Technological workshop for Thai assemblers by invitee from overseas' partners • Provide exact amount of e-bus purchasing order • Organize cross-industry collaborative network • Develop E-bus rental business model as an alternatives • ICE bus salvage and recycling policy • Components and compatibility catalogue • Funding for reverse engineering attempt • Create equipment procurement's decision tree for bus assemblers	• Special incentives for e-bus operators • Capital imbursement to BMTA • Provide feasible business plan • Manipulate oil and electricity pricing • Framework for quality control in bus services business • Assign intermediary to work among public bus association • Provide free e-bus for a certain period of time as demonstration • Enforce public organization to use e-bus as an internal fleet • Provide government-owned maintenance garage

Figure 8-10 Strategic implementation plan for scenario 3: selective manufacturing
(Source: Adapted from (Bousquet *et al.*, 2017)

8.2.4 Scenario 4: Technology Absorption

Even though other scenarios feature some form of technology absorption, this last scenario would put it as the primary objective instead of supplementary activities. Thus, there should be an exclusive in-depth study on technology transfer at the industry level, in addition to the decision at the enterprise level. To clarify, each essential technology for the manufacturing and servicing of e-buses should be individually assessed. The assessment should be made on their significance towards industrial development, feasibility of the implementation, and accessibility to the source of a technology. Furthermore, the preparation for uncertainties in shifting political climate should also be made in the form of several contingency plans, which include secondary and tertiary external parties who can relinquish the technology when the primary source has failed to complete this task. In contrast to the first three scenarios where the balance of supply and demand are encouraged, this scenario is designed to be a pro-technological push approach of the policy implementation. Therefore, most of the efforts from the government would be directed at the acceleration of technological development among domestic manufacturers. The additional value that the government could be able to provide to the industry is the potential role as the mediator between overseas enterprises and domestic firms. It is expected that initial connections with overseas entities would be easier to establish with the involvement of public organisations, because of their credibility (Jangbua, 2019). Alternatively, this scenario can also be utilised as a complementary policy implementation plan to enrich other scenarios, in the case that more rigorous technology transfer mechanisms are required. This specific topic was further discussed in 'Evolution of Knowledge Networks, Technological Learning, and Development of SMEs: A Multi-Level Perspective of Innovation and Environmental Trends in the automotive sector of Thailand', which is another thesis that predominantly target the technological development of the Thai EVs industry (Jarumilint, 2021).

The initial target for this scenario is to shrink capability gaps that were explained in section 6.4. This could be accomplished by the improvement of the current research infrastructure of the automotive industry. In addition to the formation of an exclusive research and manufacturing cluster for the e-bus industry, the establishment of research cluster in other segments of EVs would strengthen the linkage between the EVs sector and the whole automotive industry. This environment will promote the exchange of information across sector and increase the rate of re-utilisation of domestic research. For overseas linkage, it is suggested that technology localisation programmes for bus manufacturers should be implemented by NSTDA, to alleviate the associated costs among private enterprises (Wanichanukul, 2020). The technology that should be localised from foreign companies should be an enabling technology that allows manufacturers to develop and sustain their own manufacturing process of e-bus based products in long term without prolonging supports from external organisation. In other word, these technologies should engage with some of their existing capabilities. The examples of technologies that were suggested are battery packing, electrical interface components such as converters, and software-based components (Wanichanukul, 2020).

Implementation Plan - Scenario 4: Technology Absorption

Objectives

Core Idea - The attempt to acquire necessary technologies for electric vehicle's components manufacturing.
- Potentially good prospect of technological development which could add to current capabilities of the industry.

Objectives - Provide multitude of policy options to attract wide arrangement of potential alliances and partners.
- Develop contingency plan in a case that the agreement or the progress of absorption does not goes as planned.
- Design flexible initiatives for the possibility that this plan could be integrated in other scenarios as an additional option.

	Researchers	Manufacturers	Assemblers	Operators
Targets	• Absorption capacity • Promote learning environment • Business-policy researches • Match enterprises with technologies • Knowledge distribution channels • Target-based researches • Numbers of cross-enterprise trainees	• Research-industry linkage • Indicators of knowledge absorption • Indicate current field of expertise • Compatibility with partners • Technological progression • Strategic alliance plan	• Contingency plan for assembly • Domestic and overseas market • Cost-saving process • Quality control • Development time	• Quality of service • Convenient of repair and maintenance • Affordable pricing • Sufficient amount of services • Business confidence • Transparency • Profitability
Activities	• Design multiple scenarios for absorption of requisite knowledge from overseas partners. • Long-term technology roadmap with matching target enterprises. • Situational training and learning of workers and researchers • Act as intermediary for domestic and overseas firms • Create network among researchers • Exchange of human resources between researches and industry sector • Proactively make connections in the global supply chain of electric vehicles • Readily to offer opportunities to interested parties	• Develop metrics to measure technological absorption of OEMs • Establish effective communication channels between industrial and research sector • Manufacturer's capabilities analysis • Survey overseas enterprises for compatibility of technologies and corporate culture • Provide funding for endeavor in learning process and attempt to ally with overseas firms • Development of technology readiness level scale	• Contingency plan in the case that stakeholders fail to reproduce desired results • Develop market base on technology readiness level of industry • Focus on in-house process development during downtime • Facilitate collaborative network among OEMs and assemblers • Develop E-bus rental business model as an alternatives	• Special incentives for e-bus operators • Capital imbursement to BMTA • Provide feasible business plan • Manipulate oil and electricity pricing • Framework for quality control in bus services business • Assign intermediary to work among public bus association • Provide free e-bus for a certain period of time as demonstration • Enforce public organization to use e-bus as an internal fleet • Provide government-owned maintenance garage

Figure 8-11 Strategic implementation plan for scenario 4: technology absorption
(Source: Adapted from (Bousquet *et al.*, 2017)

In conclusion, different scenarios in the e-bus adoption policy would place different groups of stakeholders at a different level of engagement and responsibilities. For example, the last scenario which particularising the plan for technological absorption would require more manpower in the research sector, in comparison to the first scenario which has a focus on e-buses and their component's imports. The policy-based activities aiming at e-bus users are relatively similar across all scenarios since these scenarios do not comprise of major differences in these areas of interest. Hence, they are omitted from figures 8-9 to 8-11 to reduce the clutter in these charts. Additionally, it is expected that most of policy activities aimed at bus operators would also be very similar because of the same reason. Nevertheless, public policy programmes to support the usage of e-buses would still be essential for the adoption of e-buses in every scenario. If the scenarios were designed to focus on differences in term of service models for electric buses, there could be large variances in policy implementation for e-bus operators and users. Lastly, several initiatives might appear to be contradictory with each other. Some of them might be difficult to be cohesively implemented without additional issues. For example, it might be impossible for the government to keep funding both the BMTA and procure a large batch of imported buses at the same time, without taking in significant financial risks. Nonetheless, the search for optimised decisions between several initiatives is not the main objective for this policy framework. In contrast, this framework is designed to provide the outline for policy makers who would be able to access additional information, and ultimately pass on a more reasonable judgment on this matter.

8.3 UML Activity Diagram: The Implementation of Policy Initiatives

8.3.1 The Compilation of policy initiatives

Most policy initiatives from the previous section activities would usually be considered as an overlapping effort that would be directed towards at least 2 groups of stakeholders. As a result, these activities can be further categorised into 4 different groups, which are called 'interface' (Table 8.3.1 – Table 8.3.5). For example, the support for research commercialisation in a battery packing process should locate at the interface between research and industry. In this specific section of the thesis, the meaning of 'industry' will cover for both component's manufacturers and assemblers of e-buses. Additionally, all presented policy initiatives were also grouped based on their relevance in a specific scenario. Some activities will be exclusive to a single scenario, while some of them will be applicable for all scenarios. In summary, policy differences from this model mostly exist in the research and development process rather than the services and usage of the e-bus. There are a less diverse set of activities in the downstream, when compared to the upstream of the supply chain. Furthermore, most of the activities that would be targeted at operators-users interface will be universally applicable across all scenarios in this specific framework. These policy initiatives could be considered as favourable choices for policy makers because they could be applied in any given scenario. This could be useful in situations where the government cannot fully commit to the implementation of any single scenario. However, these activities have not yet been proven that they will be more beneficial than the more exclusive selection of policy initiatives.

Table 8-1 shows a compilation of policy activities that would be useful for the development of the e-bus industry, regardless of which scenario is pursued by the government. As mentioned before, most of these initiatives are the summarisation of suggestions that were presented in the in-depth interviews. Some activities were covered in the previous chapters of this thesis, such as the creation of a technology roadmap and the staging of prospective e-bus supply chains. In addition, the development of monitoring and measurement tools will also be covered in the next chapter. Nevertheless, these activities should be revised again after a wider scope of information from stakeholders have been collected. Furthermore, they could be tailored further to match the objectives of the scenario. This practice would make the implementation of public policy more concise and effective with regards to the current financial, human, and temporal resources that can be provided by the government.

Table 8-2 Compilation of communal policy initiatives in all scenarios

Interface	Activities
Research-Industry	• Design technology roadmap. • Development of control and measurement tools. • Establish effective communication channels between industrial and research sectors.
Manufacturer-Assembler	• Manufacturer's capabilities analysis • Provide clear-cut diagram of prospective e-bus supply chain to stakeholders. • Cross industry development programme within relating technologies. • Prepare job creation plan to accommodate potential laid off in the industry.
Assembler-Operator	• Provide some public maintenance garage for e-buses. • Provide free e-buses to operators for a certain period. • Assign intermediary to work among public bus association. • Facilitate collaborative network among OEMs and assemblers. • Develop E-bus rental business model as an alternative option. • Salvage and recycling policies for ICE buses.
Operator-User	• Designate exclusive lanes for e-bus. • Construct new express electric bus lanes that link between major locations. • Policy to prohibit the uses of diesel buses in public services. • Renew of traffic regulation in accordance with the inclusion of e-buses. • Initial discount for bus fare. • Route planning in conjunction with other mode of public transportations. • Public relation of e-bus aiming towards Bangkok population. • Pollution measurement model. • Special incentives for operators that use e-buses. • Capital imbursement to BMTA. • Provide feasible business plans. • Manipulate oil and electricity price. • Framework for quality control in bus-based transport services. • Enforce public organization to use e-buses as internal fleets. • Development of digital application for public buses.

(Source: Summarised from the data collected.)

The theme of activities in the first scenario are mostly surrounding the supports for the procurement of e-buses and their components. It is ideal for the government to also introduce countertrade strategies within these procurement policies. Offset arrangements should be made with the agreement of sales, to increase the chance for technology transfer (Yülek and Taylor, 2012). In this scenario, it is likely to have less manufacturing activities due to the limited amount of policy support for domestic manufacturing. Thus, technologies relating to e-bus public transport system, component's quality control, and field testing should be prioritised over the enabling technologies in manufacturing process. In addition to procurement policies, government would have various dealing with fiscal and investment policies. It is possible for Thailand to replicate the former model of the automotive industry and promote foreign direct investment (FDI). This strategy can lead to quick diffusion of the e-bus manufacturing industry in Thailand. However, it is found that this approach could also cause domestic entrepreneurial activity to deteriorate (Danakol *et al.*, 2017). This situation happened before in the ICE-based automotive industry, where Thai OEMs struggled to absorb higher level of capabilities from the MNCs. This circumstance limited them to remain as the suppliers in lower tiers of the supply chain. To summarise, foreign procurement and investment policies should be closely monitored, and ensure that they will not have long-lasting adverse effects to the domestic industrial economy.

Table 8-3 Compilation of applicable policy initiatives in scenario 1: pure imports

Interface	Activities
Research-Industry	• Negotiate for possible technological exchange with purchasing agreement. • Seeking economical merger and acquisition opportunity.
Manufacturer-Assembler	• Offer tax rebates or exemptions. • Develop fundamental stage of inspection for imported products. • Provide financial credit for Thai assemblers. • Component's procurement decision tree for bus assemblers.
Assembler-Operator	• Investment intensives for assemblers. • E-bus workshop for Thai assemblers by invitee from overseas. • Allocate budget for e-bus purchases within BMTA. • Assignment of assembled e-bus to testing fields.
Operator-User	N/A

(Source: Summarised from the data collected.)

The scope of policy activities in the second scenario will be much wider than the first scenario. In addition to the set of mutual policy initiatives that are universally applicable to all scenarios, successful implementation of this scenario would require extensive collaborative efforts from stakeholders in every interface of the industry. The scale of these initiatives will also be larger than other scenarios, since it was established that the industry would also need to directly compete in the global market, in addition to the saturation of domestic market with e-bus based products. Infrastructural development is the key success factor for this achievement. The three pillars for a nationwide adoption of e-buses were found to be the development of charging and energy infrastructure, the provision of fiscal policies for public and private service operators, and the scheduling and optimisation of e-bus operation. Thailand needs to restructure and transform not only their bus manufacturing industry, but the whole EV industry to attain technological and market synergy (Massamadon, 2020a). Both technological and market research would be compulsory to the competitiveness of domestically manufactured EV in the global market. In conclusion, Thailand still has the large amount of technological and infrastructural gaps to overcome. As a result, the full realisation of this scenario might take several decades of continuous policy development and corresponding implementation.

Table 8-4 Compilation of applicable policy initiatives in scenario 2: pure domestic manufacturing

Interface	Activities
Research-Industry	• Gradually transform education institutes towards modernized automotive industry. • Propose internship programmes to link research and industrial sector. • Provide awards for excellence research… • Market survey and analysis. • Block grants to different technological organizations.
Manufacturer-Assembler	• Customer segmentation of overseas market. • Automotive industry transition plan from ICE to EV. • Prepare large volume of testing facilities. • Full-scale consortium of e-bus OEMs.
Assembler-Operator	• Designate physical location for e-bus manufacturing cluster. • Adopt continuous e-bus procurement policy. • Prepare field testing facilities. • Time-based incentives to reduce research and development time.
Operator-User	• Prepare large-scale infrastructure for the full adoption of EV.

(Source: Summarised from the data collected.)

The third scenario emphasises the prioritisation of policy implementation. The inclusion of prioritisation makes this scenario arguably the most realistic alternative among the others, since there are several resources limitations in the Thai e-bus industry that were explained in chapter 6. Therefore, the focus of policy implementation should be on the activities that maximise economic value for the e-bus industry. Nonetheless, there were some arguments among stakeholders regarding the choices of activities that are currently implemented by the government. For example, the initiative for ICE to e-bus conversion was criticised on the topic of associated costs, in comparison to the quality of finished products (Suebsupanand, 2020). In contrast, this initiative was initially fully promoted by the government as the groundwork for learning opportunities for domestic assemblers to improve their proficiency in e-bus manufacturing and raise public awareness (Wongdeethai, 2020). This conflict can generate several crossroads in decision making process for this scenario. Precise and defined decisions must be made before the eventual execution of the public policies. As explained in the literature review regarding the electric vehicles market, the factual data from market research and clear market segmentation would improve the commitment of stakeholders. It would also increase the chance of success to the market introduction of finalised EV-based products. After the existing market has been established, it would be easier for the government to set the direction for research-based policies without garnering conflicting opinions among stakeholders.

Table 8-5 Compilation of applicable policy initiatives in scenario 3: selective manufacturing

Interface	Activities
Research-Industry	• Value-based research, focus on the future prospect of each component in e-buses. • Small funding to establish demonstration center and testing lab.
Manufacturer-Assembler	• Development of new value-added ventures in digital and electronics features of e-buses. • Plan to leverage existing capabilities to maximize their gains. • Develop strict quality control process for domestically manufactured components.
Assembler-Operator	• Domestic market segmentation for e-bus assemblers. • Technological workshop for Thai assemblers by invitee from overseas partners. • Provide precise amount of purchasing order. • Funding for the attempt in reverse engineering. • Component's procurement decision tree for bus assemblers.
Operator-User	N/A

(Source: Summarised from the data collected.)

There are many available technology transfer mechanisms. The choice regarding which method that should be implemented is situational and based on the current resources, technological profile, and objectives of the policy. Despite being mentioned in the first scenario, foreign direct investment (FDI) is also a viable option for a technology transfer. However, the benefits regarding technological knowledge were underwhelming in the past incident surrounding ICEVs manufacturing industry, in contrast to substantial economic benefits that were claimed by the government (Noomwong and Sutheejaruwat, 2019). This circumstance indicated that the choice of method in the technology transfer process will be the key factor for this scenario. It was asserted that successful implementation of technology transfer would require the government to specifically assess the motivation of the stakeholders, and choose the methods accordingly (Kremic, 2003). Moreover, they need to broadcast the intention to develop technologies to all actors in the system. This is the main difference from technology transfer in a corporate setting where technology transfer process is closely controlled and usually confidential. This mismatch could lead to the failure of policy initiatives to promote technology transfer schemes on a national level. As a result, it is recommended that contingency plans should be created for every tier of technologies that would be developed. The development of technology readiness level (TRL) scale would be beneficial to this endeavour, since it could provide real-time overview on technological state of the e-bus industry (Héder, 2017).

Table 8-6 Compilation of applicable policy initiatives in scenario 4: technology absorption

Interface	Activities
Research-Industry	• Design multiple scenarios for overseas technology transfer. • Situational training and learning of workers and researchers. • Act as intermediary for domestic and overseas firms. • Exchange of human resources between research and industry sector. • Proactively make connections in the global supply chain of electric vehicles. • Readily offer market opportunities to interested parties. • Develop metrics to measure learning capability of OEMs.
Manufacturer-Assembler	• Survey overseas enterprises for compatible technologies. • Provide funding for learning process and the attempt to ally with overseas firms. • Development of technology readiness level scale.
Assembler-Operator	• Contingency plan for possible failure of domestic stakeholder's learning process. • Develop the market based on technology readiness level of Thai industry. • Focus on in-house process development during idle manufacturing time.
Operator-User	N/A

(Source: Summarised from the data collected.)

After the policy initiatives were identified, their necessities and potential outcomes should be made clear to the stakeholders. For this specific purpose, the activity diagram of Unified Modelling Language (UML) will be used as the modelling structure for this section. A UML activity diagram is a behavioural diagram that is often utilised in the process of workflow design, which identifies pre and post conditions of each activity (Bennett, 2001). The application of the activity diagram in this policy framework is the creation of logical connections that would rationalise and justify the inclusion of policy initiatives that are proposed by policy makers.

The creation of activity diagram starts with the specification of a particular issue within the system. Then, a single policy initiative that is decidedly prominent among the solutions to this problem will be identified as a starting point for the diagram. For example, the adoption of continuous e-bus procurement policy would be the central instrument to improve the business feasibility for Thai e-bus assemblers (figure 8-12). Nonetheless, it can be assumed that a single solution is most likely to be inadequate for a large-scale issue in a complex system such as the automotive industry in Thailand. It is possible that there will be some adverse effects from the implementation of a specific initiative, which would setback the progress of e-bus industry (Wongdeethai, 2020). Therefore, the activity diagram would be expanded beyond the first node based on additional topical inputs that should be collected during the process of policy implementation. In this study, most of these inputs came from the data collection process, which reflect the situation of Thai automotive and e-bus research and manufacturing industry in the year 2020. Finally, many activities within the diagram can be individually extended to a new activity diagram to prevent visual clutter. For instance, incentives for e-bus operators (figure 8-12) could be established as the new starting point for another diagram that is purely focused on the promotion of e-buses usage among private service bus operators.

The total of 4 activity diagrams are presented in this thesis as a practical example. These 4 diagrams represent the most urgent issues for the e-bus research and manufacturing cluster. Nonetheless, additional diagrams for a different policy implementation plan could be formulated by using the same methods as explained before. A few extra suggestions for policy implementation plan in the Thai e-bus industry including the enforcement of the adoption of electric buses in public transportation and public fleets, the transformation of the education curriculum towards electric vehicle industry, and the establishment of a physical location for e-bus innovation cluster. Moreover, the compilation of policy activities could also be expanded by the gathering of more recent information from the local and global e-bus industry.

8.3.2 ACT 1: The Promise of Operational Feasibility for Domestic Assemblers

The continuous adoption of e-bus procurement policy is predicted to be the most essential policy initiative that would improve the feasibility of e-bus manufacturing activities among domestic manufacturers. This could be accomplished in three separate ways: the procurement for public operators, the procurement for the usage in public organisations, and the procurement for private operators. The priority is expected to be in descending order i.e., the purchase for public operators would take the top priority. Currently, there is an initial programme for the procurement of 2,511 units of e-buses to be used by the Bangkok Mass Transit Authority (BMTA), who operate public bus transport in Bangkok and its vicinity (*Ministry approve the procurement of 2,511 units of e-bus for BMTA*, 2020). Nonetheless, the market should still be assessed afterwards, to ensure that this amount is adequate to stimulate the operation of manufacturers. If the business feasibility for manufacturers is not attained, the government should increase the amount of purchasing order or adopt this form of policy in other lateral market segments.

The stimulation of demand in the private operator’s segment would be more difficult to achieve, because most of the operators are smaller enterprises who tend to lack necessary budgets for the procurement of the e-buses, as long as the current price is not comparable to the ICE buses (Thuntiwiroon, 2020). Hence, incentivised policies should be adopted to alleviate this issue. Firstly, it is possible for the transport ministry to limit the amount of ICE buses, by introducing legal penalties to private operators who operate with less environmental-friendly ICE buses. However, this approach could lead to political friction between the association of private operators and public organisations. The balance between ‘soft’ policy e.g., fiscal policies to discount the pricing of e-buses, and ‘hard’ policy e.g., the prohibition of ICE buses should be made for the attainment of market equilibrium. Additionally, a business model of e-bus rental could be permitted. The involvement of well-funded investing enterprises might lessen substantial number of risks for both smaller private operators and debt-ridden state enterprises such as BMTA, as well as allow them to prosper as a platform owner of the e-buses rental service.

8.3.3 ACT 2: The Reinforcement of Confidence in E-Bus among Service Operators

Another prominent issue that prevents the proliferation of the e-bus industry in Thailand is the lack of confidence among transport service operators. The concern that was most referred to is the economic feasibility in the utilisation of e-buses as the main service fleet (*Opinions of operators on E-Bus compared to ICE-Bus or NGV-Bus*, 2020). In fact, this circumstance is likely to be difficult to solve by the implementation of public policy alone. The pricing of e-buses is expected to be inversely proportional with the advancement of technological development in electric battery, which is the factor that could not be controlled directly by the government. Alternatively, the policy options that can mitigate this issue are the reconstruction of public bus operating model and transportation system. It was asserted that the majority of bus-based public transport services in Bangkok were not properly utilised, due to the complications of repetitive routing and badly-managed concessions (Bualar, 2013). Large scale route restructuring with the inclusion of other modes in public transportation, such as the sky train and the underground train into the design process should be implemented. This activity would greatly improve service quality of the public transportation and would positively affect public perception regarding public buses.

On the other hand, the government should also provide examples of feasible business plans for private operators to improve their understanding of the operating model for e-buses. A pilot model for e-bus transport service in 6 major urban areas was conducted by The Office of Transport Policy (Kumfoy, 2020). It could be used as the reference in this regard. Ultimately, if these activities are not adequately convincing for private operators to invest in e-buses, incentives policies should be implemented. This set of incentive policies should target at service operators instead of manufacturers. These two sets of incentive policies could be contradictory with each other. For instance, it is almost impossible for the government to reduce the price of e-buses for the service operators while also promoting the profitability of domestic manufacturers.

8.3.4 ACT 3: The Establishment of Collaborative Network within the E-Bus Industry

A well-designed collaborative network structure is mandatory for an effective communication and cooperation among stakeholders. The first step for a good design process is the determining of the network complexity. Different degree of complexity in the network structure would result in a different set of policy initiatives that could be implemented. For example, physical linkage or cluster might only be necessary in a highly complex network where the concern for security is high and the access to information is heavily restricted. It was concluded that a physical cluster could facilitate the collaborative innovation within the targeted industry (Connell, Kriz and Thorpe, 2014). However, it also requires a large amount of time and money investment to be established. Therefore, a smaller and less complex network might be benefit from a more flexible virtual cluster. In addition, it was found that inconsistent communication between stakeholders can impede the rate of progress in the implementation of public policies (Jangbua, 2019). Hence, this virtual linkage will require consistent upkeep of communication channels. The introduction of an intermediary organisation might improve the effectiveness in this regard. This model was previously applied in the food technology sector of Thailand, with the creation of Food Innopolis. In addition to domestic linkage, international networking would be especially important to scenario 2 and 4 because of their heavy emphasis on cooperation with overseas market and actors.

The monitoring of communication channels and the collaborative network is another topic that policy makers should focus on. The countermeasure should be created for the case of ineffectual communication between stakeholders. For example, cross industry development programmes could be utilised to facilitate constant engagement between research-based actors. For industrial-based actors, the clear market segmentation would improve the level of interest among new ventures and investors, and likely to stimulate the operation in the manufacturing sector during the introductory stage of e-buses adoption.

8.3.5 ACT 4: The Improvement of Domestic Manufacturer’s Technological Capabilities

It is difficult to envision a single policy instrument that should be a prominent initiative that would be central to the improvement of technological capabilities among domestic manufacturers. The difficulty originated from the differing level of technological competencies that are currently possessed by each manufacturer (Laoonual, 2020). This increases the complication of the technology transfer process because each stakeholder would respond differently to a different method of technology transfer. The suggestion for the initial stage of this implementation plan is the development of a proper target, regarding what kind of technologies should be acquired and when they should be acquired by the manufacturers. This should be prepared simultaneously with the assessment of manufacturer’s current capabilities. Both assessments will be highly contributory in the decision to choose appropriate technology transfer mechanisms that are suitable for each circumstance.

The current level of capabilities among Thai manufacturers might be an indicator towards the appropriate scenario for the policy implementation. If there is a considerable gap in technological expertise that prevents them from consistently maintaining the quality of finished products, it might be more economical to invest in e-bus imports. On the other hand, if only a small amount of enabling technologies is required for domestic manufacturers to produce products with competitive quality, the scenario of technology transfer might be a worthwhile pursuit. Another popular alternative that was used in many developing country is the import of technology (Madanmohan, Kumar and Kumar, 2004). This scheme could be considered as the compromising choice that exist between pure imports of finished products and an attempt in technological learning for manufacturing process. Regardless of the choices, several preparations still need to be made, many of them were already mentioned in the previous section of this chapter.

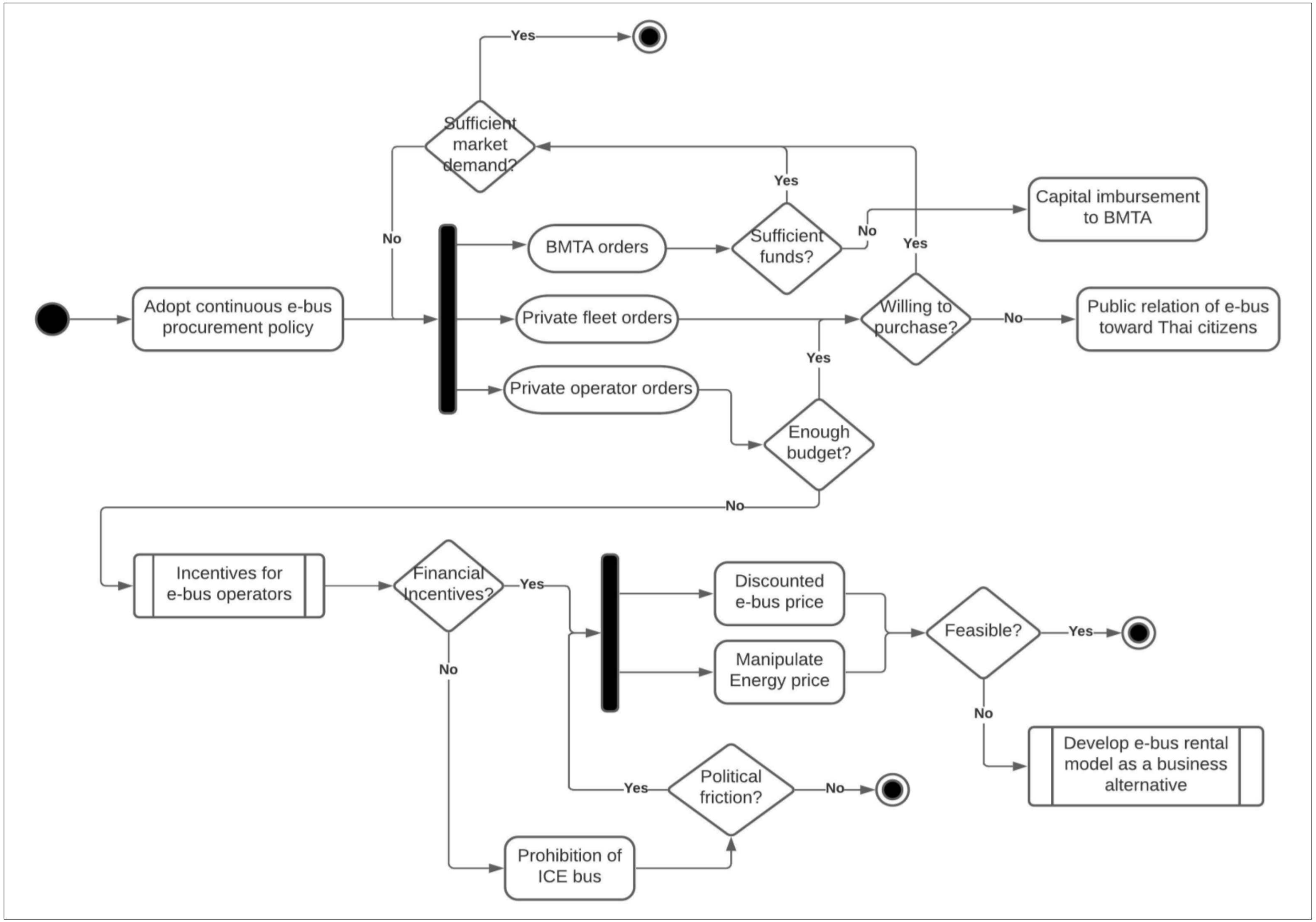

Figure 8-12 UML activity diagram 1: The promising of operational feasibility for domestic assemblers

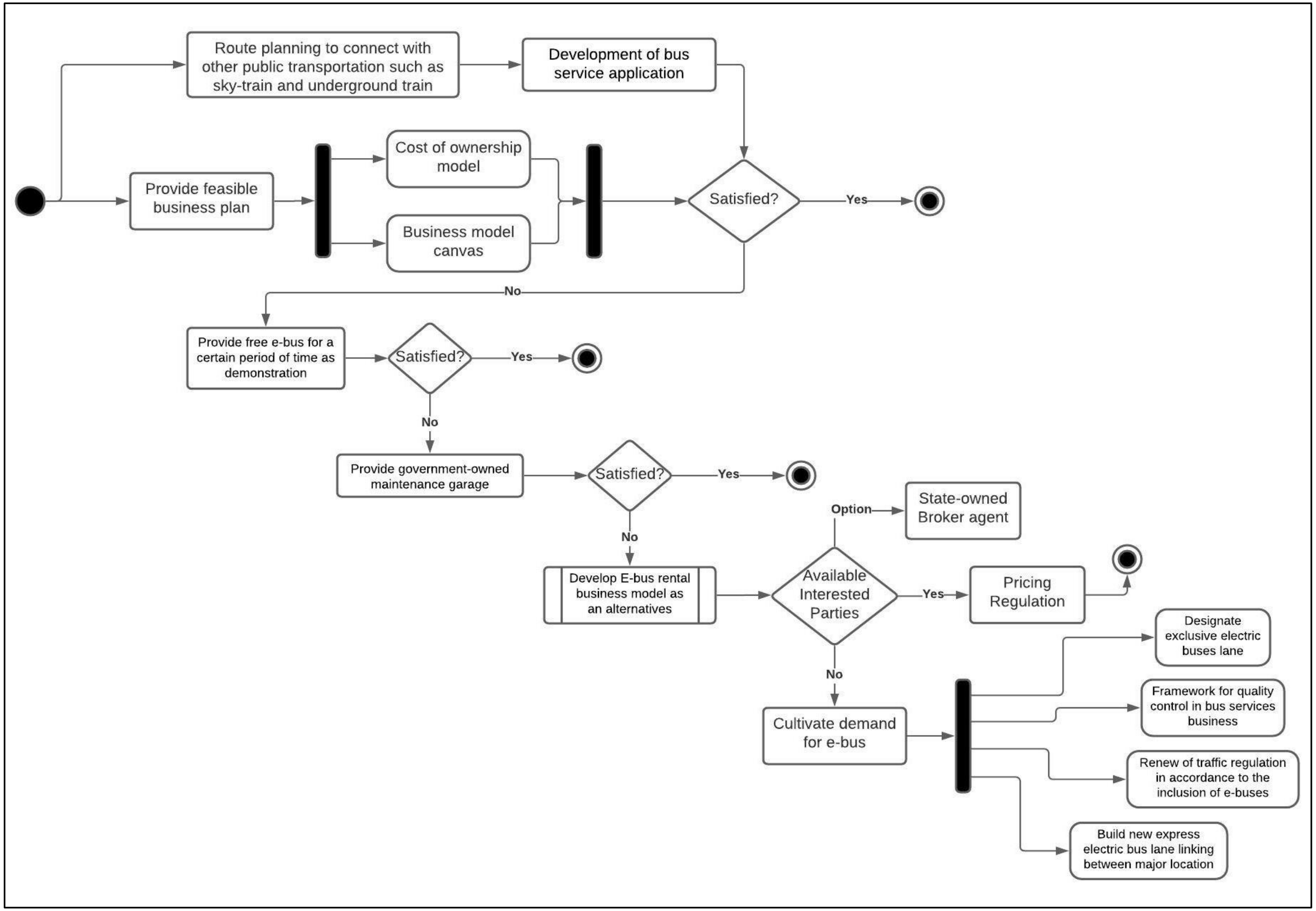

Figure 8-13 UML activity diagram 2: The reinforcement of confidence in e-bus among service operators

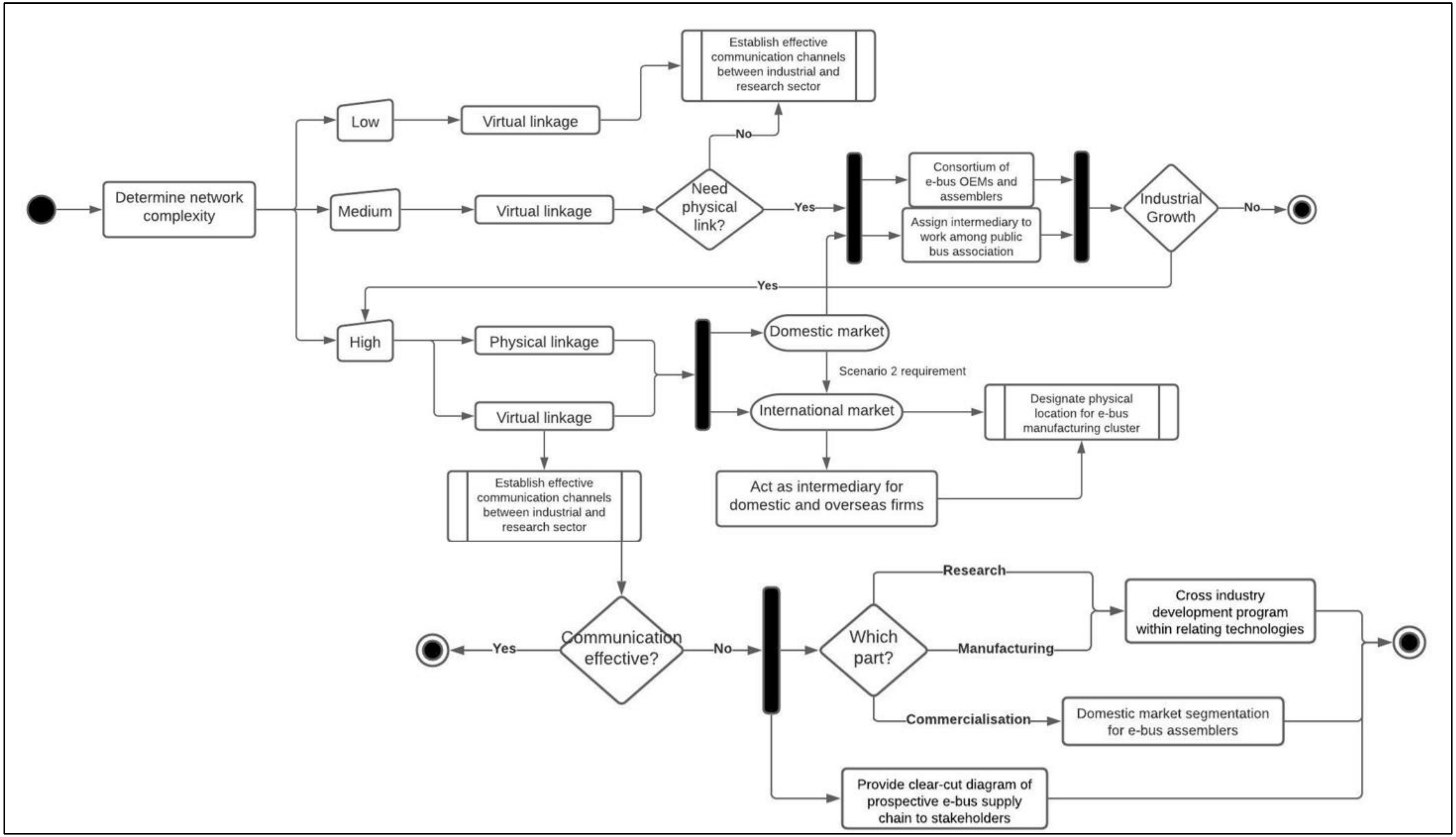

Figure 8-14 UML activity diagram 3: The establishment of collaborative network within e-bus industry

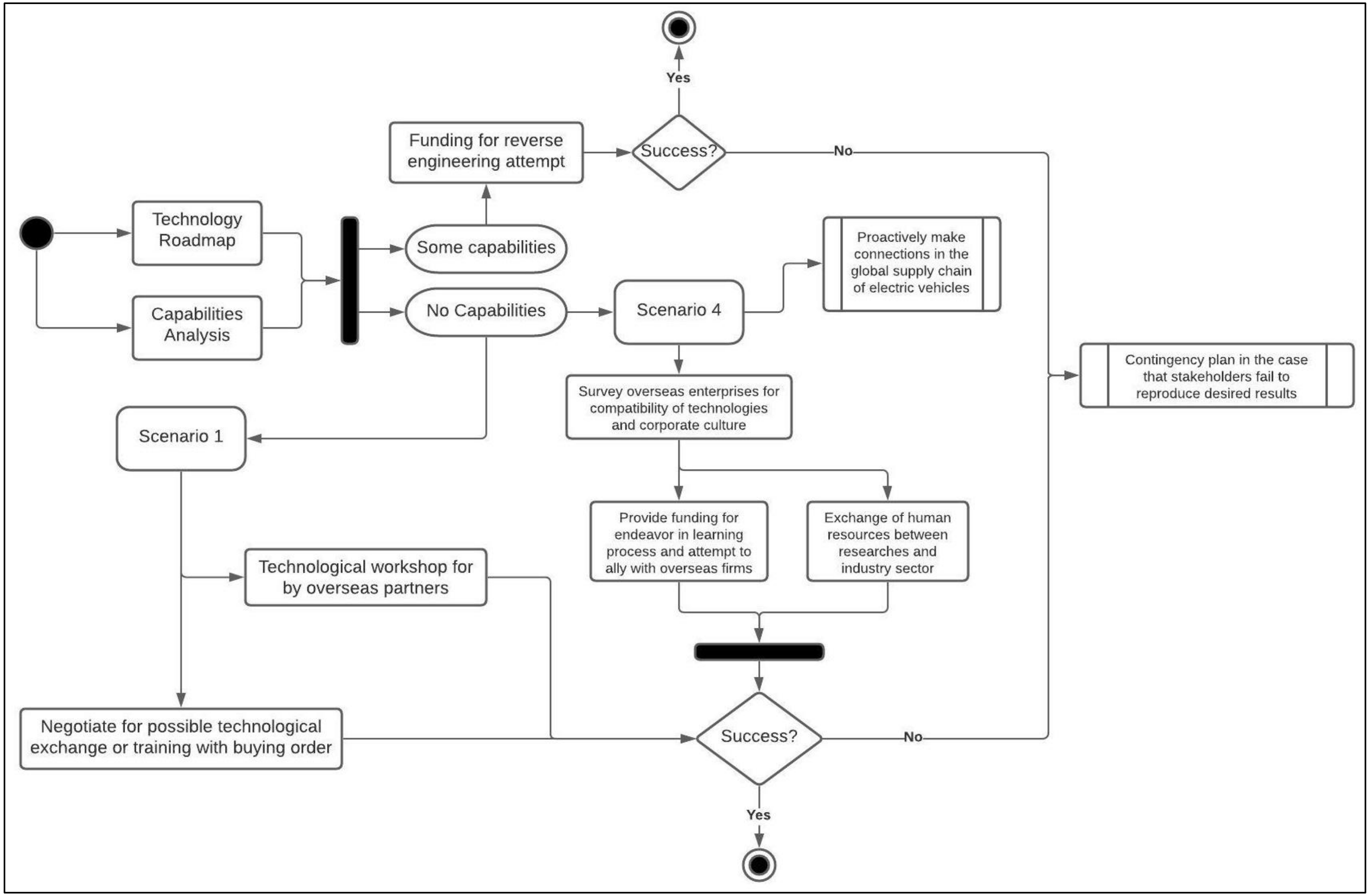

Figure 8-15 UML activity diagram 4: The improvement of domestic manufacturer’s technological capabilities

Chapter 9 The Evaluation of the Policy Plan and the Framework

9.1 Policy Plan Evaluation via Balanced Scorecard

The accountability of public policies that are implemented by the government is one of the concerns from policy experts in Thailand. It was asserted that there should be a complete performance measurement system to measure the degree of success in the implementation of national policy (Noomwong and Sutheejaruwat, 2019). Hence, a measuring tool was integrated into this policy framework for this purpose. The contents within this tool are directly connected to the plans and strategies described in this thesis to form an effective mechanism which enable the evaluation of the policy implementation in this interlinked system. Because these plans and strategies were readily presented in the previous chapters of this thesis, they could be immediately applied into the design of policy evaluation process. In this chapter, there are two monitoring tools that were applied to the policy implementation plan: balanced scorecard and work breakdown structure. The data collected from interview participants was used to assign the objectives and the appropriate metrics for the balanced scorecard. It should be noted that the target for each metrics is purely the speculation of the author based on secondary information on Thai automotive and e-bus industry. Thus, these numbers are not the actual benchmark that was set by the Thai government and should be used carefully.

Balanced scorecard, which was introduced by Kaplan and Norton (Kaplan, 1996), is a comprehensive management tool for the measurement of overall performance of the organisation. Since it was originally designed for the application in the private sector, there should be some modification to the format of the scorecard to match the attempt to utilise it in a public policy setting. Nevertheless, the core process in the creation of the scorecard is still identical to the original concept. This concept can be summarised as the derivation of performance measures from the established strategic goals of the organisation. These measures are then grouped into 4 different perspectives in the scorecard (Kaplan and Norton, 1996).

9.1.1 Economics Performance

Wealth of the shareholders is the main objective for the existence of a profit-seeking private enterprise. Hence, it is reasonable that financial performance is the first perspective within the original design of balanced scorecard. However, this definition is not fully applicable for the public policy setting since the driving forces behind national objectives are not solely based on financial profit for the government. Instead, the welfare of the country and its population should be regarded as the top priority. As a result, it is renamed into 'economics performance' in this framework to emphasise the larger scale of interests at the national level, in contrast to corporate level measurements.

The reduction of fuel consumption in the public transport sector could be contributory to the plan to reduce fuel imports in Thailand. Currently, Thailand has consistently imported crude oil worth over 600,000 million Baht (14k million GBP) in every year except 2020 during the last decade ('*Thailand's Crude Oil Imports 2011-2020*', 2021). The reduction of this amount could be an ideal tangible target in terms of economic development which is related to the adoption of electric buses. Additionally, another tangible target that could be set is the differences in carbon dioxide emission from the vehicles in urban areas after the adoption of electric buses. In addition to numerical targets, the government could also adopt conceptual targets such as a target number of electric bus service routes in Bangkok for the future. The examples of this type of targets were presented in the segment of technology roadmapping for the electric bus industry in chapter 7 to designate appropriate research topics for the industry.

It was stressed many times by Thai stakeholders from multiple sectors that the demand for electric buses would be the most important driving force for the growth of the electric bus manufacturing industry. Therefore, the opportunity for research commercialisation would be an asset for many research organisations which can positively influence the growth of the industry. This could be accomplished by the formation of active connections between electric bus manufacturers and research institutes. This linkage will have a positive effect on the impact of the research to the actual development of products in the electric bus industry. The metric for this objective includes the number of publications in research that are related to the manufacturing and the operation of electric buses. The target can be made in conjunction with national policy in technological development to maximise its relevance. For example, the topics of research in the early stage of development might focus specifically on the development of the manufacturing process instead of any other areas.

Large financial investment is expected from the government during the transformation of automotive industry into the new format of supply chain that is driven by electric vehicles (Massamadon *et al.*, 2020). This investment will not be limited to only the research and manufacturing sector, but also the extension of support towards the state enterprise. In Thailand, the Bangkok Mass Transport Authority (BMTA) is the largest service provider of bus-based public transportation. It was stated that the BMTA has not been in a healthy financial state for a long time. The annual net loss of BMTA has been consistently above 7k million Baht (163.45 million GBP) during the past decade (Laoonual, 2020). While it is almost impossible to rescue this organisation from this financial loss, it would be ideal to maintain financial stability and minimise the increment of additional debts during the future acquisition of electric buses. This could be accomplished by the major restructuring of an existing operation system, which was inefficient in term of assets utilisation.

Table 9-1 Economics performance perspective of balanced scorecard

Economics Performance			
Objectives	Reduction of fuel consumption in public transport sector.	Create opportunity for research commercialization.	Maintain economic stability while increase the investment.
Metrics	• Reduction in fuel imports for bus-based transportation • Reduction in CO2 emission from vehicles • The growth of private e-bus operators	• Number of universities research that related to the commercialization of e-bus • Number of industrial enterprises that utilize research outputs from domestic researchers	• Net income of Bangkok Mass Transport Authority • Increment of budgeting towards e-bus related initiatives • Reduction of public debt regarding bus-based public transportation
Targets	• Reduce annual crude oil import to less than 40k million liters by 2026 • Reduce national CO2 emission in transport to less than 60k million tons by 2026 • At least 5 e-bus operators and 10 routes in Bangkok by the end of 2022	• 5 publications of research that related to e-bus manufacturing process per year • 5 publications of research that related to the service operation of e-bus per year • At least 1 active connection between every e-bus assembler with at least one research institute	• Maintain annual net loss of BMTA at 7k million THB during the implementation of e-bus • Annual growth of 10% in national budget for e-bus based initiatives • Reduce monthly public debt of BMTA to 100k million THB by 2026
Initiatives	• Provide more incentives for e-bus business start-up, especially the discount on rules and regulations. • Downsizing of BMTA to free-up the market for private operators	• Pursue the research according to technology roadmap that is derived from state of the industry • Facilitate and initiate formal connection between industry leaders	• Restructure public bus services by discarding under-utilized route and create more express bus route connecting major locations

	• Accelerate the policy regarding the control of vehicles emission standard	and research organizations and universities.	• Create forward budgeting plan of public transport by considering the implementation of e-bus

(Source: Summarised from the data collected.)

9.1.2 Stakeholders Relationship

Like the previous section, the original label for this perspective of balanced scorecard was changed from 'customer relationship' to 'stakeholder relationship' to match the setting in public policy. This newly labelled perspective implies the shift in area of interests from a customer-focused metrics towards a more encompassing perspective, which also include the performance measurement regarding the relationship among suppliers and other partners. This perspective covers all inter-organisational interactions between each actor in the system. Several indicators for relationship are intangible and difficult to be systematically assessed. Nevertheless, it is essential to evaluate the performance of this specific category, since the cooperativeness of stakeholders is one of the most important elements for the effective implementation of public policy (Keast and Hampson, 2007).

There are two main objectives for this perspective. The first objective is to increase the engagement of manufacturers and assemblers in the electric bus research and manufacturing cluster. As mentioned in earlier chapters, the increase in frequency and intensity of collaborative efforts between domestic manufacturers would be one of the main themes for future development in the electric bus research and manufacturing cluster. One of the prominent challenges for this endeavour is the existence of appropriate metrics to measure this type of performance. Moreover, it might be difficult to achieve a certain level of accuracy in the measuring process, which would muddle the actual performance level, and consequentially mislead the policy makers. The utilisation of simpler methods to track and document physical interactions between stakeholders might be able to mitigate the issue of inaccuracy. It was found that there are some collaborations between manufacturers and research institutes, unknowingly to other actors within the cluster (Cherdchai, 2020). This circumstance might create a silo problem for domestic research at the national level in the long run. Thus, a clear documentation for this kind of interactions should be recorded by the central regulator to keep track of research progress and cooperative efforts between stakeholders within the cluster. In summary, an electric bus cluster should attract several dispersed stakeholders into a single regime. This action would greatly simplify the organisation of future public policy implementation within the e-bus industry in Thailand.

The second objective that is designated for this perspective in the balanced scorecard is the maintenance of positive relationship between state enterprises; mainly energy and land transportation authority, and service providers in the public transport sector. The collaboration between these two groups of stakeholders will be inevitable in the adoption of electric buses as the new alternative to urban public transportation. Therefore, a supportive relationship between them would constitute to a successful implementation of e-bus policy. Like the first objective, the positive relationship between organisations will be difficult to gauge. As a result, quantitative metrics that could be set as strategic targets would not be readily available to collect. However, it is possible that quantitative metrics could be obtained by the coding of qualitative information. For example, the feedback from stakeholders can be interpreted as either positive or negative. After that, the proportion between positive and negative feedbacks can be calculated. This proportion could be considered as a metric that will be applicable for the setting of some numerical targets.

Table 9-2 Stakeholders relationship perspective of balanced scorecard

Stakeholder Relationship		
Objectives	Increase engagement of manufacturers and assemblers in electric bus research and manufacturing cluster.	Maintain good relationship between state enterprise and private operators.
Metrics	• Number of joint projects between OEMs and e-bus assembler • Number of meetings within electric bus research and manufacturing consortium • Target percentage of participant in the consortium from the whole supply chain • Target percentage of responses from the sent questionnaire to manufacturers	• Feedback from stakeholders regarding the fairness and involvement of intermediary organization • Number of active participants who are bus service operator within e-bus consortium • Level of conflict in the partition of e-bus service routes • Positive feedback on public policy regarding the operation of e-bus public service in Bangkok
Targets	• 3 joint projects per year within the field of electric bus manufacturing • Arrangement of semi-annual meeting • 90% of all stakeholders within the industry to participate in the consortium • 75% response rate of the questionnaire that has been sent out to stakeholders	• More than 80% approval regarding the roles and responsibilities of intermediary organization • At least 5 operators among participants who are willing to invest in e-bus public transport services • No conflict in the partition regarding public services of bus and e-bus • Less than 10% of negative feedback regarding current e-bus public policy and implementation plan
Initiatives	• Arrange joint projects based on the willingness to participate and the capabilities of manufacturers • Maintain the consortium by constantly held physical meetings with the option of virtual meetings • Develop set of online questionnaire or paper questionnaire to distribute during consortium meeting to measure the progress of e-bus development	• Form intermediary organization based on the guideline that is approved by the majority of stakeholders • Create clear partition of Bangkok public bus services with a new re-structural plan with the inclusion of electric buses • Constant monitoring and follow-up process to ensure the approval of major stakeholders among bus operators

(Source: Summarised from the data collected.)

9.1.3 Internal Processes

Internal processes are the only perspective that the original definition was not altered in this iteration of balanced scorecard for a public policy. The monitoring of internal processes investigate the mechanisms related to the creation of value within an organisation (Kaplan, 1996). In this case, the value of an organisation is the formulation and the implementation of a public policy. The type of policy that would be the focus of this perspective are policies that promote operational effectiveness of an electric bus cluster and the industry at the overview level. Instead of focusing on the products and processes of the organisations, the scope for this performance measurement would be directed at several inter-organisational interfaces, which encompass actual interactions and activities that occur in the industry.

There are many possible inter-organisational interfaces within the electric bus industry. The communication across each of these interfaces hold a certain level of importance towards different segments of policy implementation. For example, the interface between researchers and the industrial sector is important to the development of technologies that would properly match industrial requirements. The interface between government and members of the industry is important to the awareness and clarity regarding the declared public policy. To maintain an appropriate level of interactions between each stakeholder, the communication via channels that were deployed by the government must be timely and accurate. Consequentially, the greater impact from collaborations could be expected if the information sharing and knowledge exchange between stakeholders are consistently effective. This impact could be measured by the increment of joint projects between stakeholders. The examples of metrics include the number of joint projects to develop new products, the rate of employment among internship student from the universities in industrial enterprises, etc. It should be noted that a high frequency of communication between stakeholders is not necessarily equate to more impact towards industrial development. It was asserted that the lack of continuous responsive feedback could be the cause for the concurrent discussion being abandoned (Cherdchai, 2020). The cluster should aim to solve this communicative gap to maximise the benefits from the formation of the consortium or a cluster.

This perspective also included some of the most tangible and urgent outputs that should be achieved by the Thai government. The first group of outputs related to the main objective to facilitate the transition of bus manufacturing supply chain towards electric buses. A good starting target for the industry is to ensure that each OEM would have at least a single product that could be supplied towards the manufacturing of electric buses. In contrast, a more top-down oriented target could be set in the form of survival rate of OEMs after the next 5-10 years. Another tangible objective is related to the preparation of infrastructure to support the growth of electric vehicles. This would be especially important for private-owned buses, which are unlikely to have the ownership of charging stations unlike public service buses. If the government plans to cultivate this segment of the market, this part of infrastructure needs to be extensively developed at the earlier stage of the industry.

Table 9-3 Internal processes perspective of balanced scorecard

Internal Processes				
Objectives	Improve effectiveness of communication channels between stakeholders.	Greater impact from the collaboration between research, industry, and government sectors.	Transition of bus manufacturing supply chain towards electric vehicles economy.	Prepare adequate infrastructural facilities for electric vehicles.
Metrics	• Clarification of national policy to stakeholders • Number of communication channels between stakeholders • Response rate for each topic that has been discussed	• Number of jointly-manufactured products • Number of internship students who are offered positions in the companies • Number of requests from industrial sector to the government	• Percentage of OEMs that could maintain their business during the transition • The number of electric bus-based products that each manufacturer could produce • Proximity between research and manufacturing sector	• Number of public charging station for e-bus • Electrical load prediction with the inclusion of charging schedule • Number of maintenance garages for electric buses
Targets	• Every stakeholder in the supply chain aware of national policy • Create a database of stakeholders for e-bus cluster • 2 times for each topic	• 3 prototype level products annually within 3 years • At least 50% of all internship students will be offered the position • Aim to process 90% of all requests with request	• Maintain 80% of former OEMs in ICE bus manufacturing industry • Each existing OEMs produce a component that could be used in electric bus.	• 50 stations throughout Bangkok area • Prepare for additional 20MW-hr of daily electrical usage during night-time in the initial stage with 10 bus routes

		filtering mechanism	• 1 industry cluster within any industrial estate by the year 2026	• 2 public garages for e-bus maintenance by 2026
Initiatives	• Formulate a public policy framework • Create the database and mapping of stakeholders in the supply chain • Surveillance and moderation of the communication between stakeholders	• Arrange researchers and manufacturers with the same expertise together • Arrange student internship programme for universities and enterprises • Establish request center for industry-related requests	• Provide support for domestic OEMs with business ideas and workforce training • Guide domestic OEMs towards potential products based on their current expertise • Establishment of e-bus cluster in physical location	• Provide public-owned infrastructure to facilitate the initial stage of e-bus public transports • Calculation of power usage based on actual intent to provide e-bus public transport services

(Source: Summarised from the data collected.)

9.1.4 Organisational Capacity

In this perspective of the scorecard, the capacity for knowledge of the electric bus cluster will be evaluated based on primary objectives of the national policy. The objectives and their corresponding targets were altered to fit with the setting of public policy. The potential of industry growth in term of knowledge, information network, and overall technological capabilities will be measured instead of internal learning potential within an organisation. The alteration of this perspective is not a novel concept. It was asserted that learning and growth perspectives should be redefined to match the purpose of its implementation (Massingham, Massingham and Dumay, 2019). Therefore, the alternate name 'organisational capacity' is used to indicate a larger scale of objectives, in comparison to the more personal-oriented title.

The first aim in this perspective is an effective prioritisation of domestic research projects. In other words, this objective is very similar to the contents of section 7.2 in this thesis, regarding the creation of a technology roadmap for the electric bus industry in Thailand. Hence, more in-depth details could be found in that section. The targets for this objective in this scorecard are more arbitrary and less grounded, which could be less useful for researchers. However, a proactive target such as the number of research funding programmes in the electric bus industry is a reasonable starting point for policy makers. Additional in-depth information could be gathered from involving stakeholders and added in the decision to set appropriate targets after the corresponding initiatives have already been approved by the government or the controlling ministry.

The recruitment of overseas business partners is the second objective for this perspective. This objective will be essential for the technology absorption scenario, which was designated in the previous chapter. It should also be significant for other scenarios, although not as prominent as this scenario. This shows that some objectives in the scorecard might be more relevant to one of the scenarios than the others. Ideally, the scenario for e-bus industry development should be selected before the objectives and targets in the evaluation process are designed. However, as mentioned in the last chapter, this thesis will not make a conclusion regarding the choice of scenario for Thai industry. Instead, rich information on each scenario would be provided to support the decision making of policy makers. As a result, this balanced scorecard is designed in a moderate fashion to maintain its relevance to any given scenario.

In contrast to the previous objective, the third objective regarding the improvement of technological capabilities among Thai stakeholders in the electric bus industry would be highly important in a different scenario. The milestone for this objective should be set higher in the pure domestic manufacturing scenario, and lower in the selective manufacturing scenario. It could be entirely absent from the pure import scenario since that scenario mainly focus on the adoption of electric buses in public service rather than the development of domestic manufacturing process. Several metrics for this objective might be among the most challenging variable to be assessed. For instance, technology readiness level (TRL) is a detailed universal measurement scheme that could be used to measure innovation in the public sector (Héder, 2017). Large quantity of informational inputs across the industry might be required for an accurate indicator in accordance with this scaling system.

Table 9-4 Organisational capacity perspective of balanced scorecard

Organizational Capacity			
Objectives	Effective prioritization of domestic research projects.	Increase the number of overseas business partners.	Improvement of stakeholder's technological capabilities.
Metrics	• The number of successful research projects • The number of research funding granted by NSTDA • Further applications of existing research	• The number of business partners and strategic alliances overseas • The number of ongoing trade agreements in e-bus industry • Connection to suppliers and customers within global supply chain	• Technology readiness level scale • The number of electric bus-based products that each manufacturer could produce • Net value of the enterprises
Targets	• 80% success rate of the total of electric bus-centric research • More than 5 research funding on electric buses annually • Each research will have at least 1 further application or supplementary research	• Secure at least 2 partners who are willing to exchange technologies related to electrical system in e-bus within 2 years • Have e-bus related trade agreements to 10 different countries by the year 2026 • Raise annual export value of automotive industry to 20 million USD by the year 2026	• Have Thai manufacturer achieve level 5 of TRL (Component's validation in actual environment) within 5 years • Each existing OEMs need to produce at least 1 component that will be used in electric bus. • At least 1 bus assembler reach 100kM THB enterprise value by 2026
Initiatives	• Create technology roadmap based on current capabilities of domestic manufacturers • Block granting scheme based on technology roadmap • Pooling of researchers who have similar interests	• Scenario-based planning for establishment of trade agreements between Thai and overseas enterprises • Proactively create the demand and market for e-bus both in domestic market and overseas market	• Develop time-based technology readiness scale for the development of e-bus manufacturing industry • Guide domestic OEMs towards potential products based on their current expertise • Long-term procurement policy for e-buses that are assembled in Thailand.

(Source: Summarised from the data collected.)

The final step of the balanced scorecard formulation is the creation of a strategy map (figure 9-1). The strategy map is normally presented to show the causal linkage between each strategic objectives in each perspective within the balanced scorecard (Kaplan and Norton, 1996). In this case, it is used to depict the linkage of the objectives in the supply chain level instead of an organisation level. This type of application was utilised before in the subject of supply chain management to explore the potential of this management tool in a larger scope of performance measurement (Okongwu, Brulhart and Moncef, 2015). The strategy map that was designed in this chapter provides a wider perspective than the current scope of this thesis i.e., it covered other areas of policy development aside from the clarification of national policy plan to the stakeholders. As a result, some micro-level metrics and targets in this and the next section of the thesis would not be completely investigated. Another limitation of the strategy map is the lack of empirical clarification of causal effect between each objectives (Silva and Abbad, 2011). It is unclear whether the achievement of the target in one perspective could directly lead to the fulfilment of an adjacent strategic objective. Hence, a strategy map should be utilised only as a complementary monitoring tool to observe the overall development of the project instead of a total solution for the system. To improve the effectiveness of the monitoring process, it is also recommended to approach each objective individually and create a set of relevant metrics and targets (Laoonual, 2020). This scheme of evaluation will be explored further in the next section.

Table 9-5 Examples of interview quotes relating to the designing of balanced scorecard.

Participant	Topics	Quotes
SW	Economic: Reduction of fuel consumption in public transport sector.	"Thailand still has no in-depth analysis on the topic. The research about the difference in energy consumption was conducted to see whether it would be economical to convert to e-bus or not."
YL	Stakeholders: Increase engagement of manufacturers and assemblers in electric bus research and manufacturing cluster.	"Because there are no clear objectives to follow-through. Like when there is a gathering of friends, will someone go if they are not close in relationship with each other's? There must be some commonalities between everyone."
SS	Processes: Prepare adequate infrastructural facilities for electric vehicles.	"Our infrastructure is still not ready for the change. It discourages any potential buyers, even in e-bus industry you will notice that most operators concern about charging process for their fleets."
NN	Capabilities: Effective prioritization of domestic research projects.	"Our research cluster's policy can be considered a silo. For example, robotics cluster could have something that are useful to autonomous vehicles. However, we still haven't connected these research groups together."
PN	Stakeholders: Maintain good relationship between state enterprise and private operators.	"The government never care about private operators, they don't take any responsibilities in our problems. A lot of our requests have been made to them, but none have been addressed properly. There was no improvement made for our business."

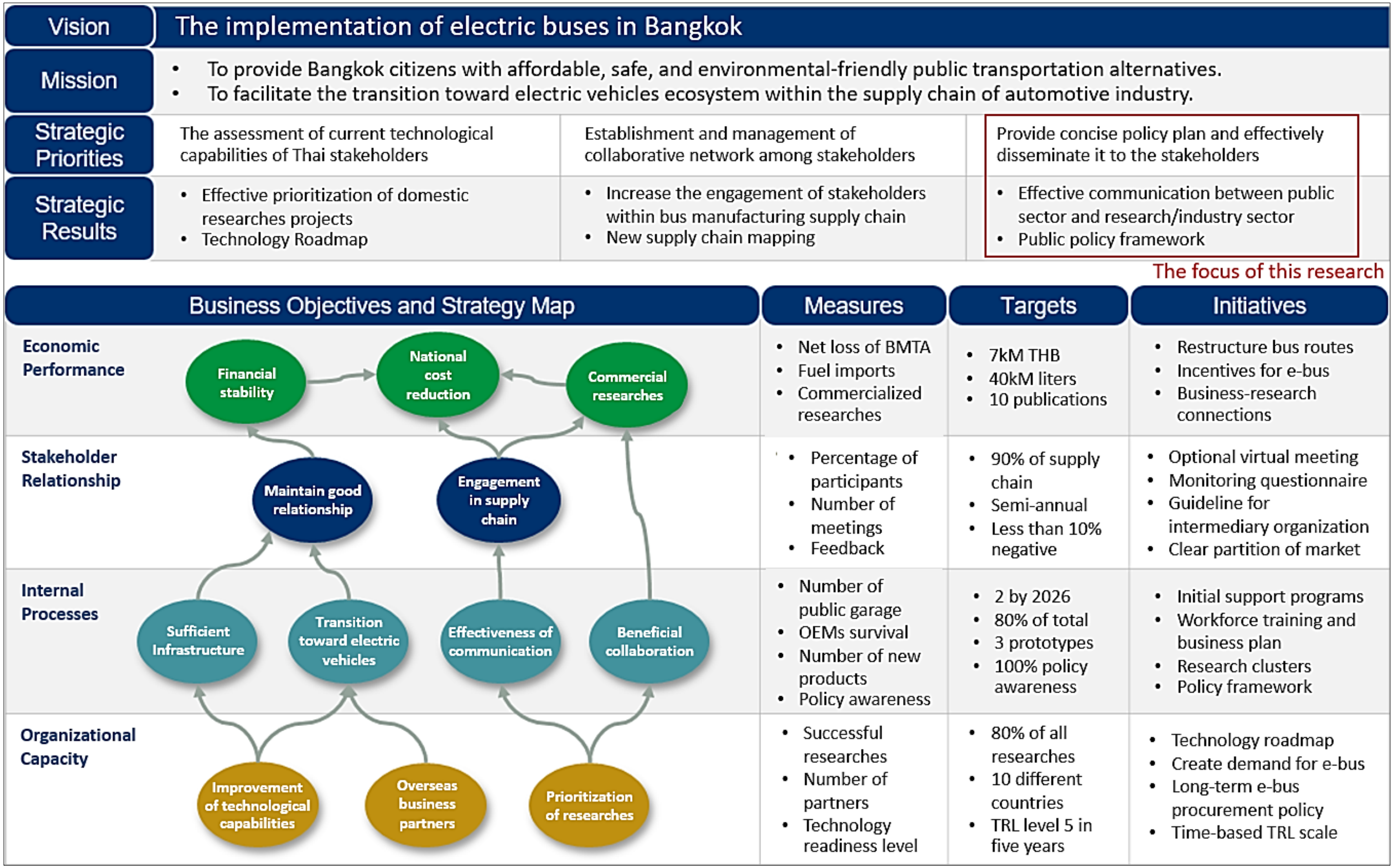

Figure 9-1 Strategy map of the implementation of public policy in electric bus industry
(Source: Adapted from Kaplan and Norton, 1996)

9.2 Process Monitoring via Work Breakdown Structure

Work breakdown structure is a project management tool that was usually utilised to decompose the project into a collection of smaller components in the system. It is often used in project management and system engineering to facilitate a complicated project by breaking it into smaller group of tasks that can be considered as requirements for the completion of the whole project (Haugan, 2001). It would be easier for a project manager to direct or delegate a specific task to a certain group of people or a certain individual, who might be the most resourceful in that specific part of the project by referencing this structure. Additionally, the work breakdown structure could be extended towards the application in the evaluation and monitoring where each tasks are assigned with their own performance indicators (Clark and Littrell, 2002). This application is in accordance to the principle of work breakdown structure, which describes itself as an outcome-based planning technique, where the structure is controlled by the predicted outcome of the project, but not vice versa (Norman, Brotherton and Fried, 2011). This basic principle is also valid in this framework because activity diagrams, which are the precursor of this monitoring process, were designed based on the idea of accomplishing a single objective. Policy initiatives that were presented in these implementation plans were linked with the corresponding objective by mechanisms proposed in the previous chapter. Therefore, it is unlikely for the contents of this process to be extended beyond its appropriate boundary, unless the design of activity diagrams for the policy implementation were altered.

In this policy framework, the work breakdown structure is adapted for the monitoring process of the policy initiatives. Unlike the balanced scorecard, it is designed to be a tool to gauge the effectiveness of sub-segments within the system, rather than an overall evaluation scheme for the whole national policy. There are 3 phases in this arrangement of the work breakdown structure (figure 9-2). Firstly, the policy plan is designated. Several ideas regarding the appropriate policy initiatives were collected from interviewees and have been subsequently assigned to the policy plan based on the formulation of activity diagrams in the previous chapter. Secondly, the category of stakeholders who would be directly influenced by the implementation of these initiatives are identified. Thirdly, the metrics that could infer to the successful implementation of the initiatives are nominated. Similar to the balanced scorecard, the exact number of the target is not concretely identified because the objective of the research is to formulate the framework. This last process was omitted in this thesis because it should be completed by consulting with experts from the respective stakeholders since some metrics could be highly technical and require extraneous labelling and explanations. The overlapping of the same metrics across several policy initiatives or policy plan are possible, since these numbers could indicate performance measures that would have noticeable effects on several aspects within the industry. Nonetheless, it might be useful to document these metrics by a method that could specify their original contribution. Ideally, the documentation of these metrics should clearly indict that they serve as performance indicators towards different objectives, despite possessing the same definitions.

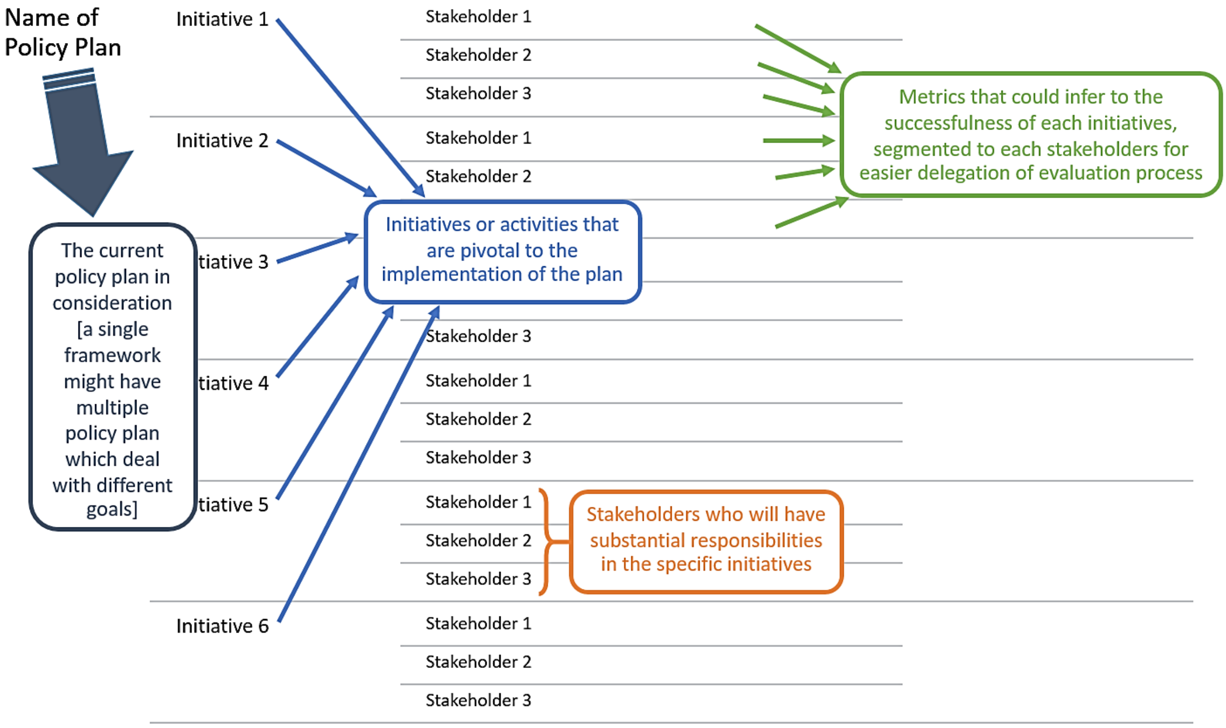

Figure 9-2 Explanation of work breakdown structure in the process monitoring

9.2.1 ACT 1: The Promise of Operational Feasibility for Domestic Assemblers

In this policy plan, there will be a heavy emphasis on financial metrics since the context of this plan is strongly related to the business feasibility of bus assemblers. It was reinforced that financial stability and economy of the enterprises would be the deciding factor in the investment in electric buses. This is true for both bus manufacturers and operators. Thus, several metrics related to corporate financial condition such as net income or debt ratio are recommended as suitable choices for the monitoring of their involvement in the transaction regarding electric buses. For example, debt management would be the top issue for the BMTA. It was recorded that several state enterprises in Thailand has been performing poorly in term of financial feasibility for a very long time (Charoenloet, 1989). BMTA, as one of these state enterprises, would be faced with a significant financial challenge during the large-scale adoption of electric buses, since electric buses are normally sold at a higher price compared to CNG or LPG buses. Additionally, their lower operation cost would not be realised without abundant energy production from low emission energy sources such as solar, water, and wind power (Gabriel *et al.*, 2021).

On the other hand, the government might have to endure a financial loss during the development of this policy plan. It would be difficult for the industry to survive without the future investment in EV products and EV manufacturing process. This aspect is also true for the previous evaluation of ZEV mandate in the United States (Greene, Park and Liu, 2014). Metrics from other categories that would reflect the progress of the plan should also be used in conjunction with the financial indicators. For example, the penetration rate of electric buses as public transportation services could indicate the level of acceptance towards this mode of public transport, and consequently reveal the feasibility of electric bus manufacturing industry. Financial feasibility of bus manufacturers is one of the most essential driving mechanisms for this industry to propagate and grow in accordance with the national agenda for the development of EV industry. The implementation of public policies that would unravel this prospect should be carried out pre-emptively before any other initiatives in the downstream of the supply chain.

Table 9-6 Example of process monitoring in ACT 1 by work breakdown structure

Policy Initiatives	Responsible Stakeholders	Metrics of Measurement
Adopt continuous e-bus procurement policy	BMTA	order per quarter / fulfilment rate / total asset turnover
	Public fleet	percentage of coverage / cost of ownership
	Private operators	cash ratio / fulfilment rate / profit margin
Capital Imbursement to BMTA	BMTA	future value / debt ratio
	Ministry of finance	public debt to GDP / budget expenditure
Public relation of electric bus services	EVAT	articles published / penetration rate
	Bus operators	passengers' feedback / number of passengers
Prohibition of ICE buses	Ministry of Transport	number of operating buses / vehicle emission standard
	Bus assemblers	inventory turnover ratio / ICE bus inventory
	Bus operators	current ratio / remaining life of ICE buses
vehicles pricing discounts	Ministry of Commerce	e-bus sales / ratio between ICE and e-bus sales
	Ministry of industry	change in number of assemblers / OEM's product pricing
	Bus assemblers	gross profit / net income
Manipulate energy prices	Ministry of Energy	cost of electricity / global oil price / refining cost
	Bus operators	operating cost / net income

(Source: Summarised from the data collected.)

9.2.2 ACT 2: The Reinforcement of Confidence in E-Bus among Service Operators

Confidence in a new technological product is a multi-faceted dimension which could be affected by several factors. High confidence in the product might be essential to the propagation and growth of the industry. Conversely, low confidence could also sabotage any attempt to cultivate the industry beyond its current potential. It was proven that the purchase and investment intention of electric vehicles are strongly influenced by the confidence of users, but it is not straightforward to make an assessment of 'confidence' (Nurul Syafiqah and Muhammad Iskandar, 2020). As a result, different amounts of tangible and intangible metrics would be used as required for the monitoring of different policy initiatives. For example, pricing regulation for electric buses might heavily rely on tangible business-oriented metrics, while quality control in electric bus services would involve more intangible measurements.

Since the activity diagram for this objective is slightly more complicated than the first one (see figure 8-13), the metrics in this policy plan would also be more diverse. Unlike the previous case where most metrics are strictly tangible and quantitative, some existence of intangible values cannot be avoided in this topic. It should be noted that metrics of measurement in this application of work breakdown structure are mostly created in a tangible and quantitative format, with the small exception when some variables would be more accurate indicators in its qualitative label. As the main theme of this plan, the level of confidence about an object i.e., the electric bus is not primarily a numbered attribute that can be readily defined. The most used solution for this is to assign confidence level to a quantitative scale for the assessment (Mansour, 2020). As a result, this method of variable replacement might be used in the assessment of passenger's satisfactory in electric bus services. Despite having a singular aim, each activity diagram for the implementation of policy initiatives would contain varying disposition of the elements in the monitoring process. This variety originated from the design principle of the activity diagram in the previous chapter. A policy initiative might seem to be disjointed and disconnected to some initiatives that appear in the same policy plan because they are not immediately adjacent in the diagram that was designed in the previous step.

Table 9-7 Example of process monitoring in ACT 2 by work breakdown structure.

Policy Initiatives	Responsible Stakeholders	Metrics of Measurement
Provide feasible business plan	Bus assemblers	return of investment / earnings before interest and taxes
	Private operators	return of investment / earnings before interest and taxes
	BMTA	average number of passengers / bus utilization ratio
Development of bus tracking application	NSTDA	lead time / number of application bugs
	Bus operators	accuracy timetable / integration with e-bus
	Passengers	satisfactory / number of daily users
Offer free e-bus for a certain period	Intermediary	number of connection / warranty fulfilment
	Private operators	target running time / turnover rate
Establish public maintenance garage	Intermediary	working hours / success case / number of cases
	OEMs	percentage of defective product / repair time
	Bus assemblers	inspection time / number of buses broke down
E-bus pricing regulation	Ministry of commerce	e-bus sales / ratio between ICE and e-bus sales
	Ministry of industry	components quality / components pricing
	Bus assemblers	gross profit / asset utilization ratio
Quality control in bus services business	Ministry of transport	number of accidents / numbers of traffic law violations
	Bus operators	journey time discrepancies / passenger load factor
	Passengers	satisfactory / fare collection rate

(Source: Summarised from the data collected.)

9.2.3 ACT 3: The Establishment of Collaborative Network within the E-Bus Industry

The establishment and sustenance of the collaborative network is beneficial to several dimensions of industrial development. It was asserted that effective collaboration would positively affect the quality of scientific research (Tahmooresnejad and Beaudry, 2018), strategic planning in the supply chain (Barnes and Liao, 2012), and product innovation (Nieto and Santamaría, 2007). The richness of the literature surrounding this topic reinforces its key role in the development of the electric bus industry. In fact, it was designated as one of the main aims for the development of this public policy framework towards a successful adoption of electric bus in Thailand. In this policy plan, a collaborative network would be treated as an element that has the potential to accelerate large-scale industrial development, by collectively pooling national resources into a unified plan. As mentioned before in the previous chapters, there were past attempts to establish collaborative networks in the Thai EV industry, but there were several issues that prevented it from reaching its full potential. A new blueprint for this type of network should incorporate several new metrics that are assigned to the evaluation of this policy plan. Ideally, these metrics should reflect a potential development in the future, which might make them appear less indicative of the current state of the industry.

Like the previous work breakdown structures, the examples of these metrics will be diverse because they fall under disparate policy initiatives which possess different objectives. In this example, initiatives regarding cross-industry research would be categorised in the category of research improvement, while the assignment of intermediary might be more directly beneficial to the strategic planning within the e-bus supply chain. As a result, the metrics to measure performance would be collective across the industry in the former, but very stakeholder-specific in the latter. This categorisation is further broken down into several sub-segments based on which stakeholders should be responsible for the measurement process. In some scenarios, Thai OEMs and bus assemblers are combined into a single incorporation as ‘manufacturers’ because the metrics that would be used to assess them will be relatively similar in this plan (ACT3), despite the difference in the size of manufacturing operation. In contrast, the metrics from the manufacturers could be starkly difference in another implementation plan. In that case, the stakeholders would be separated as OEMs who supply smaller bus components, and bus assemblers who are the integrator of the larger systems in electric buses.

Table 9-8 Example of process monitoring in ACT 3 by work breakdown structure.

Policy Initiatives	Responsible Stakeholders	Metrics of Measurement
Consortium of e-bus OEMs and assemblers	Ministry of Industry	number of participants / net value of EV industry
	OEMs	number of sales channel / business performance
	Bus assemblers	number of supplier contacts / segmentation of market
Assign intermediary to work among public bus association	Intermediary	number of connections / formation time
	NXPO	responsiveness of stakeholders / amount of policy plan
	Bus operators	acceptance of intermediary / transparency
Initiate cross-industry research and development programme	NSTDA	R&D expenditures / Industry competitiveness index
	Universities	overall h-index / licensing income
	Manufacturers	number of patents / applications of research
Create a clear-cut diagram of prospective e-bus supply chain	Intermediary	number of foreign partners / values of supply chain
	OEMs	number of EV based products / production outputs
	Bus assemblers	market size / requisite for supply / production outputs
Domestic market segmentation for electric buses	Ministry of commerce	market value / export value / import cost
	Bus assemblers	specialized product / production output
	Bus operators	route distribution / allocate buses order
Designate physical location for e-bus research and manufacturing cluster	Ministry of industry	number of tenant / years in development
	Ministry of science	number of tenant / research outputs

(Source: Summarised from the data collected.)

9.2.4 ACT 4: The Improvement of Domestic Manufacturer’s Technological Capabilities

The improvement of technological capabilities of Thai stakeholders in the manufacturing of electric vehicles has been a primary objective in national-level public policy regarding the future development of Thailand automotive industry. Even though the importance of this specific topic was slightly overshadowed by the recent movement towards a quick solution for environmental issues that were originated from ICE vehicles, it is still one of the top concerns for the Thai government (Jarumilint, 2021). The importance of technological capability development regarding the progress of Thai automotive industry was established even before the disruption by electric vehicles industry. The role of local automotive part suppliers as active learners who gradually absorb manufacturing capabilities from multinational companies were pivotal to the evolution of Thai automotive industry from the import-substituting industry to the full-scale exporting industry (Intarakumnerd and Techakanont, 2016). This proved that the mechanisms for knowledge transfer in Thai automotive industry already existed. It is only the matter of the ability to apply this potential in a different technological environment, in addition to the search for the new suitable partners who possess proper expertise in the electric vehicles manufacturing industry.

Technological improvements might be the most technical topic in the whole process of performance monitoring and measurement via work breakdown structure, especially among manufacturers. It is very likely for the manufacturers to develop an exclusive measurement scale to measure their technological capabilities. For the improved relevance of the metrics, a proper scientific development might be required along with the reconfiguration of the measurement system (Chen, Wu and Huang, 2013). Policy makers could reinforce the effectiveness of the monitoring process by clearly identifying the characteristics or features of the performance indicator according to their strategic objectives. For example, if they are looking to build a wider connection to the global supply chain, they might suggest manufacturers to devise detailed product specifications that could be benchmarked against global standards for electric vehicles. Since the resurgence of electric vehicle technologies is still relatively new, most of the metrics that would be developed to measure its progression might appear to be naturally speculative. These metrics should be reviewed regularly, both in term of the measurement standard and the choice of metrics to indicate a specific dimension of the technology.

Table 9-9 Example of process monitoring in ACT 4 by work breakdown structure.

Policy Initiatives	Responsible Stakeholders	Metrics of Measurement
Design technology roadmap	NSTDA	target fulfilment rate / information coverage
	Research institutes	shifting of research focus / funding's allocation
Capabilities analysis of Thai manufacturers	NSTDA	total factor productivity / industrial production index
	OEMs	readiness for EV industry / net income
	Bus assemblers	number of suppliers / information sharing efficiency
Find connections in global supply chain of electric vehicles	Ministry of commerce	growth of imports and exports value / number of overseas trade agreements
	Manufacturers	product specification / transferred employees
Funding for the attempt to form strategic alliance	Ministry of finance	financial capital / public debt to GDP
	NSTDA	research expenditures / number of overseas contacts
	Research institutes	number of internship student / shared publication
Negotiate with overseas firms for technological exchange	NSTDA	level of technological capability / total factor productivity
	Manufacturers	number of alternative technologies / percentage of firms with foreign connections
Prepare contingency plan for possible failure in technological absorption	NSTDA	number of technological alternatives / reserve funds
	Intermediary	number of optional plan / levels of manpower

(Source: Summarised from the data collected.)

This part of the policy plan was loosely designed as a guideline towards a bottom-up approach of process monitoring. Most of the metrics are speculative and based on the experience of the researcher, hence they are labelled as 'examples' in this proposal. In fact, many policy initiatives in activity diagrams from the previous part were left out from the examples. As such, this section of the thesis presents the work breakdown structure as a conceptualised model, rather than the complete construction of the monitoring process in the policy implementation. Therefore, the main limitation of this permutation of WBS is the incomplete coverage of the metrics. There are several measurement gaps that should be addressed by the inclusion of additional metrics. This work breakdown structure should be improved further by the designing of new metrics. Thai government should cooperate with responsible stakeholders to come up with a proper set of metrics that could reflect actual task conditions for each respective stakeholder. In further research, the benchmark from additional case studies could also be used to help this design process. However, several metrics used in other countries should be thoroughly investigated before being replicated into the industrial environment in Thailand, since different external environment could cause the same evaluation schemes to result in a different standard of measures.

In conclusion, this work breakdown structure would provide the electric bus industry with a systematic method to monitor actual activities that were undertook by stakeholders, in contrary to an overview scenario that was represented by the balanced scorecard. However, a lot of background work should be made to ensure that this method of evaluation consist of valid information. Several metrics should be handled and described by the experts, for them to reflect authentic performance indicators within a specific part of the system, and in relative to policy programmes that were assigned to the stakeholders. As a result, this section of a policy plan is highly expected to be altered in the upcoming future. Additional details might be added to enhance the usefulness of the monitoring tool to the development of the electric bus industry in Thailand. Since this section is a direct follow-up to the implementation plan from section 8.3, additional work breakdown structures could be created based on the inclusion of other activity diagrams. This could be accomplished by the application of the same process that was described at the beginning of this segment.

9.3 Framework Review via Feedback from the Stakeholders

9.3.1 The Presentation of the Framework to the Stakeholders

According to the original design of this research, the last phase of the data collection will be conducted after the finalisation of this policy framework. The main purpose of this data collection is the gathering of feedback from several groups of stakeholders who are involved in the electric bus research and manufacturing industry. In addition, they must be impacted by the possible adoption of public policies which might be set in motion by the introduction of this framework. The assessment of the formulated framework is made based on the feedback which was collected during the presentation of this public policy framework via an arranged online meeting. The main contents of this presentation focused on the structure and the explanation regarding the purpose of each component in the framework. Additionally, the connection between each part of the framework was also extensively clarified to make sure that the audience grasp the ideas behind the interconnection between each component in the framework (figure 9-3).

Furthermore, this meeting was arranged to disseminate the latest results from this research to the people who are currently involved in practical and related applications within the e-bus industry. The contents of this presentation were slightly altered to cater for the interests of the target audience. Additional details outside the scope of this research were added to ensure that there will be sufficient participants from every segment of this industry. Since most components in this framework would be more relevant to the policy maker, additional information regarding the market state and business value of the e-bus manufacturing industry were added to attract the bus manufacturers and operators. The presentation also focused on the expected outcome after the implementation of e-bus policies, in addition to the methods that were utilised in the formulation of this public policy framework. In summary, there are 5 groups of stakeholders who participated in this review: policy makers, researchers, manufacturers, service operators, and general users. It was expected that the sample size of at least 3 participants from each group of the stakeholders would be achieved.

The length of the presentation was set at 30 minutes because of the major concern in a possible lower number of active participants. With this highly constraint time limit, the focus of this presentation was to briefly summarise the mechanisms of the framework and the expected benefits for the stakeholders, rather than present all the details within a policy plan that were generated by the framework. The presentation was structured into 4 parts which is identical to the original structure of the framework. This included the current situation in Thai e-bus industry, the organisation and strategic planning for the future, the implementation of e-bus public policies, and the monitoring and evaluation of policy plan. In addition, there was also a 30-minutes discussion session between the presenter and the audience at the end of the presentation. The purpose of this session was to gather additional information regarding possible modifications that could be made, to improve the effectiveness and the usability of this policy framework.

After the presentation and discussion session, participants were encouraged to complete an online questionnaire that was designed to evaluate this framework. There are two parts of this questionnaire. The first part is a quantitative analysis that utilised the 7-point Likert scale to evaluate the framework in three areas: the usefulness of the policy framework, the ease of understanding of the details, and the accuracy and completeness of information in comparison to the actual situation. The second part was a qualitative analysis that utilised open-ended questions. This online questionnaire was designed to collect additional inputs that could be used in the future adjustments, to ensure the feasibility of the whole framework and its corresponding policy plan in the real situation within the industry.

The pandemic situation in 2020-2021 forced this presentation to be in an online format instead of a face-to-face session. Since the participation was not compulsory and the resulting policy plan was not intended to be the official public policies for the e-bus industry, many of the stakeholders including people who were originally the interviewees in the previous data collection process did not feel sufficiently incentivised to participate in this online presentation. The resulting low number of participants (14 people) might invalidate the quantitative analysis. Nevertheless, most of the information from open-ended questions will be considered as a valid suggestion despite the low number of responses. These suggestions could be applied in the future modification of this framework and policy plan to reflect these stakeholder’s viewpoints and recent developments in the Thai e-bus industry.

9.3.2 Results and Discussions of the Survey

The results of the quantitative survey are summarised in figure 9-4. The figure shows the average review score of the policy framework that was gathered via an online presentation and a subsequent questionnaire of 14 participants who came from different sectors of e-bus research and manufacturing industry. It can be concluded that this policy framework appealed to several stakeholders in all three dimensions because the overall framework has received above average review scores (approximately 6 out of 7). The slightly higher score in the accessibility dimension of the framework implied that it is highly accessible to people who possess different backgrounds within the industry. The framework was not as well-received in term of usefulness and accuracy, but only by a marginal difference. It can be implied that the data that were used to formulate this framework and the corresponding policy plan for the e-bus industry might be slightly outdated but still relevant, since the situation regarding e-bus public policies have not changed significantly in the past 2 years since the first data collection process. Extra details from the segmentation of stakeholders suggested that this framework is more useful for policy makers and researchers, in comparison to bus manufacturers and service operators. On the other hand, the accessibility is approximately the same across all types of the stakeholders. This supports the conclusion that this framework was sufficiently simplified for the dissemination to any group of stakeholders. Interestingly, the accuracy of the information within the framework and a policy plan was better received by bus manufacturers and service operators, in comparison to researchers and policy makers. It can be concluded that the information that was contained in this framework are more relevant to current responsibilities of the latter group. Thus, the overall concept of this policy framework is likely to invite more scrutiny from them.

For the first part of the framework (Chapter 6 in this thesis), the results are very similar to the review of an overall framework. However, it can be observed that the usefulness and accuracy of information scored lower than the average score from an overall framework. This might imply that the information in this specific part is more outdated than the information in other parts of the framework. It was found that the usefulness of this part is more apparent for policy makers and researchers, in comparison to bus manufacturers and service operators. In contrast, policy makers found this part easy to understand, while researchers and service operators were less impressed with the explanation of the current situation surrounding the Thai e-bus industry. This suggested that the analysis of the current situation might need to be revised, to make the results more accessible to these two groups of stakeholders. This situation mainly includes the changes in the supply chain, especially regarding the oversees suppliers and the stance of the government relating to the number of public e-buses that would be financially supported. Lastly, the accuracy of information had the highest score from service operators and users, which mean that there is no mismatch between the information that was presented and the expectation of the public. This circumstance might have originated from the fact that these two groups normally have less access to an in-depth information in public policy when comparing to the other groups, which might generate this positive bias.

The second part of the framework (Chapter 7 in this thesis) scored the highest in term of its usefulness. However, the accuracy of information presented in the policy plan was questioned by the stakeholders. Most participants found that it was slightly more difficult to understand the mechanisms that were used to formulate the policy plan in this part when compared to part1 and part3. This might be due to several technical terms that were used in this specific section. Aside from the overall score in the review of each dimension, the segmentation of results by each group of stakeholders also did not reveal any significant differences. Most of the review scores in this part of the framework were in the same proximity regardless of which stakeholders' group they originated from. In addition, it can be clearly observed that this part of the framework was better received by policy makers in all dimensions when compared to other groups, due to its clear differentiation between each sub-segment which made the contents seemingly more relevant to the larger scope of stakeholders.

The third part of the framework (Chapter 8 in this thesis) shared very similar results in comparison to the review of the overall framework. The only exception was in the accuracy of the information, which was perceived to be less accurate compared to the information that were presented in other parts. The limited arrangement of implementation scenarios and activity diagrams, which could not cover every aspect of public policies in the e-bus industry is expected to be the main cause of this poor reception. The usefulness of policy implementation was also disparaged by the participants who identified themselves as e-bus manufacturers. This is a surprising result, considering that most of policy initiatives are mainly catered towards the improvement of market position in the supply chain for e-bus manufacturers and assemblers. Further investigation might be required to develop a more detailed explanation for this discrepancy. Additionally, policy makers found that this part slightly less understandable when compared to other parts in the framework. This is another discrepancy since the information in this part are mostly related to government agencies and public organisations. It might be concluded that the overwhelming details of this part are likely to disorient policy makers, in comparison to the lighter information from the other sections. Nevertheless, the review score that was collected is not significant in terms of the numerical difference.

The final part of this framework (Chapter 9 of this thesis) has been poorly received in all dimensions by most stakeholders. This could be a signal that the revision of this part should be prioritised before any other section in this framework. However, the feedback from many stakeholders in the discussion session were not overwhelmingly negative. This was reflected by the above average scores in figure 9-4. The criticisms for this part are put together in the next segment of this survey, which contains several qualitative suggestions. The primary source of the low review score in this part came from the low perception of usefulness among e-bus manufacturers and service operators. This might stem from the fact that most metrics that were used are skewed towards public policies rather than business performance, which would reduce the usefulness of this evaluation scheme in corporate settings. Moreover, most researchers seemed to think that this part of the framework is mediocre in term of accessibility and accuracy. These weaknesses should be addressed before they could pose a problem to the adoption of public policies in the future. Most objectives and metrics should be revised, and their linkage with primary scientific research should be rationally justified.

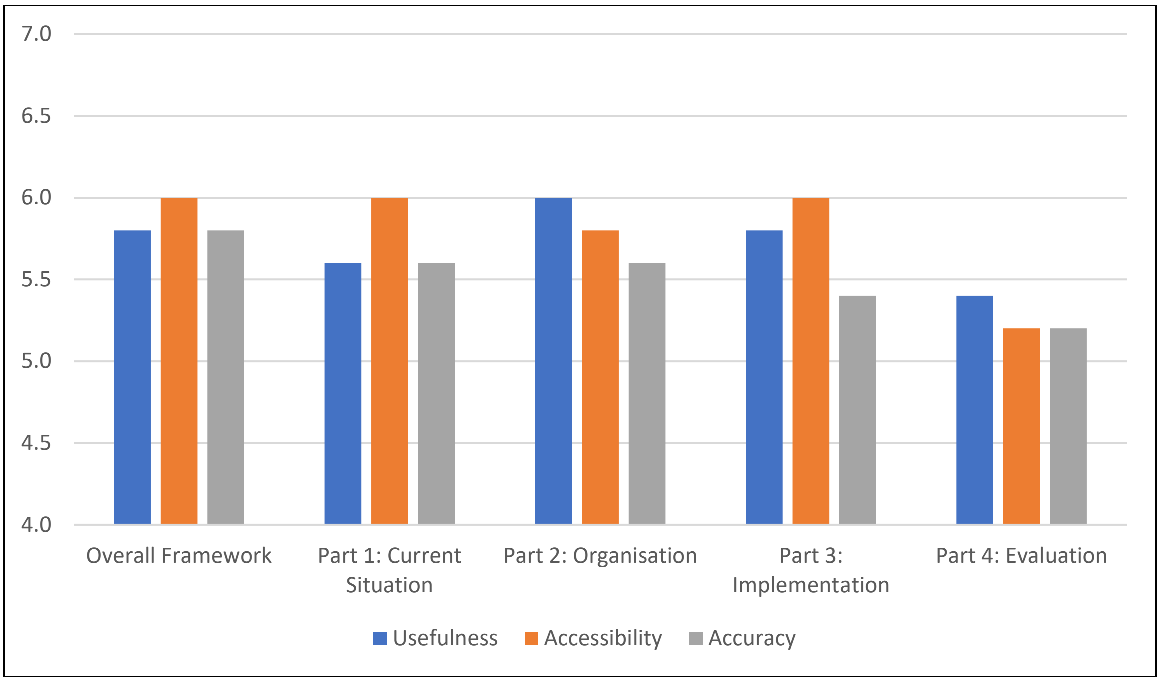

Figure 9-3 Summary of quantitative feedback from the review of the policy framework
(Source: Summarised from the data collected.)

9.3.3 Potential Modifications to the Framework

The analysis of the current situation in the Thai e-bus industry was remarked as mundane by many stakeholders. It was stated that several pieces of information were already circulated within the industry, hence their usefulness are limited. Another criticism was directed at the outputs from stakeholder engagement. Some participants did not agree with the result that was presented by this research and requested further examination of the analysis. Furthermore, it was requested that additional information should be included in this section to strengthen the argument that could lead to crucial decisions of policy makers. The information included the current number of registered ICE buses, and considerations regarding alternative fuel sources e.g., hydrogen fuel cells. For the existing contents of this policy framework, it was suggested that the market should be extensively researched to convince most business-oriented stakeholders to invest in e-bus development and manufacturing. The declaration of numerical policy targets such as the number of e-buses that Thailand would adopt within 5 years in the future would substantially improve the confidence of manufacturers. Additionally, e-bus manufacturers also suggested state penalties to be imposed on users and manufacturers who still purchase and produce ICE buses. Lastly, it was stated that many private corporations would likely begin their operations without waiting for the adoption of public policies if the market requirements were met.

Another topic that was mostly criticised by the researchers in terms of its accuracy is the technology roadmap. There were multiple additional suggestions for the current permutation of the technology roadmap that was formulated in this thesis. The first suggestion was to create a proper timeline for the development of each proposed technologies in the roadmap, which should include the start date and the end date for the milestone in technological development. The second suggestion was to include more justification and in-depth explanation on the choice of technologies within the roadmap. The third suggestion was to create a separate development plan for each group of relating technologies. These relating technologies would be bounded together to form a more detailed sub-plan in the overall roadmap. Additionally, the targets for necessary technological acquisition were suggested as additional features for the second part in this framework. However, some of these suggestions would steer the direction of this research into the area of technical research for e-bus manufacturing rather than policy research. Thus, these comments would be put in the last chapter of this thesis, which will describe future considerations and some potential applications of this research.

Numerical and quantitative information were cited as a potential modification to the process of policy implementation that was proposed in chapter 8. It was asserted that it would be easier for policy makers to justify the adoption of multiple policy initiatives that were suggested in this thesis with this type of information. Furthermore, additional comments were directed at the origin and the importance of each component in the framework. The thorough clarification of each component was suggested to enhance the impact of the policy implementation process towards non-governmental stakeholders. Since several policy initiatives that were presented in this thesis are currently implemented, there were suggestions from several participants regarding the utilisation of an updated information as the inputs for a future modification of this framework. As a result, additional topics for activity diagrams were created after the end of this review session in response to this suggestion (figure 9-5). This figure shows that there are more possibilities to apply this framework to other areas in the development and adoption of e-buses, without restricting the research scope to only the elements that were presented in this thesis.

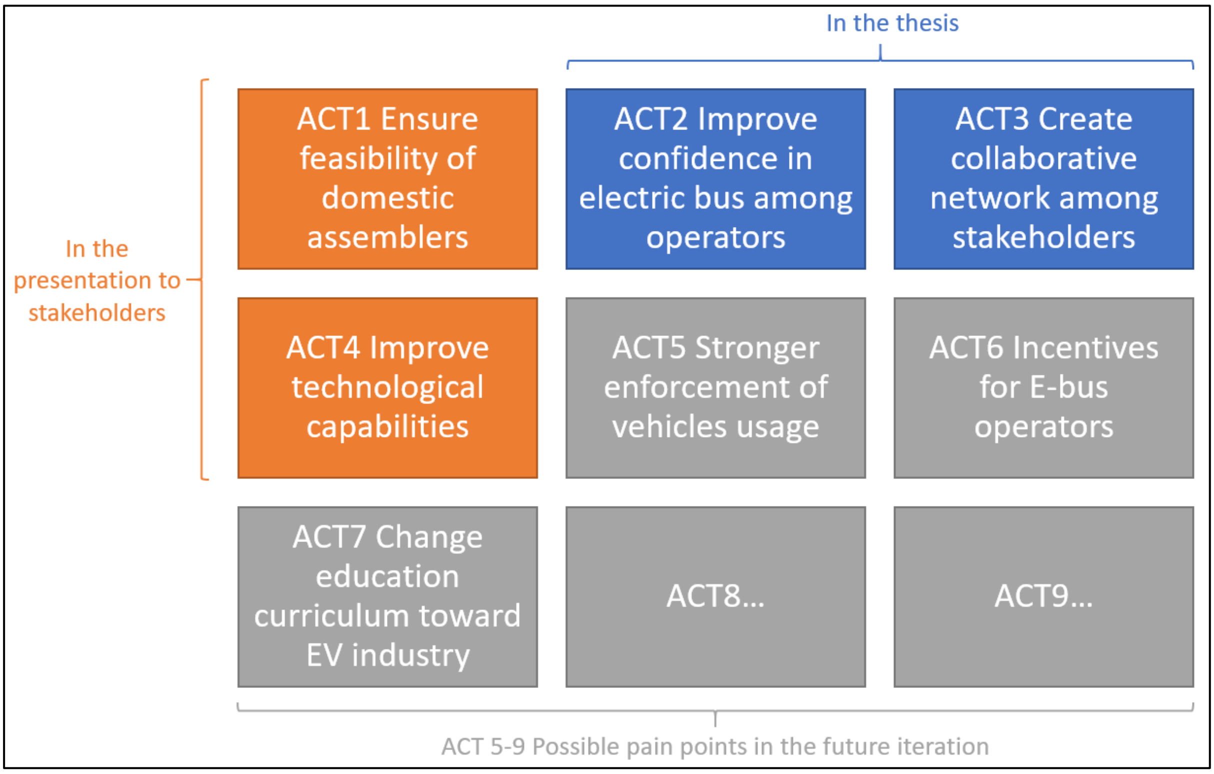

Figure 9-4 Activity diagrams that could be proposed by the government regarding e-bus policy.

Despite scoring the lowest in the quantitative survey, there were only few criticisms that were raised against the final part of this policy framework. Nevertheless, it was clearly suggested that the monitoring and evaluation schemes that were utilised by this framework are inadequate to fully control the collaborative efforts in the adoption of e-bus policies. More relevant information regarding the e-bus market should be included in the balanced scorecard to reflect the feasibility of investment to both old and new ventures because business feasibility was predominantly established as the main market driver in the e-bus industry. However, this addition might shift the perspective of this policy framework into the region of a business plan, which would make the framework poorly aligned with the original objective of this research. It was also suggested that there should be more direct collaboration between this research and other ongoing domestic research. The example included the collaborative research between The Office of Transport and Traffic Policy and Planning with technological institutions; KMUTT and KMITL (Kumfoy, 2020). Lastly, it was commented that the presentation of the framework prior to this review should be recorded for future uses. This recommendation would be followed in the future opportunities if the government agree that the results from this research are valid and not harmful to the institution.

Table 9-10 Summary of qualitative feedback from the review of the policy framework

Topics	Feedbacks
Additional Features	• Purchasing and development target for necessary technological capabilities. • Methods to incorporate recent inputs into the policy framework and policy plan. • Information of the current number of registered ICE buses and e-buses. • Additional considerations in alternative vehicle’s fuel sources e.g., hydrogen fuel cells. • Origin and Importance of framework components, especially activity diagrams. • More relevant information that business corporation can utilize.
Changes and Improvement	• Pricing catalogue of e-buses offered by both local and overseas manufacturers. • Collaboration of this research to another existing domestic research. • Exact numerical policy targets for both local content policy and proportion of e-buses. • More numerical information to justify the implementation of policy initiatives. • Proper timeline for roadmap, including the timespan for research and development. • More in-depth explanations on the choice of technologies in technology roadmap. • Separation of development process for each technology in the roadmap.
Other Suggestions	• Many of the policies presented in this plan were already implemented by the industry. • Private organizations are not waiting for public policies to be adopted. • Requirement of more meetings between all stakeholders in e-bus industry. • Office of transport and traffic policy and planning has similar research. • Recommendation to record voice and image of this presentation.

(Source: Summarised from the data collected.)

Chapter 10 Conclusion

The formulative process for a public policy framework in this thesis is an attempt to alleviate limitations in practical settings of the school of thoughts within innovation system and industrial cluster, by exploring and utilising applicable practices within the engineering management discipline. From this study, it can be concluded that the issues within the Thai electric bus cluster could be identified as either systemic or practical issues. Systemic issues should be addressed by the modification of the contextual approach that is used to study or analyse the system such as the re-design or the formulation of the policy framework. On the other hand, practical issues should be addressed by the alteration of the contents based on actual industry data. In this thesis, systemic issues were addressed by the formulation of a new public policy framework by considering systemic gaps in the literature, while practical issues were addressed by the development of a new policy plan based on the actual data collection within the electric bus cluster and electric vehicles industry in Thailand. The failure to individually view these two different forms of issues is a pitfall of many systems i.e., most systems tend to imitate the whole aspect of an existing case or best practice rather than separating between the context and the contents of the case and sparingly apply them in an appropriate manner.

This research primarily focused on the practical limitations regarding collaborative efforts deficiency among the members of the systems or clusters. It utilised the electric bus research and manufacturing cluster in Thailand as a practical case to reflect several gaps of the theoretical approaches in an actual industrial setting. This public policy framework was formulated as a conceptual resolution to mitigate these systemic gaps within the approach of innovation clusters. In addition, this framework can also be considered as a structural guideline to address the lack of shared vision in the implementation of public policy. All components within this framework were specifically designed to deal with contemporary issues in the Thai electric bus research and manufacturing cluster, in addition to systemic issues within the concept of innovation clusters. The identification of the industry gaps in the Thai electric vehicles industry and electric bus research and manufacturing cluster provided additional insights to the state of the electric vehicles industry in Thailand. Consequentially, a public policy plan was designed based on the structure of the formulated framework and the identification of domestic industrial gaps to mitigate both systemic issues of the cluster and industrial issues of the electric bus industry. This policy plan consists of the information that should be applicable to the development of electric vehicles industry in other developing countries. The three aims of this research would be addressed in the next key findings section to summarise the results and the outcome from this formulation of a framework.

10.1 Key Implications of the Research

10.1.1 Systemic gaps in the previous applications of engineering management processes towards innovation clusters and systems approach.

This first implication is based on the first objective of this thesis: To determine limitations within the application of innovation system which might be the cause of suboptimal operation in an innovation cluster. It was firstly established in the literature review of this thesis that many innovation clusters are complex adaptive systems (Katz, 2016). Therefore, an attempt to initiate and manage the cluster would require a pragmatic planning process which involves the extensive study of the existing literature to identify the systemic gaps of the previous cluster policy approaches. Additionally, a set of integrative management processes must be developed to mitigate the operational issues that usually occur in large and complex systems. However, it was asserted that many applications of the technological management process are too detailed and complex for the general audience (Uflewska, Wong and Ward, 2017). These circumstances lead to a challenge in the presentation of these tools in a format that would be easy to understand to the public who are being the stakeholders in the system. The integrated public policy framework presented in this thesis is a practical model that attempts to facilitate the understanding of all stakeholders in any industry and innovation clusters. This feature is crucial in the implementation of public policies, considering that the framework would be disseminated to a broad range of stakeholders in Thailand, including experts and non-experts from several different fields of expertise.

There were many studies that attempted to modify technology management concepts to make them more responsive to the rapid change of technology (Prakhya and Hull, 2006;Cetindamar, Phaal and Probert, 2009;Uflewska, Wong and Ward, 2017). These attempts could be categorised into two major types; firstly, technology management tools could be altered based on the pre-existing framework of a system in application, and secondly, technology management tools could be fine-tuned in real-time fashion based on the actual situation and current outlook of the system. The second type of attempt usually focuses on a specific type of technology and its application and strives to provide a case-specific solution. Thus, it was used as a blueprint in the design of this policy framework based on the electric bus industry in Thailand. Temporal aspects of technological change are not the only factor that could affect the effectiveness of the management processes. Cultural differences in each case or settings could also instigate this deficiency. The same management tools would likely operate on a different wavelength among various organisations with a degree of distinction in cultural embeddedness. For example, technological transfer in western countries tends to be more informal in comparison to technological transfer in eastern countries (De Moortel and Crispeels, 2018). This could potentially result in different forms of policy framework being developed. Aside from a chance of being unresponsive or less effective in a certain environment, some management tools are not feasible in the study of the whole supply chain. This is especially true for a large-scale industry that involves numerous actors and interconnecting networks such as the automotive industry in Thailand. To counter this, management processes should be used in conjunction with an industrial clustering approach. This thesis separates the electric bus industry from the general EV industry in Thailand to ensure that the policy framework could properly encompass the whole supply chain of electric bus research and manufacturing in Thailand while excluding irrelevant part of the supply chain.

The modification of the management process according to its surrounding environment is not the only path to bridge these gaps. Alternatively, it is also possible to alter the surrounding environment, so that a respective management process would become more suitable for the assessment of the situation. This practice might be valuable for several cases in technology and engineering management, since there are already a significant number of facilitation and management tools such as several online platforms that users could access via the internet. There is a high chance that some of these techniques or platforms could provide a good solution to a specific issue that any organisation or any system would encounter. The re-utilisation of existing ideas would also effectively lessen the efforts in the development of a completely novel framework. However, the formulation of an entirely new framework is sometimes unavoidable, especially with a highly specific problem. As a result, the balance between the usability of the framework to a specific case and the accessibility of the framework to the general audience must be carefully considered. In this thesis, the summary of how to formulate a convincing, approachable, and effective policy framework was presented prior to the data collection and was further modified in the later chapters by utilising the actual data of the industry. This was done to mitigate the predicted issues which were outlined in the literature review section of this thesis. In summary, the outline of the framework was created but it is not yet completed without the actual inputs from the data collection which could put this framework in motion and allowed its effectiveness to be evaluated. As a result the formulated policy framework was planned to be developed in conjunction with the inputs of collected primary data; the process in which will be thoroughly explained in the following sections as the remaining key implications of this research.

10.1.2 The formulated public policy framework

The second key implication is based on the second objective of this thesis: To create a structural guideline that address policy inefficacy relating to the operation of innovation cluster via the formulation of public policy framework. It was established in the literature review that the policy framework requires three main features in its formulation to become fully effective. Firstly, it requires management tools and techniques that could be practically visualised to aid the understanding to a wide range of audiences. Secondly, it requires inputs from all categories of stakeholders within the system to capture the complete viewpoints to the cluster. A proper set of management processes must be employed to address each specific problem within the system in consideration i.e., business plan for profit-seeking enterprise, policy implementation plan for policy makers, etc. Thirdly, it requires the conceptual mapping that can be used as an outline to the whole structure of the framework. The collection of framework components in this thesis were connected in a logical and progressive manner to facilitate the understanding of the whole framework. Additionally, these three important parameters were evaluated in the third phase of data collection to test the degree of accomplishment of the formulated framework to the audience in these three topics.

The first feature of the framework focuses on the visualisation of analysed information in a clarified and meaningful approach to the audience. There are three important considerations for this topic. First, any diagrams or figures that are used in the policy framework must be clear and not cluttered with excess information. They should be easy to understand without unnecessary information that could distract the audience. Second, the visual imagery must be contributory to the explanation of the details. A good visual imagery could facilitate audience's understanding and minimise the confusion in a more complex scenario. Third, the information should be complete and not misleading. Most of the information was aimed towards stakeholders who are directly involved in the implementation of e-bus policies; hence the accuracy of information is critical to the effectiveness of the policy implementation.

The second important feature of the framework involves the actual adoption of the plan that was described in this policy framework. Despite having good visualisation techniques, they would not be sufficient to convey the proper direction for the plan. All efforts in the communication would be meaningless without the practicality of the framework. This risk should be avoided by the persistent inclusion of signposting within the framework and the inclusion of all types of stakeholders within the system in data collection process. However, the full details should be excluded from the presentation format which should only focus on the broader conceptualisation of this policy plan because they could produce unnecessary clutter to the contents. Nevertheless, the written thesis will be provided as a more descriptive information to the interested stakeholders and involved organisations.

The last important feature for the application of this public policy framework to the environment of a complex adaptive system such as e-bus industry is the logical connection between each component of the framework. The usage of several management tools and techniques in a single unified policy framework might be difficult for the audience to grasp. Hence, a holistic view to observe where each component would fit in the overall structure is essential. An interconnected multi-layer framework should have a single encompassing conceptual diagram to show the contribution of each part of the framework to the central issue. The structure of the framework should be constructed in a progressive fashion, so that each component is created and designed based on the expected results from the preceding step in the framework.

10.1.3 Policy outputs for electric bus research and manufacturing cluster in Thailand

Finally, the third key implication is based on the last objective of this thesis: To identify specific gaps in the Thai electric vehicles and electric bus research and manufacturing cluster. Even after the essential features of the policy framework were completely designated and designed, additional inputs from the analysed interview data from the Thai e-bus industry were also utilised in the constant re-designing of the formulated policy framework. The finalised structure of the formulated policy framework is shown in figure 10-1. This final format of the policy framework was used to complete the public policy plan for the Thai electric bus research and manufacturing cluster. The resulting policy plan was separated into 4 main parts and organised into 4 chapters as described in the results and discussions section of this thesis. This policy plan is expected to address the current gaps within the electric bus research and manufacturing cluster and aim to facilitate the operation of the cluster and potentially accelerate the adoption of electric buses in Thailand.

Chapter 6 was the first part of results and discussion section. It also served as the first building block in this policy framework. This chapter discussed the current situation in Thailand electric vehicle industry, especially its electric bus research and manufacturing cluster. The details in this chapter included the analysis of current and potential stakeholders in Thai e-bus industry. Additionally, this chapter also explained the urgency and importance for electric buses adoption in Thailand and provided cross-analysis that showcased the current research and manufacturing gaps and the competitive advantages and disadvantages of the current Thai electric bus industry.

Chapter 7 was the goal-setting part of this framework. It consisted of the specific industry goals that were envisioned by Thai policy makers, and possible paths for development that could enable the Thai automotive industry to reach those goals. This section of the policy framework contributed comprehensive ideas to organise the current automotive supply chain towards an electric vehicles economy, including the introduction of intermediaries to facilitate cluster organisation. The main topics in this section discussed essential technologies that should be obtained or developed to accelerate the progress in electric bus industry, and the embellishment of the business model for different groups of stakeholders to cultivate a necessary level of demand in the electric bus market.

Chapter 8 developed the policy implementation plan for visions that were set out in the previous chapter. This implementation plan consists of three major components; the design of multiple scenarios regarding the adoption of e-bus which were illustrated by IDEF0 model, the segmentation of policy initiatives which were presented as a strategic implementation plan, and the creation of a situational decision-making tool via the UML activity diagram. These three steps provide a specific but flexible structure that could be replicated in any format of policy making. This chapter also integrated various insights from overseas cases of electric bus research, manufacturing, and service operation. Their best practices were integrated into several policy initiatives that were proposed in this framework.

Chapter 9 presented systematic methods to monitor policy implementation plan which was formulated in accordance with the mechanisms proposed in this policy framework. It covered the indicators and metrics to measure the successfulness of electric bus adoption, based on the proposed policy plan. This evaluation process consisted of two separate mechanisms which would be relevant in different administrative scopes. A balanced scorecard is a more relevant tool at national policy level because of its top-down perspective, while work breakdown structure is designed to be more suitable for the delegation of controlling process to several stakeholders. This chapter also contained analysed results from the feedback survey in the final phase of data collection, which was designed to measure the accuracy and usefulness of the framework and the policy plan that was formulated in this thesis.

In conclusion, the formulated framework is initially designed with the intention to address the systemic gaps of the previous applications of cluster policy concept and engineering management processes in the complex adaptive systems. It was specifically designed to cover most pitfalls of the existing foundation while maintaining the usability and comprehensiveness of the applied management methods. However, it was concluded that the newly designed framework will not be sufficient to address practical issues and industrial gaps within a specific industrial setting. In this case, an inclusive in-depth data collection and data analysis should be conducted as a supplementary process to develop the corresponding policy implementation plan to maximise the effectiveness of the framework in a specific environment. Therefore, the electric bus research and manufacturing cluster in Thailand was chosen as a case to evaluate the effectiveness of the proposed framework.

With these two building blocks, it is expected that this research would provide a valuable set of policy management tool that could be easily reimplement within the field of cluster policy, engineering management, or any other relating applications.

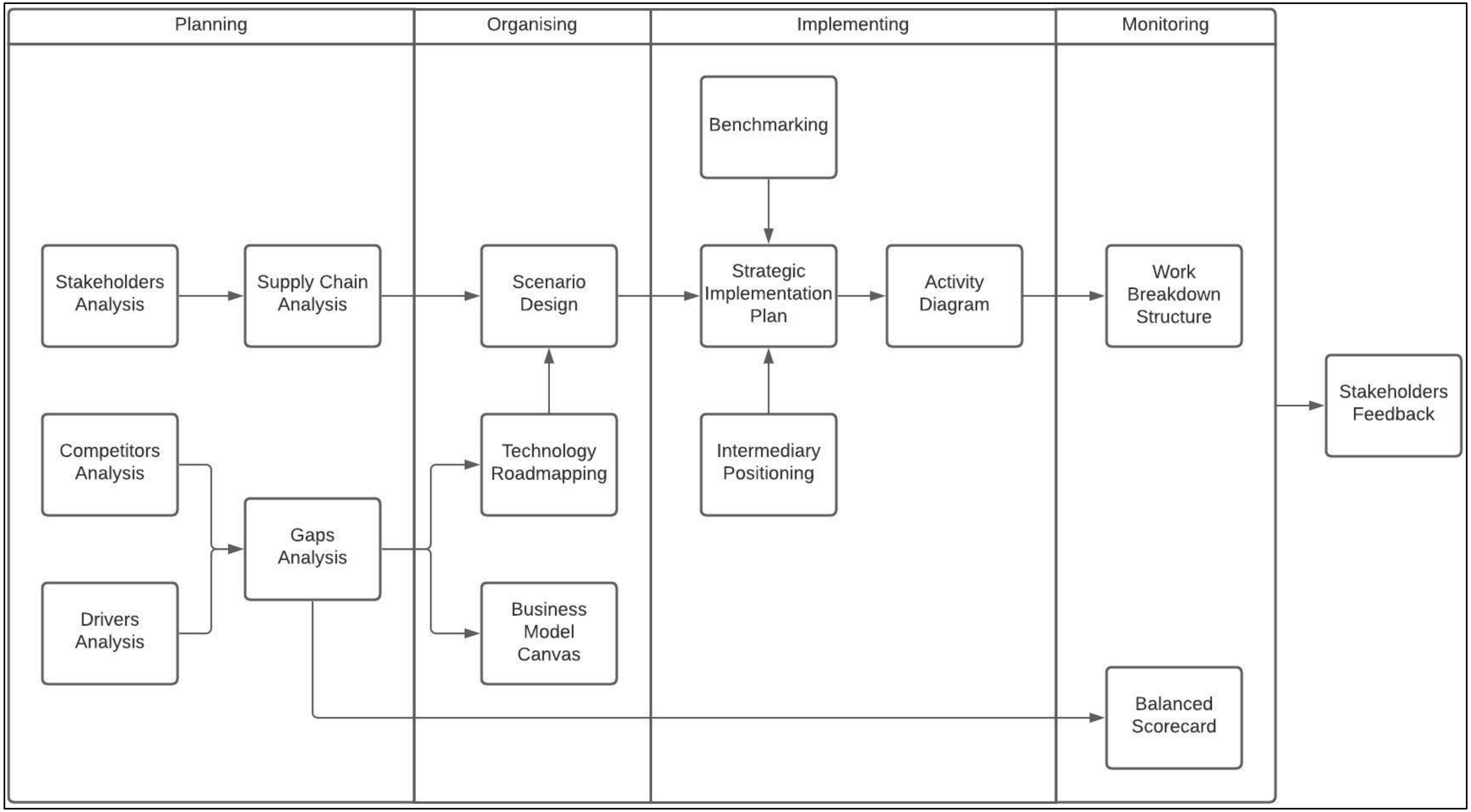

Figure 10-1 The overall structure of the formulated policy framework.

10.2 Contribution to Academic Knowledge

10.2.1 The process of framework formulation that can be further modified or imitated

The pre-existing framework for the policy-based application in the literature are not sufficient to solve a specific issue in a unique setting. Most of the existing guidelines or frameworks are either focused on the small section of the policy or are too general to be useful in the actual implementation. There are two reasons that this policy framework was created. The first reason is already explained in the previous section i.e., to solve the systemic gaps in the application of engineering tools towards a complex innovation cluster. The second reason is that the existing knowledge is most often not compatible with the specific research problem. Most of the frameworks in the literature such as Tesla's technology roadmap are difficult to replicate or imitate based on the limited amount of the required in-depth information. To create an encompassing policy framework that will mobilise the whole system, more concern should be put into the overall picture since most stakeholders are motivated by different elements. Thus, having an encompassing viewpoint instead of deep but overly inclusive information is extremely crucial for the success of the policy implementation where effective collaboration between many groups of people is emphasised. This policy framework straddles between the two extremes and ensures that it has enough in-depth information in each component while also having sufficient breadth to cover all interests among every actor within the system.

The results of this research should be sufficient to become a general guideline to effectively analyse industry clusters and provide an alternative solution for cluster-based policies based on the damaging changes that could occur via technological disruption or other abrupt changes in the external environment. Additionally, the resulting framework also provides several mechanisms that could mitigate drastic effects on the supply chain and operationalisation of a specific industry which could originate from any external deviations in the environment such as political or demographic changes. This policy framework could also be used as a coarse outline to model the public policy plan by the utilisation of a set of tools that were presented in this framework. However, the methods that were employed in this study might not be completely transferable to another context. Some technical and cultural aspects in this case are highly specific to Thailand. This consideration must be considered when the new policy plan is designed for a different industry or different organisation.

In a similar way to the case studies that were used in the literature review, this policy framework could be a base of academic knowledge that could be utilised by other researchers who aim to achieve relatively comparable objectives. Moreover, it is expected that the framework will be academically accessible to a wide range of people because it was specifically designed as a non-technical and simplified framework. In addition, further customisations of this framework could be made to address different levels of industrial and policy issues. For example, a more in-depth technology roadmaps could be a sole focus of the research that aims to develop a more advanced technological development plan for a specific industry. The roadmap could be expanded to cover a wider range of time or deeper aspects of technology, instead of the generalisation of technologies that were presented in this framework.

Each component within the framework would be fully replicable in similar applications. The foundation in the formulation of several parts within this policy framework are consisted of the existing engineering management techniques and models, which were then modified to be compatible with the main objectives of this research. In addition, this framework also incorporated a variety of dissimilar concepts into its contents, such as industry analysis, business plan, and public policy implementation. Therefore, there is a likelihood that some components would be useful to a certain group of practitioners. For instance, research and development teams from a private enterprise might be able to fully adapt the technology roadmap for their respective uses, while policy makers would likely to accumulate more benefits from the section regarding policy implementation plan. This conclusion was confirmed by the feedback section in this thesis where it was found that different parts of the framework were perceived differently by distinct groups of stakeholders in the Thai e-bus industry.

In conclusion, three important questions need to be considered to maximise the academic usefulness of this research and its formulative process of the policy framework. Firstly, are the mechanisms and components in the framework compatible to the respective industrial and other external environments? Secondly, does the general uses of the framework match with the current problems that will be addressed? Thirdly, are there any better alternatives of frameworks or tools that could be applied instead of the one that was considered? Even if the framework succeeds in all three criteria, it still should be transformed into the intuitive presentation format that is easy to communicate with a large group of audience. All these elements are the challenges that academic researchers should attempt to overcome by adapting the policy framework into their own iterations, which directly address their own research questions. The originality of this research exists in the emphasis of its own iteration and the amalgamation of multiple engineering and management concepts to solve multiple organisational issues in a single complex system. This thesis also focuses on the concept of utilising existing academic knowledge and applying them in a dynamic perspective. Hence, the newly collected primary and secondary data was constantly re-utilised to design an evolving policy plan that would accurately reflect the latest situation in the Thai electric bus industry.

10.2.2 Insights towards electric vehicles industry and the corresponding process of policy planning in a developing country

The contents of this thesis might be relevant for the next few years because the electric vehicles are currently a contemporary topic. Nevertheless, the quick progress in EV-related technologies might invalidate some of the findings in this thesis and shorten its long-term applicability. Some parts of the policy outputs from this thesis can be applied in other situations outside Thailand. The information that was presented here is relevant to an electric vehicle industry in other developing countries. There are many insights that might be a reflection towards similar struggles of many other developing countries to adopt the EVs into their transportation system. There are several identical barriers for policy makers to consider, such as a sizable gap of price and technical performance of EVs when compared to ICEVs. In addition, the lack of confidence towards EV related technologies should also be addressed. This should be mitigated by the preparation of necessary charging infrastructure, and the mechanisms for local manufacturers to absorb EV-related technological capabilities. Public policies should be systematically formulated by applying updated information that covers the whole range of the automotive supply chain. In summary, the successful adoption of EVs throughout the country would largely depend on governmental support for both technological and market development.

From the results of this thesis, it was concluded that the main driver for the transformation of the transportation system towards EV is constantly shifting, due to several circumstantial external factors. Currently, it was found that environmental concern is highly influential to the awareness and market opportunity for the EV industry. In the case of the Thai automotive industry, economic concerns are equally critical because a large portion of the automotive manufacturing industry could be disrupted by the growth of electric vehicles. However, many stakeholders within the industry are still not yet ready for this transformative change. The Thai government must come up with several mechanisms to convince and engage these stakeholders with the reformed automotive supply chain that would be primarily driven by the manufacturing of electric vehicles. Moreover, it is widely accepted that Thailand is still lagging in EV research and manufacturing capabilities, in comparison to many overseas competitors such as China and South Korea. These gaps need to be resolved during the formation of an industry cluster that links all the essential stakeholders together in a unified supply chain. A technology roadmap and business plans were also designed to facilitate the strategic movement of these stakeholders. It was concluded that battery related technologies are currently a substantial feature within the value chain in the e-bus manufacturing industry. However, alternative solutions for research were suggested for Thai manufacturers because of the lack of readiness in terms of production costs and technological capabilities. Ideally, most of the proposed technologies must integrate existing capabilities of domestic bus manufacturers, to maintain the stability of the national industrial economy.

In this thesis, multiple scenarios were designed to provide different policy options for the e-bus cluster that the government could implement. These scenarios mainly focus on the research and manufacturing segment of the supply chain, as stated in the original title of this thesis. The multitude of different scenarios that the e-bus cluster could adopt range from the full-scale imports of the products from overseas sellers to the complete domestic manufacturing of the products. These scenarios were analysed and were put into a diverse implementation plan that featured a variety of industrial targets. These targets were assimilated into different policy initiatives which could be implemented. The policy initiatives were linked together in a singular diagram to illustrate the appropriate order of these initiatives. It was concluded that there was a large insufficiency in the current evaluation schemes for public policies that were employed by the government, i.e., most of policy initiatives that were adopted by the government have no means to assess its own effectiveness. Hence, two different methods which are suitable for different scopes of assessment were suggested in the framework. The top-level strategic vision and low-level implementation plan must be properly linked by the proposed targets and metrics of measurement for the evaluation schemes to function effectively. This practice will provide valuable insights to the next step of public policy planning in any governmental programme.

The adoption of electric vehicles in an actual transportation system might seem like a distant technology-intensive target for many developing countries. However, there are many indicators from the literature and statistics that this adoption would provide substantial benefits to the national economy. Several potential impacts from the adoption of e-bus were explored in this thesis. It was established that the increment of e-bus usage in public transportation would lead to a large amount of reduction in air pollution and fossil fuel consumption. Additionally, the development of a public e-bus system would complement with the development of EV manufacturing industry in general. This includes other technologies in the next generation of vehicle development i.e., autonomous driving system, vehicle's connectivity, and shared mobility which would all contribute towards the improvement of road safety and the reduction of traffic congestion. On the other hand, the growth of the global market in EVs could also be considered as a risky prospect for some automotive industry that are heavily devoted to the production of internal combustion engine vehicles (ICEVs). For Thailand, the large amount of export value from this industry could be lost by this potential technological revolution. A proper preparation for the transition of domestic automotive supply chain towards the new form of research and manufacturing processes should be made as a failsafe plan to minimize the negative impacts that could occur in the future.

10.3 Future Applications of the Research

10.3.1 Further improvement of EV-based policy in Thailand

It was stressed multiple times throughout the thesis that the dynamic and constant changes in the industrial and technological environment will strongly affect the form of public policies that would be formulated and implemented by the government. As a result, an unbending policy plan is highly likely to be less effective than its flexible counterpart that was adjusted in accordance with the shifting conditions of the system. In this case, the adjustment could be made along the finer details within the policy plan for e-bus adoption, while utilising the same framework as a model for the design. The example of adjustments that could be made are the use of different implementation scenarios or monitoring metrics. Conversely, the framework itself could also be altered, but this undertaking would likely take a lot more time and effort. Hence, it was the original intention of this research to shorten the time for the adoption of public policies, by implementing a framework that is ready to be modified by various inputs and feedbacks. This point was addressed in the previous chapter where the policy plan and its governing framework are reviewed in an independent process i.e., not relating to the formulation of the previous permutation of a policy plan. This review process resulted in collective ideas to improve the underlying policy framework and a policy plan for e-bus clusters and its adoption in public setting.

The amount of monetary and non-monetary costs that the Thai government plan to invest in the future which pertain the transition of automotive manufacturing industry from ICEVs-based to EVs-based will be enormous, since it is currently one of the largest industries in Thailand. If several policy initiatives in electric bus research and manufacturing cluster could be effectively implemented, the significant amount of national treasury could be saved and redirected towards the development of the larger and more profitable segments in the electric vehicle industry. Additionally, the favourable results and interactions from this cluster could lead to several positive impacts for the development of other segments of EV industry. This includes the possibility of technology spill-over, heighten technological knowledge in EVs, and the establishment of EV-based supply chain and infrastructure.

In conclusion, the formulation of a public policy framework to encourage effective collaboration within an electric bus research and manufacturing cluster would be beneficial to Thailand's automotive industry and its stakeholders. Nevertheless, it is imperative that the appropriate components of the framework are presented to the right party. The overall and holistic framework structure is important to the policy making and implementation process, however the same cannot be said for the operation of every actor in the system. Policy makers need to fine-tune their contents to the intended audience. The mismatch between the contents and the motivating factors of stakeholders could demotivate them to participate in the government endeavour. The complete policy framework which was presented in this thesis would encourage consistent collaborative efforts within the electric bus cluster. The rigorous cooperation in research and manufacturing of electric buses between the government, industrial enterprises, and universities will accelerate the adoption of electric buses in public transport. Ultimately, it is hoped that the widespread uses of electric buses in Thailand would mitigate vehicular pollution problems in metropolitan areas, and act as a catalyst to the transformation towards an electric vehicles ecosystem in the land-based transportation system throughout Thailand.

10.3.2 Applications of the framework in other settings

The direct application for this policy framework is to use it to formulate policy programme in other sectors, which can be either industrial or non-industrial public policies. However, the application of the framework in non-industrial settings might require slightly more modification than the application in an industrial setting. The scale of policy research and information gathering could be smaller in the application that does not necessarily cover the full range of a specific industry. For example, if the framework is used in tourism policies that aim towards the vicinity of a specific province such as Phuket, the scope of information gathering would change dramatically. As a result, the focus of a policy framework could be shifted to suit the creation of appropriate policy programme. In addition, it is imperative to designate the boundaries for the application of this public policy framework. For example, this thesis established that the framework will be a catalyst for the formulation of a policy plan that would only cover the e-bus segment of the EV industry in Thailand, and this policy plan had the sole purpose in initiating a wider e-bus adoption throughout the country. Similarly, the boundary of tourism industry in Phuket should be indicated. Will the resulting policy plan also include the infrastructural planning of the city? or it would purely focus on marketing aspects of tourism? The utilisation of this framework would be a reaction to this predetermined constraint. Based on this specification of policy objectives, some parts of the framework might be emphasised while the others might be entirely excluded from the final design of the modified framework.

In a slightly less direct application, this framework can also be adapted and applied in a corporate setting. The framework will be a suitable tool to manage and visualise organisational projects because many components in the framework originated from several established management concepts. However, it might be more appropriate to utilise only some parts of the framework in this type of application. For example, a complete analysis of the whole supply chain might not be necessary i.e., it might be more fitting for a corporation to focus on their adjacent suppliers and customers. Subsequently, the smaller number of partners in consideration would alter the scale of stakeholder's analysis and relationship profiling in the first part of the framework. Likewise, the creation of an intermediary entity to manage internal collaboration might not be needed in a corporate setting, since the scope of activities would not be vast enough to warrant additional investments. Nevertheless, this idea might be applicable for a large-scale corporation that controls multiple subsidiaries. On the contrary to its original purpose, the concept regarding policy implementation in chapter 8 would be almost completely replicable as the method to formulate internal corporate strategies. Multiple scenarios concept can be used to model different business strategies that an enterprise could pursue, and the activity diagram could be used as a guideline towards the operational-level action plan for company employees. It is a demanding task to reapply all the details in the framework in a new situation, thus the corporation should make sure that they are able to allocate sufficient manpower and resources to generate and manage this plan. This type of framework would enhance the clarity of corporate goals to all personnel in the firm. Additionally, it would establish a clear linkage from top-level corporate strategies to an array of operational plans; the circumstance which was reflected in the original purpose of the framework formulated by this thesis.

10.4 Concluding Remarks

10.4.1 Dissemination of the research

The summary of this research could be featured in a quarterly journal published by The Office of National Higher Education Science Research and Innovation Policy Council (NXPO). This journal is publicly accessible to any interested researchers. For internal usage, NXPO, as the primary sponsor of this research will use this research to aid in their continuing development of e-bus industry and EV industry in Thailand. Additionally, this framework was already utilised by some of the policy staff to analyse and develop public policies for other industries, especially for cluster policy.

Supplementary information that provides extra details for this thesis are included in the appendix. Some primary unanalysed data that were deemed unnecessary for the complete understanding of this thesis were excluded. The examples of these data are the recording of interviews in sound format, dataset and spreadsheet that were used for data analysis, and various presentation files. Please contact the author for the request regarding this exclusive information. However, the sharing of the materials is not guaranteed, due to the inclusion of several sensitive information that was filtered by this thesis. Total consent from some of the primary and secondary data sources was not fully acquired, thus additional process is required to obtain the consent from original data sources. This thesis will also be made available as an academic resource of the University of Strathclyde.

10.4.2 Ethical consideration

This research directly dealt with Thailand's national public policy. There might be some issues with monetary data of Thailand national treasury, regarding the amount that was invested in the implementation of several policy initiatives. The content in the thesis that entails this numerical information was carefully verified, to prevent possible controversies and dissenting opinions that could be directed at fiscal policies of the government.

Since most of the data collection was based on multiple interviews with influential individuals responsible for public policies and automotive industry in Thailand. It was expected that some interviewees might not be willing to disclose full information to the researcher. Moreover, it was difficult to verify the extent of truthfulness within the information that was extracted from the interviewees. Therefore, there might be a slight skew in term of information accuracy that could negatively impact the outcome of this thesis. Nevertheless, all the participants were aware of this complication and granted the approval to use their interview data for this specific research.

Conflicting opinions that were presented were toned down to avoid apparent impartiality within the content of this thesis. There was clear conflict of interests among several stakeholders in the e-bus industry. These potentially sensitive comments were moderated in the interview transcriptions. Nevertheless, it should be noted that the power struggle and political issues are prevalent and play a pivotal role not just to the development of e-bus industry, but also in a larger scope of the Thai EV industry. As a result, from these three reasons, it is possible that some people would openly dispute on the ethical integrity of this research.

10.4.3 Limitation of the research

Some of the limitations of this research are elaborated within the main contents of the thesis. These limitations are compiled in this section. Firstly, it is important to acknowledge the negative effect of global pandemic situation from corona virus during 2020 to 2022, which reduced the amount of primary information that were collected in the data collection process. The amount of information gained from the process was adequate for the thorough analysis of e-bus industry. However, a large amount of improvement to the results can be expected from additional collection of primary data. Moreover, the pandemic situation also negatively affected the overall progress in the EV industry within Thailand. This circumstance might warrant the revision of some components within the policy plan that were formulated by utilising matured information. It is important to note that the number of feedbacks that were used to assess the framework were also lesser in volume than the original intention. This deficiency might affect the precision and accuracy of the assessment. The scarcity of response also limited contributing suggestions that could be used to improve the formulated policy framework in the future.

Since the electric vehicle industry is a constantly moving technology at the present, many of the resources in the literature review that were used or based on will be less relevant while the technology progressing into the next stage. It might be beneficial for the readers or policy implementers to regards most technical contents that were presented by this thesis as being non-finalised. It can be concluded that there would be some changes to this technology in the near future. For example, electric vehicle’s battery might be a big barrier within the industry at the moment, but many people also predicted an upcoming technological breakthrough which could substantially decrease their manufacturing cost. As a result, industrial consideration might be placed in other areas of the industry rather than the development and acquisition of the battery. This could be other aspects of CASE technologies such as a higher level of autonomous system or a more efficient solution for land-based public transportation. It is suggested that a contemporary literature review regarding the state of electric vehicles industry in every 3-4 years should be conducted, in the case of making new research that would use a lot of information from to this specific technology.

Another limitation of the research is the limited content regarding the possible application of this policy framework to other settings. Aside from a condensed explanation that was presented in the previous segment, extensive applications of the framework to corporate setting and other forms of public policies were not explained in detail. Additionally, the full range of the e-bus industry was not fully covered by this policy framework. Many potential implementation scenarios were neglected to give more emphasis on the research and manufacturing part of an e-bus cluster. The possible variances located at the downstream of the supply chain such as the operation of public bus services, charging infrastructure, and energy-based businesses were not given the full attention. This thesis also excluded detailed explanation in other alternatives vehicle types that use other fuel sources aside from battery electric vehicles (BEVs). The main reason is the limited amount of domestic research and technological progression regarding the utilisation of other alternative fuel sources for electric buses. It was clearly stated by several experts in EV industry that BEVs would be a more suitable alternative for the large-scale adoption of electric buses at the present and in the foreseeable future for Thailand.

As a result, this research put more focus on the development of BEVs, in proportion to the higher chance of its being realised as the main driving force for Thai e-bus industry.

10.4.4 Suggestions for future research

Following the limitations that were summarised in the previous section, several improvements could be made for future research that would be based on this thesis. It was established from the results of this thesis that a more in-depth information from the proponents of an e-bus cluster would be beneficial to the construction and the acceptance of public policy plan that will be formulated by the government. Hence, additional data could be gathered to revitalise the pre-existing policy plan in accordance with the changing environment. This information could be used as inputs to the existing policy framework which was formulated by this research. The deficit of information is the most prominent limitation of this thesis. This inadequacy was most apparent in the quantitative analysis within the final review that assess the effectiveness of the framework. Thus, after the redevelopment of a policy plan or the modification of the framework itself, it is recommended to completely re-enact the review process again. However, the focus of this process could be changed according to the goals of the assessment. For example, the participants of the review could be from a different group of audience depending on the new objectives of the altered framework or a new policy plan.

Alternatively, further research that would be based on this thesis could take an indirect approach by studying other aspects in the EV industry. For example, potential new research could focus on the downstream part of the supply chain instead of research and manufacturing activities. This choice would make the research strongly differ from the current module in this thesis. Therefore, the framework or some of its components might need some adjustments because they might not be relevant to the new research direction. Another concept that is worth considering is the study of other industries by applying identical or similar mechanics that were employed by this framework. Researchers could use this framework to assess other industries, which are crucial to their own situation and agenda for national development. The adjacent example included the study of hydrogen fuel cell vehicles (FCEVs) in applicable countries that have prominent development in this branch of technologies. As mentioned before, the policy framework proposed by this thesis was designed to be universally applicable to any application involving large-scale strategic planning for the adoption of public policies. Nevertheless, some alterations should be made in accordance with the intended purpose of the new research to maximise the benefits from the findings and implications that were presented within this thesis.

Additionally, case studies from other countries that have considerable progress in utilising electric vehicles within their public transportation system could be conducted to extend or expand the perspective on electric vehicles as the alternative mode for public transportation. Researchers can use this type of case study to compare these benchmark systems to their own supply chain of research, manufacturing, and operation of e-buses. However, this type of research would take a lot of efforts to coordinate and implement, while at the same time lacking the original contents. Therefore, this practise should only be used as a supplementary material in addition to the core research goal such as the formulation of the policy framework. To develop a new policy plan, additional primary data collections from the targeted subject is recommended to make the research more robust in term of its applicability. Case studies in a fast-moving technological field such as electric vehicles can be difficult to validate in the future since many of the contents especially the technological-based information or specification can be easily outdated. Hence, the researcher should make sure that all collected information from the case studies remain relevant to the current aims and objectives of their research.

Appendix A – Ethical Approval

Consent Form for [Name of the Interviewee]

Name of department: Design, Manufacturing and Engineering Management
Title of the study: The Formulation of Public Policy Framework: Encouraging Effective Collaboration within the Electric Bus Research and Manufacturing Cluster to Accelerate the Adoption of Electric Buses in Thailand

- I confirm that I have read and understood the Participant Information Sheet for the above project and the researcher has answered any queries to my satisfaction.
- I confirm that I have read and understood the Privacy Notice for Participants in Research Projects and understand how my personal information will be used and what will happen to it (i.e., how it will be stored and for how long).
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences.
- I understand that I can request the withdrawal from the study of some personal information and that whenever possible researchers will comply with my request. This includes the following personal data:
    - audio recordings of interviews that identify me.
    - my personal information from transcripts.
- I understand that anonymised data (i.e., data that do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the research will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project.
- I consent to being audio recorded as part of the project.

(PRINT NAME OF THE INTERVIEWEE)	
Signature of Participant:	Date:

Appendix B – Analysed Dataset

Contents	Retheme	Categories	Hit	Total
Bangkok and urban city pollution	Reduction of fuel consumption in public transport sector	Economic Performance	6	9
traffic congestion		Economic Performance	1	
Energy efficiency and global conciousness of energy uses		Economic Performance	2	
No target from the government	Create opportunity for researches and commercialization	Economic Performance	5	8
No large amount of procurement policy		Economic Performance	3	
conserve domestic industry by import tax wall on EV	Maintain economic stability while increase the investment	Economic Performance	4	6
e-bus components are taxes less than passenger cars		Economic Performance	2	
more in-depth information from stakeholders	Increase engagement of manufacturers in electric bus research and manufacturing cluster	Stakeholders Relationship	3	5
Mostly combined with EV in general		Stakeholders Relationship	2	
Bad perception from operators in e-bus compared to ICE bus	Maintain good relationship between state enterprise and private operators	Stakeholders Relationship	1	2
Bad experience with NGV model of government		Stakeholders Relationship	1	
number of users of policy that was adopted	Improve effectiveness of communication channels between stakeholders	Internal Processes	1	2
Putting this as a general study for developing countries		Internal Processes	1	
No evidence based fact about e-bus market	Greater impact from the collaboration between research, industry, and government sectors	Internal Processes	4	8
Future based metric or prediction		Internal Processes	2	
outputs of project and outcome of the initiatives		Internal Processes	2	
Lack of supporting policies to complement the change to e-bus	Transition of bus manufacturing supply chain toward electric vehicles economy	Internal Processes	2	5
Local content could not reach policy requirement		Internal Processes	3	
Universal charging system and process	Prepare adequate infrastructural facilities for electric vehicles	Internal Processes	3	8
EVAT EGAT		Internal Processes	2	
Lower electricity pricing		Internal Processes	3	
NSTDA and TAI	Effective prioritization of domestic research projects	Organisational Capacity	1	2
Pooling of resources and technology know-how		Organisational Capacity	1	
creation of collaboration with external partners	Increase the number of overseas business partners	Organisational Capacity	1	2
Confident in technological capabilities and competition with china		Organisational Capacity	1	
technology readiness level scale for each sector (recommendation)	Improvement of stakeholder's technological capabilities	Organisational Capacity	1	5
think that Thailand have good amount of basic knowledge for e-bus		Organisational Capacity	1	
Education system change from ICEV to EV		Organisational Capacity	3	

Top Theme	Total Hit
Reduction of fuel consumption in public transport sector	9
Greater impact from the collaboration between research, industry, and government sectors	8
Create opportunity for researches and commercialization	8
Prepare adequate infrastructural facilities for electric vehicles	8
Maintain economic stability while increase the investment	6

Dataset 1: Drivers for the development of the Thai e-bus cluster

Contents	Retheme	Categories	Hit	Total
TEV, EVT, Skywell	E-bus Manufacturers	Identification	3	8
BYD Loxley (import)		Identification	1	
Cherdchai, Panthong, SakunC, Sabai Motor		Identification	2	
Sunlong by EA (old model)		Identification	2	
No economy of scale, low profit	Thai manufacturers	Interest	4	17
Not enough funding for smaller companies		Power	3	
Low EV expertise of existing large corporation		Engagement	2	
Change of global market and trends will force many manufacturers		Engagement	3	
Think some stakeholders are actively prevent EV from happening		Engagement	4	
Confident in technological capabilities and competition with china		Interest	1	
Disemination of EV general knowledge	End Users	Influence	5	8
Grow more demand for e-bus		Interest	3	
Meeting and agreement between all relating parties	Government	Engagement	2	6
More formal meeting or brainstorming		Engagement	1	
there is a cluster for clean public transport policy		Engagement	1	
Mostly combined with EV in general		Engagement	2	
Rental model for BMTA to reduce maintenance and labor cost	BMTA	Interest	3	3
Lack of confident in new technology		Interest	3	
Risk of outdated technologies		Power	1	
No service from domestic manufacturers		Engagement	4	
Large amount of public debt		Power	3	
BMTA should order higher number of e-bus		Influence	2	
NSTDA and TAI	Mediators	Identification	1	3
EVAT EGAT		Identification	2	
KMUTT korean-imported bus	Universities	Engagement	1	3
KMUTNB charging station skywell		Engagement	1	
University and manufacturers KMUTT+KMUTNB		Identification	1	
Shenzhen e-bus	Foreign manufacturers	Influence	1	5
Public organization prevent private corp to reap profit		Power	3	
Skywell never formally request research support from NSTDA		Engagement	1	
Corporate fleet and B2B based buyers	Private fleet and operators	Interest	2	7
minibus type vehicles of private operators		Interest	3	
Poorly managed, overlapping bus route		Power	2	
Rental agency	Renting agency	Interest	1	1
NSTDA don't want skywell to do commercial charging station	Charging station	Power	1	3
Charging time issue		Influence	2	

Top Theme	Total Hit
Thai manufacturers will be pivotal to this revolution	17
Require acceptance from end users	8
Private fleets and operators must be on board	7
Government has sufficient power to drive the industry	6
Optional plan to cooperate with foreign manufacturers who have technologies	5

Dataset 2: The analysis of stakeholders in the Thai e-bus cluster

Import	Retheme	Categories	Hit	Total
BMTA recently order 30 units of e-bus (2,500 in 4 years)	quick purchase from government	Opportunity	4	5
Possibly the whole e-bus		Opportunity	1	
Technological experts who could work individually	Flexibility	Strength	1	9
Importing part to assemble in Thai garage		Strength	5	
can sell components to be assembled		Opportunity	3	
No after sales service	Less services	Weakness	4	4
Battery from china, tesla progress on EV would be a factor	Technology Capabilities	Opportunity	4	4
conserve domestic industry by import tax wall on EV	Import Tax	Threat	4	4
Domestic Manufacturer	**Retheme**	**Categories**	**Hit**	**Total**
No economy of scale, low profit	low economic incentives	Threat	4	12
Auto supply chain dominated by FDI companies		Threat	4	
Don't agree with tax wall which make price of EV too high		Threat	4	
Not enough funding for smaller companies	Low funding	Weakness	3	3
Change of global market and trends will force many manufacturers	Forced change	Opportunity	3	3
Low EV expertise of existing large corporation	Lacking tech capabilities	Weakness	2	7
Lack of qualified experts on e-bus and manpower		Weakness	2	
lacking practical field for research and development		Weakness	3	
Market is not well-developed	Low initial sales	Threat	1	1
state owned vehicles concern less about quality	Lower quality are accepted	Opportunity	2	3
Motor from ZF, battery from BYD		Opportunity	1	
Foreign Manufacturer	**Retheme**	**Categories**	**Hit**	**Total**
Strong overseas competitors	Technology Capabilities	Strength	2	3
Tesla not specialised in battery tech		Opportunity	1	
No in-depth research on e-bus operation	Low field knowledge	Weakness	1	1
expansion of industrial output	Expanding market	Opportunity	1	3
e-bus components are taxes less than passenger cars		Opportunity	2	
Market is not well-developed	Low initial sales	Threat	1	1
relationship and reliability with overseas suppliers	Network and Connection	Strength	2	2
Conversion	**Retheme**	**Categories**	**Hit**	**Total**
NSTDA funding 4 manufacturers in e-bus conversion	Government support	Opportunity	2	6
Older bus or van that change can be enforced		Opportunity	4	
think that Thailand have good amount of basic knowledge for e-bus	Improving knowledge	Strength	1	2
Think that converted e-bus would have acceptable quality		Strength	1	
Import is of higher quality than e-bus conversion	Low quality	Weakness	2	2

Top Theme	Total Hit
Low current economic incentives for Thai manufacturers	12
Flexible strategy for e-bus and components imports	9
Thai manufacturers are lacking technology capabilities	7
High government support for e-bus conversion	6
Government has a tendency for a fast purchase	5

Dataset 3: Competitors analysis in the Thai e-bus industry

Categories	Themes	Contents	Hit	Total
Capacity	Not sufficient research incubators	Require more testing facilities	2	10
	Not enough testing facilities	PTT but there is a scaling problem for production	1	
	Low R&D expenditures	Collaboration between local tech institute and manufacturers	3	
	No economies of scale	No economy of scale, low profit	4	
Human Resource	Lack of skill labours	EA still not yet construct the factory (tech acquire from taiwan)	1	4
	Different level of expertise in cluster			
	Brain drain	Education system change from ICEV to EV	3	
Technology	No technological diversification to produce alternative products	Lack of qualified experts on e-bus and manpower	2	10
	Few overseas technological alliance	No reliable domestic battery supplier	2	
	Require technological specialization in research and development	Low EV expertise of existing large corporation / lacking practical field for research and development	2+3	
	Low technological absorptive capability	No in-depth research on e-bus operation	1	
Economics	Low labour market efficiency	No service from domestic manufacturers	4	4
	Rely too much on exports			
	High level of immigrant workforce			
Finance	Adverse effect from FDIs policy			11
	The budget is not targeted toward meaningful activities	interconnected issues such as cost for development	4	
	No credit policy for EVs manufacturers and users	Not enough funding for smaller companies / Bad experience with NGV model of government	3+1	
	Require heavy funding to transform the industry	Large amount of public debt	3	
Vision	No strategic vision on national scale	No target from the government	5	7
	Lack of local content policy			
	No technology localisation policy	Lack of supporting policies to complement the change to e-bus	2	
	No clear objectives for each organisations that are synthesized from industrial gaps			
Measurement	No clear evaluation and measurement scheme for national policy	Mostly combined with EV in general	2	6
	No evaluation schemes for actual effects toward the environment			
	Current measurements are not indicative of technological performance	No evidence based fact about e-bus market	4	
Communication	Miscommunication in next generation vehicle policy	More formal meeting or brainstorming	1	2
	The transition from policy to implementation is difficult	justification for the adoption of policies	1	
Opportunity	Supply leads demand in EVs industry	BMTA should order higher number of e-bus / No large amount of procurement policy	2+3	19
	High risk of new competitors	Risk of outdated technologies	1	
	Lagging behind oversea competitors	Large corporation utilise e-bus as a fleet (mostly Chinese e-bus) / Strong overseas competitors	2+2	
	Low market growth	Grow more demand for e-bus / Need small and consistent buying lots / Market is not well-developed	3+1+1	
	High tax wall for part exports	conserve domestic industry by import tax wall on EV	4	
Awareness	Domestic demand for EVs is too low	Market size still small, lack of information	2	15
	Not sufficient communication to public	Disemination of EV general knowledge / People will have confidence in practical usage examples	5+6	
	few communication channel to the government	Meeting and agreement between all relating parties	2	
Business Model	Lack of incentives to invest for both public and private organisations	difficult to control private enterprises	3	10
	EVs disrupt other relating business	Change of global market and trends will force many manufacturers	3	
	No integrative business model for the whole industry	Rental model for BMTA to reduce maintenance and labor cost / Mostly how to operate e-bus and policy base	3+1	
Implementation	Multiple EVs manufacturing platform	Need to redesign operation model for e-bus	3	12
	State enterprise inertia	Slowness of communication between agencies	3	
	Require guidance from the intermediary	Poorly managed, overlapping bus route	3	
	Bottle-neck within process	Covid 19 situation	3	
	Inertia in old automotive manufacturers			

Collaboration	Silo mentality in researches initiatives			3
	Lack of intermediary organisation that is flexible and neutral			
	Multiple iteration of clusters			
	Require better university integration			
	Weak collaboration with industrial partners	Lower electricity pricing	3	
Supply Chain	30% of Thai auto industry is not transferable to EV industry			13
	Low bargaining power of Thai OEMs	Auto supply chain dominated by FDI companies	4	
	Decreasing value of supply chain	More public charging station infrastructure	4	
	Lack of supporting infrastructure for EVs	Charging time issue / Maintenance garage	2+3	
Cultural	Short-term business mindset	Lack of confident in new technology / E-bus will not worth it in business sense (currently)	3+2	6
	Perception of unfairness within cluster	Bad perception from operators in e-bus compared to ICE bus	1	
	Lack of research focus			
Total Hit	Top Theme			
19	create more market opportunities for e-bus cluster			
15	increase public awareness regarding e-buses and invigorating the demand			
13	support the transition toward e-bus by providing necessary infrastructure within the supply chain			
12	Speed up the implementation by reducing redundant task and assign the intermediary			
11	Manage and create additional fiscal policies			
10	Provide integrative business model for stakeholders in the cluster			
10	create more training program and collaborative effort with technological firms			
10	Provide research opportunity and facilities			

Dataset 4: Gaps in the Thai e-bus industry

Contents	Categories	Retheme	Hit	Total
there is a cluster for clean public transport policy	structure	Infrastructure	1	2
University and manufacturers KMUTT+KMUTNB	structure		1	
TEV, EVT, Skywell	structure	Manufacture	3	10
BYD Loxley (import)	structure		1	
Cherdchai, Panthong, SakunC, Sabai Motor	structure		2	
Sunlong by EA (old model)	structure		2	
Mostly combined with EV in general	structure		2	
Corporate fleet and B2B based buyers	structure	Service	2	6
minibus type vehicles of private operators	structure		3	
Rental agency	structure		1	
interconnected issues such as cost for development	consideration	Battery and energy storage	4	7
Technological experts who could work individually	consideration		1	
No reliable domestic battery supplier	consideration		2	
Quick charging station by SUT (suranaree)	consideration	Charging infrastructure	3	6
KMUTNB charging station skywell	consideration		1	
Charging time issue	consideration		2	
Vehicles Integration	consideration	Electric bus assembly	1	12
KMUTT korean-imported bus	consideration		1	
Importing part to assemble in Thai garage	consideration		5	
EA still not yet construct the factory (tech acquire from taiwan)	consideration		1	
difficult to control private enterprises	consideration		3	
Need small and consistent buying lots	consideration		1	
conserve domestic industry by import tax wall on EV	consideration	Components manufacturing	4	8
e-bus components are taxes less than passenger cars	consideration		2	
Separate and general components that also used in EV	consideration		2	
No after sales service	consideration	Service and maintenance	4	4
Poorly managed, overlapping bus route	consideration	Asset management	2	3
Urban traffic congestion	consideration		1	
Tracking system	consideration	Digital platform	1	1
Auto supply chain dominated by FDI companies	movement	Foreign manufacturers	4	9
Battery from china, tesla progress on EV would be a factor	movement		4	
Possibly the whole e-bus	movement		1	
Motor from ZF, battery from BYD	movement	Thai manufacturers	1	12
Components to be assembled	movement		3	
more in-depth information from stakeholders	movement		3	
Think that the value is in assembling process, not battery mfg.	movement		1	
Government does not care about smaller operators	movement		1	
Battery, Motor for e-bus	movement		3	
System integration	movement	Infrastructure	2	5
e-bus as a starting point for ev ecosystem	movement		3	

Top Theme	Total Hit
Electric bus assembling will be the biggest concern for the new e-bus supply chain	23
Components manufacturing outside battery and the survival of Thai OEMs	19
The acquisition of battery and its relating technologies	16
The preparation of charging infrastructure in the crucial areas	11

Dataset 5: Supply chain revision for e-bus manufacturing industry

Contents	Categories	Retheme	Hit	Total
NSTDA funding 4 manufacturers in e-bus conversion	Physical components	functionality of vehicles is moderately important and thai assembler should	2	2
Low EV expertise of existing large corporation	energy storage	High cost to develop battery and motor	2	10
Tesla not specialised in battery tech	energy storage		1	
Assemblers think e-bus conversion would be a waste of resources	energy storage		2	
Think that converted e-bus would have acceptable quality	Physical components		1	
Confident in technological capabilities and competition with china	Physical components		1	
Battery, Motor for e-bus	Physical components		3	
No evidence based fact about e-bus market	policy and services	public awareness and regulation moderately high importance	4	9
No in-depth research on e-bus operation	policy and services		1	
Future based metric or prediction	policy and services		2	
outputs of project and outcome of the initiatives	policy and services		2	
lacking practical field for research and development	field test	mid to high importance for field test	3	9
People will have confidence in practical usage examples	field test		6	
Separate and general components that also used in EV	electronics	lower cost and time to develop electronics components	2	2
Quick charging station by SUT (suranaree)	charging station	low importance of fast charge in comparison with slow charge	3	3
Vehicles Integration	connectivity	moderately important and cost to develop	1	2
Tracking system	connectivity		1	
KMUTT korean-imported bus	field test	low cost to establish field test	1	1
Urban traffic congestion	sharing	moderate importance to develop vehicles sharing model	1	2
traffic congestion	sharing		1	
KMUTNB charging station skywell	charging station	High cost to develop charging infrastructure	1	3
Charging time issue	charging station		2	
Bangkok and urban city pollution	policy and services	Environment test is important	6	6
Battery from china, tesla progress on EV would be a factor	energy storage	battery component is of very high importance	4	5
Motor from ZF, battery from BYD	Physical components		1	
Possibly the whole e-bus	body and chassis	body and chassis are lower cost than battery and motor	1	1
Components to be assembled	Physical components	reverse engineering could be importance if they are successfully implemented	3	5
Reverse engineering imported product	lab test		2	
Require more testing facilities	lab test		2	3
technology readiness level scale for each sector (recommendation)	lab test	testing facilities is at high importance	1	
battery swapping would be expensive, volume of vehicles not enough	sharing	battery swapping is at low importance	1	1
Universal charging system and process	charging station	Charging infrastructure must be developed	3	3
Local content could not reach policy requirement	body and chassis	body and chassis are of low importance	3	3
Battery recycling business to reduce import tax	energy storage	recycling is a good prospect to reduce cost	1	1
System integration	autonomous	Autonomous is of middle importance	2	2

Top Theme	Total Hit
High cost to develop battery and motor by ourselves	10
regulation and awareness are lower cost to develop compared to tech and moderately important	9
field testing for demonstrate practical usage is very important for e-bus buyers	9
Environment test is important for target based on pollution reduction	6
reverse engineering could be important for tech learning if they are successfully implemented	5
Battery and motor are very important for the value in e-bus manufacturing	5

Dataset 6: Technology Roadmapping for e-bus research

Government	Categories	Retheme	Hit	Total
Import is of higher quality than e-bus conversion	Resource	Import vs conversion	2	2
Require more testing facilities	Cost	preparation cost	2	2
conserve domestic industry by import tax wall on EV	Activity	Legal actions	4	8
Older bus or van that change can be enforced	Activity		4	
More public charging station infrastructure	Activity	Infrastructure	4	4
Mostly how to operate e-bus and policy based case	Activity	Policy readiness	1	1
Grow more demand for e-bus	Relationship	difficult to convince buyers	3	4
Bad experience with NGV model of government	Relationship		1	
Energy efficiency and global conciousness of energy uses	Value	Energy efficiency, sustainability	2	2
Manufacturer	**Categories**	**Retheme**	**Hit**	**Total**
Shenzhen e-bus	Partner	Overseas partner	1	1
PTT but there is a scaling problem for production	Partner	Domestic partner	1	1
Quality and performance of battery	Resource	Battery	4	4
Reverse engineering imported product	Activity	Selection between import and manufacture	2	7
Importing part to assemble in Thai garage	Activity		5	
Bad perception from operators in e-bus compared to ICE bus	Relationship	perception of e-bus could affect sales	1	1
affordable pricing	Value	Affordable Pricing	3	3
No after sales service	Value	After sales service	4	7
Maintenance garage	Value		3	
think quality is very comparable between brand	Value	Comparable driving performance	2	2
e-bus components are taxes less than passenger cars	Cost	Highly dependent on tax structure	2	6
Don't agree with tax wall which make price of EV too high	Cost		4	
E-bus will not worth it in business sense (currently)	Revenue	not profitable in short term	2	3
Need small and consistent buying lots	Revenue		1	
Corporate fleet and B2B based buyers	Customer	Public organisation	2	2
minibus type vehicles of private operators	Customer	Private corp	3	3
Rental agency	Customer	Rental Agency	1	1
Market is not well-developed	Channel	selling via government contracts	1	1
Operator	**Categories**	**Retheme**	**Hit**	**Total**
Large corporation utilise e-bus as a fleet (mostly Chinese e-bus)	Partner	Overseas sellers	2	2
Need to redesign operation model for e-bus	Activity	Develop sales and services platform	1	1
battery swapping would be expensive, volume of vehicles not enough	Activity	Lack of alternative business model	1	1
Air conditioned bus is more popular	Value	e-bus will be air conditioned	2	2
People will have confidence in practical usage examples	Value	Practical usage have to be demonstrated	6	6
Poorly managed, overlapping bus route	Relationship	Need better services to customers	2	2
Rental model for BMTA to reduce maintenance and labor cost	Cost	BMTA debt is high	3	6
Large amount of public debt	Cost		3	
Lower electricity pricing	Revenue	lower energy cost	3	10
Profitibility of operators from fuel-saving	Revenue		7	

Top Theme	Total Hit
lower energy cost is number 1 reason that attract operators toward e-bus	10
Legal actions will be important to stimulate the e-bus manufacturing industry	8
Selection between which part to import and which part to manufacture is crucial for domestic assemblers	7
After sales service promise will give a large competitive advantage to Thai manufacturers	7
Manufacturing activity will depend a lot on tax structure because components imports is inevitable	6
BMTA debt and financial struggle is high, they would not be able to afford e-bus on their own	6
Users and passengers of e-bus will have more confidence if there are practical real usage of e-bus	6

Dataset 7: Dataset for the designing of Business Model Canvas

Contents	Categories	Retheme	Hit	Total
Collaboration between local tech institute and manufacturers	where this located	research-manufacturers linkage	3	3
Meeting and agreement between all relating parties	how it works	Promote more formal meetings	2	3
More formal meeting or brainstorming	how it works		1	
Slowness of communication between agencies	why it is needed	To speed up the communicative process	2	2
NSTDA and TAI	who will be responsible	former mediator could transform into the newly formed intermediary	1	3
EVAT EGAT	who will be responsible		2	
more in-depth information from stakeholders	what is the purpose	facilitate and ease up the confidential business information among firms	3	3
Japanese ICE manufacturers also pay tax to the government	why it is needed	Try to mitigate and solve the internal conflict within the cluster	3	11
NSTDA don't want skywell to do commercial charging station	why it is needed		1	
Public organization prevent private corp to reap profit	why it is needed		3	
Think some stakeholders are actively prevent EV from happening	why it is needed		4	
Lower electricity pricing	what is the purpose	generalise the public regulation and prepare the system before adoption	3	6
Universal charging system and process	what is the purpose		3	
Skywell never formally request research support from NSTDA	why it is needed	To solve misunderstanding in communication and rectify mistakes	1	7
Government does not care about smaller operators	why it is needed		1	
Local content could not reach policy requirement	why it is needed		3	
Assemblers think e-bus conversion would be a waste of resources	why it is needed		2	
Don't agree with tax wall which make price of EV too high	how it works	Public regulation opinion and agreement	4	4
E-bus will not worth it in business sense (currently)	when it will form	Only in short term and mid term plan to facilitate the business	2	2
Disemination of EV general knowledge	what is the purpose	To disemminate and share technological and general knowledge in e-bus	5	7
Pooling of resources and technology know-how	what is the purpose		1	
think that Thailand have good amount of basic knowledge for e-bus	what is the purpose		1	
Think that converted e-bus would have acceptable quality	how it works	Manufactures are confident and this should be disemminate via the intermediary	1	4
think quality is very comparable between brand	how it works		2	
Confident in technological capabilities and competition with china	how it works		1	
Think that the value is in assembling process, not battery mfg.	where this located	focus the work on assembling process	1	1
creation of collaboration with external partners	where this located	Intermediary to external overseas partners	1	3
relationship and reliability with overseas suppliers	where this located		2	

Top Theme	Total Hit
Try to mitigate and solve the internal conflict within the cluster	11
To solve misunderstanding in communication and rectify mistakes	7
To disemminate and share technological and general knowledge in e-bus	7
generalise the public regulation and prepare the system before adoption	6

Dataset 8: The assignment of intermediary organisation

Contents	Categories	Retheme	Hit	Total
University and manufacturers KMUTT+KMUTNB	Domestic	The existence of collaborative efforts between domestic researchers and manufacturers	1	8
Collaboration between local tech institute and manufacturers	Domestic		3	
Vehicles Integration	Domestic		1	
Tracking system	Domestic		1	
Separate and general components that also used in EV	Domestic		2	
No service from domestic manufacturers	Domestic	Manufacturer and operator business relationship	4	6
Market size still small, lack of information	Domestic		2	
No target from the government	Domestic	Policy issues regarding the progress of electric bus cluster for domestic manufacturing	5	11
conserve domestic industry by import tax wall on EV	Domestic		4	
Mostly combined with EV in general	Domestic		2	
Lack of qualified experts on e-bus and manpower	Domestic	The current level of infrastructural research relating to EVs in Thailand	2	8
Quick charging station by SUT (suranaree)	Domestic		3	
Urban traffic congestion	Domestic		1	
think that Thailand have good amount of basic knowledge for e-bus	Domestic		1	
PTT but there is a scaling problem for production	Domestic		1	
Might have less value in interview	Mixed	The possible issues in the design of this policy plan	1	2
should put this as a general study for developing country	Mixed		1	
Importing part to assemble in Thai garage	Mixed	The mixed strategy of imports and domestic manufacturing is viable	5	16
Reverse engineering imported product	Mixed		2	
No reliable domestic battery supplier	Mixed		2	
Local content could not reach policy requirement	Mixed		3	
Think that the value is in assembling process, not battery mfg.	Mixed		1	
Components to be assembled	Mixed		3	
minibus type vehicles of private operators	Mixed	Mixed policy for imports and manufacturing will invite more market opportunities	3	4
Rental agency	Mixed		1	
KMUTNB charging station skywell	Mixed	The current level of external collaboration with overseas enterprises	1	4
creation of collaboration with external partners	Mixed		1	
Technology transfer with overseas corporation	Mixed		2	
Future based metric or prediction	Mixed	Improve stakeholders confident via systematic technological and market research	2	5
Lack of confident in new technology	Mixed		3	
think quality is very comparable between brand	Foreign	Discrepencies in opinions regarding quality of overseas e-bus	2	6
Import is of higher quality than e-bus conversion	Foreign		2	
state owned vehicles concern less about quality	Foreign		2	
Think that converted e-bus would have acceptable quality	Domestic	Conflicting opinions regarding e-bbus conversion initiatives	1	3
Assemblers think e-bus conversion would be a waste of resources	Domestic		2	
Motor from ZF, battery from BYD	Foreign	External factors from overseas which will affect the choice of component's import	1	6
Battery from china, tesla progress on EV would be a factor	Foreign		4	
Possibly the whole e-bus	Foreign		1	
KMUTT korean-imported bus	Foreign	Research and development connections with foreign companies	1	3
relationship and reliability with overseas suppliers	Foreign		2	

Top Theme	Total Hit
The mixed strategy of imports and domestic manufacturing is viable and recommended	16
Several policy issues regarding the progress of electric bus cluster for pure domestic manufacturing	11
There are many unchecked collaborative efforts between domestic researchers and manufacturers	8
The current level of infrastructural research relating to EVs in Thailand is high but not implementation	8

Dataset 9: Scenarios design for Thai e-bus industry

Contents	Categories	Retheme	Hit	Total
conserve domestic industry by import tax wall on EV	Import	Regulation on e-bus and components import taxes	4	7
e-bus components are taxes less than passenger cars	Import		2	
Battery recycling business to reduce import tax	Import		1	
Close proximity of research-industry linkage	Research	Collaboration between researchers and manufacturers	1	4
Collaboration between local tech institute and manufacturers	Research		3	
Lack of supporting policies to complement the change to e-bus	Manufacturer	Direction based research plan and policy making	2	5
Future based metric or prediction	Assembler		2	
justification for the adoption of policies	Research		1	
Technology transfer with overseas corporation	Research	Relationship and negotiation with overseas enterprises	2	6
relationship and reliability with overseas suppliers	Research		2	
No reliable domestic battery supplier	Manufacturer		2	
Education system change from ICEV to EV	Research	Transform education curriculum in automotive engineering	3	3
technology readiness level scale for each sector (recommendation)	Manufacturer	Assess the current level of technological capabilities	1	1
Japanese ICE manufacturers also pay tax to the government	Manufacturer	Deal with former influential parties in the ICE vehicles supply chain	3	3
Need small and consistent buying lots	Assembler	Consistent e-bus procurement policies	1	8
No large amount of procurement policy	Assembler		3	
BMTA recently order 30 units of e-bus (2,500 in 4 years)	Assembler		4	
Low EV expertise of existing large corporation	Assembler	Low capabilities to produce large amount of high value components	2	5
Local content could not reach policy requirement	Assembler		3	
Reverse engineering imported product	Assembler	Imports could lead to the improvement of tech capabilities	2	2
there is a cluster for clean public transport policy	Operator	Cluster and group of operators	1	1
Older bus or van that change can be enforced	Operator	Additional market opportunities for e-bus industry	4	7
minibus type vehicles of private operators	Operator		3	
Bad experience with NGV model of government	Operator	Bad experience with previous government initiatives	1	1
battery swapping would be expensive, volume of vehicles not enough	Operator	Control of operating cost would be crucial to buying decision	1	4
Lower electricity pricing	Operator		3	
More public charging station infrastructure	Operator	Users will have confidence in practical usage examples and readiness	4	14
Bad perception from operators in e-bus compared to ICE bus	Operator		1	
Universal charging system and process	Operator		3	
People will have confidence in practical usage examples	User		6	
Air conditioned bus is more popular	User	E-bus will be more convenient and popular to users	2	2
Urban traffic congestion	User	Traffic congestion problem should be mitigated	1	3
Poorly managed, overlapping bus route	User		2	

Top Theme	Total Hit	
Users will have confidence in practical usage examples and readiness	14	ACT 2 - Confidence in e-bus
Consistent e-bus procurement policies	8	ACT 1 - Profitability of manufacturers
Additional market opportunities for e-bus industry	7	
Regulation on e-bus and components import taxes	7	
Relationship and negotiation with overseas enterprises	6	ACT 4 - Technological capability
Low capabilities to produce large amount of high value components	5	
Direction based research plan and policy making	5	ACT 3 - Collaborative network

Dataset 10: The identification of policy initiatives

Categories	Contents	Retheme	Hit	Total
ACT 1 - Profitability of manufacturers	BMTA recently order 30 units of e-bus (2,500 in 4 years)	Procurement of BMTA	4	6
	BMTA should order higher number of e-bus		2	
	No economy of scale, low profit	Procurement Policy	4	8
	Need small and consistent buying lots		1	
	No large amount of procurement policy		3	
	Older bus or van that change can be enforced	Law Enforcement	4	7
	minibus type vehicles of private operators		3	
ACT 2 - Confidence in e-bus	Change of global market and trends will force many manufacturers	Natural Transition	3	3
	Urban traffic congestion	Better Public Services	1	3
	Poorly managed, overlapping bus route		2	
	Require more testing facilities	Testing	2	2
	Maintenance garage	Maintenance	3	3
	More public charging station infrastructure	Charging Station	4	4
	People will have confidence in practical usage examples	Examples of actual uses	6	11
	Disemination of EV general knowledge		5	
ACT 3 - Collaborative network	Collaboration between local tech institute and manufacturers	Research-Industry Collaboration	2	3
	Close proximity of research-industry linkage		1	
	Lack of supporting policies to complement the change to e-bus	Justification of Policies	2	3
	justification for the adoption of policies		1	
	Japanese ICE manufacturers also pay tax to the government	Power and Conflict in the cluster	3	5
	NSTDA don't want skywell to do commercial charging station		1	
	Skywell never formally request research support from NSTDA		1	
	Need to redesign operation model for e-bus	Collaboration with operators	1	1
ACT 4 - Technological capability	NSTDA funding 4 manufacturers in e-bus conversion	Research Fundings	3	10
	Not enough funding for smaller companies		3	
	interconnected issues such as cost for development		4	
	Technology transfer with overseas corporation	Overseas Connections	2	4
	relationship and reliability with overseas suppliers		2	
	Risk of outdated technologies	Uncontrollable Factors	1	4
	difficult to control private enterprises		3	
	No reliable domestic battery supplier	Measurement of Capabilities	2	3
	technology readiness level scale for each sector (recommendation)		1	
	Technological experts who could work individually	Facilitation Programs	1	3
	Reverse engineering imported product		2	
	Education system change from ICEV to EV	Education System	3	3
Total Hit	Top Theme			
11	ACT2 - Practical Examples are crucial for confidence in E-bus			
10	ACT4 - Low Research Funds			
8	ACT1 - Need Procurement Policies			
5	ACT3 - Control of Conflict within the cluster			

Dataset 11: Application of policy initiatives

Contents	Retheme	Categories	Hit	Total
Bangkok and urban city pollution	Reduction of fuel consumption in public transport sector	Economic Performance	6	9
traffic congestion		Economic Performance	1	
Energy efficiency and global conciousness of energy uses		Economic Performance	2	
No target from the government	Create opportunity for researches and commercialization	Economic Performance	5	8
No large amount of procurement policy		Economic Performance	3	
conserve domestic industry by import tax wall on EV	Maintain economic stability while increase the investment	Economic Performance	4	6
e-bus components are taxes less than passenger cars		Economic Performance	2	
more in-depth information from stakeholders	Increase engagement of manufacturers in electric bus research and manufacturing cluster	Stakeholders Relationship	3	5
Mostly combined with EV in general		Stakeholders Relationship	2	
Bad perception from operators in e-bus compared to ICE bus	Maintain good relationship between state enterprise and private operators	Stakeholders Relationship	1	2
Bad experience with NGV model of government		Stakeholders Relationship	1	
number of users of policy that was adopted	Improve effectiveness of communication channels between stakeholders	Internal Processes	1	2
Putting this as a general study for developing countries		Internal Processes	1	
No evidence based fact about e-bus market	Greater impact from the collaboration between research, industry, and government sectors	Internal Processes	4	8
Future based metric or prediction		Internal Processes	2	
outputs of project and outcome of the initiatives		Internal Processes	2	
Lack of supporting policies to complement the change to e-bus	Transition of bus manufacturing supply chain toward electric vehicles economy	Internal Processes	2	5
Local content could not reach policy requirement		Internal Processes	3	
Universal charging system and process	Prepare adequate infrastructural facilities for electric vehicles	Internal Processes	3	8
EVAT EGAT		Internal Processes	2	
Lower electricity pricing		Internal Processes	3	
NSTDA and TAI	Effective prioritization of domestic research projects	Organisational Capacity	1	2
Pooling of resources and technology know-how		Organisational Capacity	1	
creation of collaboration with external partners	Increase the number of overseas business partners	Organisational Capacity	1	2
Confident in technological capabilities and competition with china		Organisational Capacity	1	
technology readiness level scale for each sector (recommendation)	Improvement of stakeholder’s technological capabilities	Organisational Capacity	1	5
think that Thailand have good amount of basic knowledge for e-bus		Organisational Capacity	1	
Education system change from ICEV to EV		Organisational Capacity	3	

Top Theme	Total Hit
Reduction of fuel consumption in public transport sector	9
Greater impact from the collaboration between research, industry, and government sectors	8
Create opportunity for researches and commercialization	8
Prepare adequate infrastructural facilities for electric vehicles	8
Maintain economic stability while increase the investment	6

Dataset 12: National Policy Evaluation via Balanced Scorecard

Categories	Contents	Retheme	Hit	Total
ACT 1 - Profitability of manufacturers	BMTA recently order 30 units of e-bus (2,500 in 4 years)	Adopt continuous e-bus procurement policy	4	6
	BMTA should order higher number of e-bus		2	
	No large amount of procurement policy	Prohibition of ICE buses	3	3
	Components to be assembled	Reduction percentage of taxes in component's imports	3	3
	Government does not care about smaller operators	Calculation of the future value of e-buses	1	1
ACT 2 - Confidence in e-bus	Disemination of EV general knowledge	Provide feasible business plan	5	5
	Bangkok and urban city pollution	Quality control in bus service business	6	7
	traffic congestion		1	
	outputs of project and outcome of the initiatives	bus utilisation ratio among operators	2	2
	Poorly managed, overlapping bus route	rearrangement and tracking application	2	2
ACT 3 - Collaborative network	KMUTNB charging station skywell	Initiate cross-industry research and development program	1	1
	People will have confidence in practical usage examples	Offer free e-bus for a certain period	6	6
	more in-depth information from stakeholders	Consortium of e-bus OEMs and assemblers	3	3
	NSTDA don't want skywell to do commercial charging station	Assign intermediary to work among public bus association	1	2
	Skywell never formally request research support from NSTDA		1	
ACT 4 - Technological capability	NSTDA funding 4 manufacturers in e-bus conversion	Capabilities analysis of Thai manufacturers	2	2
	Risk of outdated technologies	Prepare contingency plan for possible failure in technological absorption	1	1
	Technological experts who could work individually	Negotiate with overseas firms for technological exchange	1	1
	Think that converted e-bus would have acceptable quality	Find connections in global supply chain of electric vehicles	1	1
	Reverse engineering imported product	Funding for the attempt to form strategic alliance	2	2

Total Hit	Top Theme
7	Measures for quality control in bus service business
6	Measure for continuous e-bus procurement policy
6	Measure for the demonstration of e-buses for a certain period
5	Measure for the outcome of provided business plan

Dataset 13: Process Monitoring via Work Breakdown Structure

Appendix C – An Online Questionnaire for Framework Review

Part 1 – Overall Review

Q1.1) What is the status of the respondent?

- Policy Makers
- Researchers
- Manufacturers
- Operators
- Passengers
- Others

Q1.2) Please rate the usefulness of this policy framework to the respondent on the scale from 1 to 7 (1 is least useful and 7 is most useful).

Q1.3) Please rate the continuity and rational connection of each component within this policy framework on the scale from 1 to 7 (1 is the poorest and 7 is the greatest).

Q1.4) Please rate the accuracy and completeness of information in this policy framework on the scale from 1 to 7 (1 is least complete and 7 is most complete)

Part 2 – Components Review

Q2.1) Please rate the usefulness of Part 1: The Current State of Electric Bus Industry in Thailand to the respondent on the scale from 1 to 7 (1 is least useful and 7 is most useful).

Q2.2) Please rate the ease of understanding of Part 1: The Current State of Electric Bus Industry in Thailand (1 is least understandable and 7 is most understandable)

Q2.3) Please rate the accuracy of information within Part 1: The Current State of Electric Bus Industry in Thailand (1 is least accurate and 7 is most accurate)

Q2.4) Please rate the usefulness of Part 2: Organisation and Vision for the Electric Bus Industry to the respondent on the scale from 1 to 7 (1 is least useful and 7 is most useful).

Q2.5) Please rate the ease of understanding of Part 2: Organisation and Vision for the Electric Bus Industry (1 is least understandable and 7 is most understandable)

Q2.6) Please rate the accuracy of information within Part 2: Organisation and Vision for the Electric Bus Industry (1 is least accurate and 7 is most accurate)

Q2.7) Please rate the usefulness of Part 3: The Implementation of Public Policy to the respondent on the scale from 1 to 7 (1 is least useful and 7 is most useful).

Q2.8) Please rate the ease of understanding of Part 3: The Implementation of Public Policy (1 is least understandable and 7 is most understandable)

Q2.9) Please rate the accuracy of information within Part 3: The Implementation of Public Policy (1 is least accurate and 7 is most accurate)

Q2.10) Please rate the usefulness of Part 4: The Evaluation of the Policy Plan and the Framework to the respondent on the scale from 1 to 7 (1 is least useful and 7 is most useful).

Q2.11) Please rate the ease of understanding of Part 4: The Evaluation of the Policy Plan and the Framework (1 is least understandable and 7 is most understandable)

Q2.12) Please rate the accuracy of information within Part 4: The Evaluation of the Policy Plan and the Framework (1 is least accurate and 7 is most accurate)

Part 3 – Additional Comments

Q3.1) What additional features or information should be included in this policy framework?

Q3.2) Which components of this policy framework are still not clear, and how they should be fixed?

Q3.3) Please share any additional suggestions, concerns, or comments here.

Appendix D – Related Published Journal Paper

Challenges for the Adoption of Electric Vehicles in Thailand: Potential Impacts, Barriers, and Public Policy Recommendations

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Sustainability 2023, 15(12), 9470; https://doi.org/10.3390/su15129470

Received: 21 September 2022 / Revised: 30 November 2022 / Accepted: 2 December 2022 / Published: 13 June 2023

Abstract

The impacts of electric vehicles (EVs) to the current transportation and logistics system is an emerging topic that has recently garnered public interests in many countries. Several developing countries that rely on the large amount of production in automobiles manufacturing are preparing to adopt national strategies to mitigate the negative impacts from the shift towards electric vehicles. In addition, the restructuring of the transportation system and traffic regulations to prepare for the integration of electric vehicles into the current transportation model is also an important concern for policy makers. The study of potential impacts and barriers regarding the adoption of EVs would provide better insights that could aid the implementation of public policy. The topics that will be discussed here are both from technological standpoints such as differences in the general properties of EVs, in comparison to internal combustion engine vehicles (ICEVs), and social and environmental standpoints which are predicted to be pivotal drivers for their adoption. These features are collectively analysed to aid the relating implementation of industrial, transportation, and environmental public policies. Moreover, additional policy recommendations for the situation in Thailand are proposed based on this discussion. It is concluded that extensive public policy framework for the adoption of EVs and the development of EVs manufacturing industry is essential for the developing countries with less technological readiness to effectively integrate this new type of vehicular technology into its industrial and transportation economy.

Keywords

Electric Vehicle
Innovation cluster
Technological disruption
Complex system
Automotive industry
Public Policy

Appendix E – References

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