Banana by-products in Thailand

Exploring its feasibility as bioplastics feedstock for food packaging

Ratchadetch Termpitipong

DIVISION OF PACKAGING LOGISTICS | DEPARTMENT OF DESIGN SCIENCES
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Abstract

This study aims to determine the operational feasibility of utilizing banana cultivation by-products as an alternative raw material in bioplastic production, replacing bio-based feedstock that is otherwise used as food in Thailand. By following the exploratory qualitative research approach, a combination of secondary sources of information together with interviews with the identified stakeholders involved in banana cultivation and bioplastic value chains were used in data collection process. The obtained data was reviewed and used for constructing a value chain map and analyzing for the success and barriers factors, using DEFT as a tool. It was found that the current bioplastic supply in quantity, mainly the PLA and PBS derived from lactic acid production from sugarcane and cassava, would be unable to sufficiently serve the demand of the market. A large volume of banana by-products is discarded to landfill without further uses post-cultivation. Furthermore, as banana production in agricultural sector is expected to rise continuously, this could lead to more waste generation. Other studies have revealed potential of utilizing cellulose extracted from agricultural wastes as a raw material for fermentation process for bioplastic production. This also reveals that banana by-products could be an alternative bio-based feedstock for bioplastic production. Even though there are approaches and supports from the government and other stakeholders in promoting the utilization of bioplastic materials, but limitation regarding the properties, applications, cost effectiveness, and legislation support can cause banana by-products to be less attractive than the existing ones. The approach of utilizing banana by-products for this purpose is, hence, not yet existing in Thailand. However, this could be possible, but not in the immediate future.

Key words: Banana by-products, bio-based packaging, bioplastic, value chain, Thailand, feasibility, DEFT analysis

Executive summary

Introduction

Studies have claimed that carbon dioxide (CO_2) is one of the greenhouse gases that causes global warming. Plastic, a low cost and high-performance fossil-based polymer, has been used worldwide and is one of the main contributors to greenhouse gas emission.

Many countries have made attempts to initiate the curb of plastic production and consumption. In European and other developed countries, most of the plastic wastes are sorted, recycled, and incinerated for energy recovery (Gironi and Piemonte, 2011; WWF, 2019). While among Asian countries including many developing countries with greater numbers of population and high consumption demand, more than 50% of plastics wastes were mismanaged leading to plastic-related pollution (Geyer et al., 2017). In the context of Thailand, there is also a call to reduce the usage of plastics and to increase the demand for bioplastic as an alternative to fossil-based plastic. The government has launched several policies in cooperation with major business firms to ban single-use plastics and to promote research and development of sustainable innovations (Vassanadumrongdee and Marks, 2020). These protocols can be seen to comply with many of the United Nations (UN) - Sustainable Development Goals (SDGs).

Thailand is also known as an agricultural country; the agricultural sector contributes 9.9% of the country's GDP (FAO, 2021). The country has exported almost 200 billion euros of agricultural goods in 2020 (OPS, 2021). Banana is one of the top five exported fresh fruits of the country with 1.12 million tonnes produced in 2019. On the downside, banana generates a lot of organic wastes, as only the fruit – which accounts for 12% of the whole plants (Sakharkar, S., 2019), while the rests are discarded. In addition, there are studies related to value addition of the banana by-products including being utilized as a raw material for bioplastic production.

This leads to the approach of this study to understand the value chain and to investigate the operational feasibility of utilizing by-products obtained from banana cultivation as an alternative raw material for bioplastic production in Thailand.

Research purpose

To be able to analyze the feasibility of utilizing banana by-products in bioplastic industry, the main task is to capture the broad picture of banana cultivation, bioplastic production value chain, and the involved stakeholders. The main purpose of this study is therefore:

> *To explore the operational feasibility of utilizing banana cultivation by-products as an alternative raw material in bioplastic production, replacing bio-based feedstock that is otherwise used as food in Thailand.*

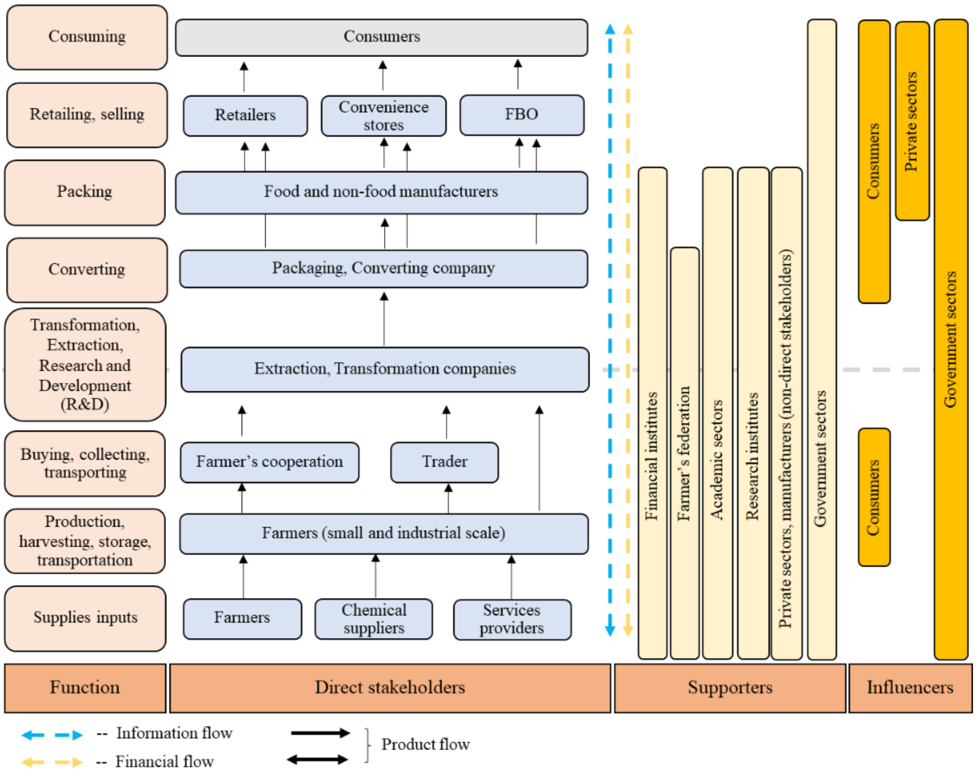
To gain a deeper understanding in the topic of interest, the following research questions (RQs) were asked:

1. *Who are the stakeholders involved in the banana cultivation value chain and the bioplastic value chain?*
2. *What are the by-products obtained from banana cultivation and how are they handled?*
3. *How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?*
4. *What are the barriers and success factors in using banana by-products to produce bioplastic that can be used as food packaging in Thailand?*

Methodology

The research following the interpretivism philosophy by using an inductive approach, is aimed to report the findings based on knowledge of those who have experienced. The research begins with a purpose instead of a hypothesis. (Dudovskiy, 2018; Mills and Birks, 2014). This exploratory research helps improve understanding of the situations and provides new set of data and insights. The approach started from the secondary research to obtain a general background on bioplastic, banana cultivation, and the situation of both industries in Thailand and global scale. Further steps were aimed to explore more details with the identified stakeholders through qualitative interviews, guided by a semi-structured questionnaire. The information is reviewed, coded, categorized, and analyzed which later developed into a finding of this study (Mills and Birks, 2014). The information that were unable to obtain from the interview was complemented by the study of literatures, reports, and publications.

Results and discussion



Value chain map illustrating the flow of utilization of banana by-products into bioplastics and food packaging industries

There were eight function stages together with direct stakeholders, supporters, and influencers, identified as shown in the figure. After harvesting for the fruits, except for the small portion of banana trunks and leaves from specific strains of banana that goes towards traditional utilization, e.g., food and food wraps, religious activities, and animal feeds, the rest of the wastes were unused and discarded to landfill. The government sector together with other identified players play an important role in supporting and influencing stakeholders in the value chain throughout the idea of using banana by-products for bioplastic industry and initiating an evaluation of its feasibility. There is no evidence that banana by-products have crossed over for utilization in the bioplastic industry, at least, not beyond preliminary research activity. However, the stage of extraction, transformation, and R&D could be a connecting point to link between the value chain of banana cultivation and bioplastic. Moreover, by looking into examples of how other biomass feedstock like cassava and sugarcane have been used, we can have some references of how to potentially introduce banana waste into the bioplastic value chain.

Summary of DEFT Analysis

DEFT	***Factors***	***Details***
Drivers	Government	Supportive policies and legislations in utilizing bio-based and bioplastic products. Education and training programs offered.
	Producers	Higher production leads to higher by-product generation. Demand for solutions in by-product utilization. Act in response to government policy and consumer's demand
Enablers	Consumers	Trend of sustainability. Demand for sustainable solutions and alternative bio-based options.
	Raw materials	Insufficient current biomass feedstock. Reduction in current biomass feedstock production. Increase in banana production and cultivation. Utilization of waste instead of potential food source.
Frictions	Government	Lack of supportive legislation. Limited access to proper support from the government sectors. Limited access to proper education and training
	Raw materials	Uncertain supply of raw materials. Cost competition over conventional and major group of bio-based materials due to complexity in processing. Limitations related to material properties and applications. Alternative applications of banana by-products (i.e., not bioplastic production)
	Technology	Lack of access to technology
Turners	-	-

DEFT was used as a tool to analyze the operational feasibility of utilizing banana by-products in Thai bioplastic industry. There are drivers from the government sectors through policies and strategies in supporting the utilization of bio-based and bioplastic products, as well as the upstream sides of producers and manufacturers acting in response to the government's plan and market needs. The drivers receive supports from the two enablers which are the consumer factors from the trend of sustainability and demands for more sustainable solutions. The other enabler is the raw material factor from the mismatch of biomass where the demand is greater than rate of supply, reduction in the main biomass feedstock production, the increase in the cultivation, and conflicts over the food supply chain, which make the banana by-products could potentially be an alternative of interest as it is a waste which could be utilized into something valuable.

On the other hand, there are some obstacles that may negatively affect the feasibility, such as lack of proper support in legislation, education, and training from the government sectors. This makes a big impact on the feasibility of the approach, as the by-product from banana is not currently in the focus of the government. More time is needed for the new legislation to support the utilization of new materials. Other obstacles from the raw material side include insufficient and inconsistent supply of the raw materials and competitions with existing or other bio-based alternatives in terms of cost and limitations from the material properties and applications. Other alternative agricultural wastes like rice straw, corn cob, and sugarcane bagasse seems to be more attractive in the aspect of supply, as well as research and production technology. Lastly, there are no stakeholders found to be actively opposing to the utilization of banana by-products for the bioplastic industry.

Conclusion

The value chain was mapped following the approach of Saunders et al (2019). The direct and in-direct stakeholders, as well as their relationships were identified. According to the study of the possibility in utilizing by-products obtained by Banana cultivation, most parts of the plant can be used. Where cellulose as a major component found in the by-products could potentially be used as a second-generation feedstock for bioplastic production. With the aim to explore the operational feasibility of the approach, DEFT was used. It revealed that cellulose extracted from banana by-products could potentially be used as a second-generation feedstock. However, considering all the success and barrier factors identified in this study, it is therefore concluded that utilizing banana by-products in Thailand as bioplastic feedstock could be possible but might not likely to happen in the near future.

Recommendations for future work

It is recommended to keep track ingon the progress of legislative development between TISI, Thai FDA and other responsible parties, as it might increase the opportunity for the new bioplastic materials to be marketed. A further investigation can also be done to identify any hidden stakeholders and activities that may get involved in the future, as well as an analysis of economic and financial feasibility, as the value chain can evolve over time (Faße et al., 2009).

The continuous study of the value chain, method for improving extraction and production techniques of banana by-products to have potential in competing with existing bio-based feedstock could also be done in parallel. Moreover, a study of properties of cellulose and other materials that can be extracted from domestic banana strains is recommended as it can lead to an opportunity in utilizing these materials efficiently.

Other alternative bio-based feedstock, e.g., rice and corn should also be taken into consideration as they have a better quantity in supply and have some existing developed business models (Kamthai S., personal communication, 23 March 2021). Lastly, another interesting topic could be the feasibility of utilizing banana by-products in other countries that have greater numbers of banana cultivation such as India, China, and Indonesia (FAO, 2020) where the supply issue will not be a challenge.

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Lund, June 2021

Ratchadetch Termpitipong

Table of contents

Abstract i
Executive summary ii
Table of contents viii
List of figures xi
List of tables xii
List of acronyms and abbreviations xiii
1 Introduction 1
1.1 Introduction 1
1.2 Research purpose and questions 2
1.3 Scope and delimitations 3
1.4 Thesis structure 4
2 Frame of reference 5
2.1 Bioplastics 5
2.1.1 Bio-based non-biodegradable plastics 6
2.1.2 Bio-based biodegradable plastics 6
2.1.3 Cellulose as potential source of biomass 8
2.1.4 Standards and Certifications 11
2.2 Overview of bioplastics in Thailand 12
2.2.1 Bioplastics production in Thailand 14
2.3 Banana 14
2.3.1 Morphology 15
2.3.2 Banana production in Thailand 17
2.3.3 Banana waste and its possible applications 18
2.3.4 Banana in bioplastic industry 20
2.4 Value chain map 21

3 Methodology 23
3.1 Research approach... 23
3.2 Data and data collection 24
3.2.1 Secondary research... 25
3.2.2 Interviews 25
3.3 Data analysis... 28
3.3.1 Analysis of interviews 28
3.4 Value chain mapping 30
3.5 Analysis of feasibility... 32
3.6 Effects of existing pandemic 33
4 Results and Discussion... 34
4.1 Value Chain map 37
4.1.1 Supplies input 38
4.1.2 Production, Harvesting, Storage, and Transportation........................... 39
4.1.3 Buying, Colleting, and Transporting 40
4.1.4 Transformation, Extraction, and Research & Development (R&D) 40
4.1.5 Converting 41
4.1.6 Packing 42
4.1.7 Retailing, Selling 42
4.1.8 Consuming.. 43
4.1.9 Supporters... 44
4.1.10 Influencers 48
4.2 DEFT Analysis 50
4.2.1 Drivers 51
4.2.2 Enablers 53
4.2.3 Frictions.. 55
4.2.4 Turners (Blockers).. 61
5 Conclusion.. 63
5.1 Recommendations for future work 64
6 References 66

Appendix A Work distribution and time plan 78
Appendix B Interview questions 79
B.1 Interview guideline for Banana farmers 79
B.2 Interview guideline for Farmer's cooperative... 80
B.3 Interview guideline for Researchers from academic sector and research institutes.. 81
B.4 Interview guideline for plastics and bioplastics converter and manufacturers 82
B.5 Interview guideline for Food manufacturers... 83
B.6 Interview guideline for Government sectors... 84
Appendix C List of standards 85
Appendix D 88
D.1 Polylactic Acid (PLA) 88
D.2 Polybutylene succinate (PBS) 89

List of figures

Figure 1 Material coordinate system of bioplastics 5
Figure 2 Main components of lignocellulosic biomass 9
Figure 3 Second-generation biofuel production from lignocellulosic wastes 10
Figure 4 Logo of standard bodies; ISO (left), CEN (middle), and ASTM (right). 11
Figure 5 Financial support ratio by type of bioplastics provided by the Government 13
Figure 6 Thailand's 20-year National Strategy from 2018 – 2037........................ 13
Figure 7 Simplified production flow of cassava and sugarcane in bioplastic industry 14
Figure 8 Morphological diagram of fruiting banana plant with sucker................. 15
Figure 9 Banana market model in Thailand 18
Figure 10 Figure 10 Figures of banana by-products applications (a) Bai Sri tray, (b) Pad thai with banana blossom as a side, (c) Banana leaf used as food wrap, (d) Young banana shoots used in wedding ceremony 20
Figure 11 Netchain concept.. 22
Figure 12 Research onion - adapted version based on the study by Saunders et al (2019). 23
Figure 13 Thematic analysis framework by Maguire and Delahunt (2017).......... 29
Figure 14 Sample of thematic map from the study 30
Figure 15 Flow of conducting value chain map 31
Figure 16 Value chain map illustrating the flow of utilization of banana by-products into bioplastics and food packaging industries... 37
Figure 17 Workflow of legislation approval for new materials and packed foods and the responsible organizations in Thailand 56
Figure 18 Mr.Thanakorn Sodsai (right) and the products from Tanee Brand made from banana by-products... 60
Figure 19 Simple production process of PLA pallet 88
Figure 20 Simple production process of PBS pallet 89

List of tables

Table 1 Summary of characteristics and applications of various bioplastics 7
Table 2 Three generations of bioplastics feedstock.. 10
Table 3 Lignocellulosic composition and moisture content of agricultural by-products 16
Table 4 Total banana production in Thailand in year 2019.................................. 17
Table 5 Banana by-product utilization matrix for food and non-food applications. 19
Table 6 Stakeholder’s role and objective of an interview 26
Table 7 List of interviewees and key takeaways from the interview 35
Table 8 Summary of DEFT Analysis 51
Table 9 Standards for bioplastic products in packaging industry.......................... 55
Table 10 Project's Gantt chart.. 78
Table 11 Lists of international bioplastics standards and certifications 85

List of acronyms and abbreviations

ASTM	American Society for Testing and Materials
CEN	European Committee for Standardisation
CMC	Carboxymethyl cellulose
CO_2	Carbon dioxide
COVID-19	Coronavirus Disease 2019
FAO	Food and Agriculture Organization
FBO	Food Business Operators
FDA	Food and Drug Administration
ISO	International Organization for Standardization
MOAC	Ministry of Agriculture and Cooperatives
NIA	National Innovation Agency
PIT	Plastics Institute of Thailand
PLA	Polylactic Acid
RQ	Research question
SDGs	Sustainable Development Goals
TBIA	Thai Bioplastics Industry Association
TISI	Thai Industrial Standard Institute
UN	United Nations

1 Introduction

1.1 Introduction

For decades, scientists have been reporting on the “global warming” phenomenon. The studies have claimed that carbon dioxide (CO_2) is one of the greenhouse gases that causes global warming. Plastic, a polymer with cheap production cost and versatile properties, have been widely used across the world with abundant applications. About 99% of total plastic feedstock is derived from fossil-fuel which is a non-renewable resource. It is one of the main contributors for greenhouse gases with the rate of emission at 1.78 Gigaton CO_2 equivalent (Gt CO_2-eq) in 2015 and expected to reach 6.5 Gt CO_2-eq in the next 30 years (Meys et al., 2020).

Many countries have made an attempt to initiate the curb of plastic production and consumption. In 2015, the Paris agreement had been signed by the 195 nations to set a goal for limiting and reducing greenhouse gases emission (Spencer, 2020). For plastics production and degradation by incineration, this releases massive amount of CO_2 with only 14-18% recycled in global scale. In European and other developed countries, most of the plastics wastes are sorted, recycled, and incinerated for energy recovery (Gironi and Piemonte, 2011; WWF, 2019). Another attempt is the banning of single-use plastics such as straws and plastic bags. Many European countries have raised taxes on plastic bags and consumers are obliged to purchase a bag for groceries instead of free distribution. Some other countries have implemented a full plastic bags banning policy where there will be fines for breaking the law (Earthday, 2020). However, the plastic banning policies are not strongly implemented among Asian countries including many developing countries. With greater numbers of population and high consumption demand, more than 50% of plastics wastes were mismanaged leading to plastic-related marine pollution (Geyer et al., 2017).

Thailand is one of the countries that have signed the Paris agreement and set the goal of 20% greenhouse gasses cut with the timeframe of 10 years during 2021-2030 (ONEP, 2015). Consequently, this leads to the call to reduce the usage of plastics and increase the demand for bioplastic as an alternative to fossil-based plastic. The material is derived from bio-based or renewable sources and can either have similar properties to fossil-based polymers or bio-degradable materials. Moreover, this type of material can reduce the carbon footprint compared to a fossil-based plastic supply chain (European bioplastics, 2018). With the realization of these benefits, the Thai government has launched several policies with cooperation from major business firms such as chained convenience stores and shopping malls on a single-use plastic ban and has promoted research and development of sustainable innovations (Vassanadumrongdee and Marks, 2020). These protocols can be seen to comply with many of the United Nations (UN) - Sustainable Development Goals (SDGs) 9th – Industry, innovation and infrastructure, 12th – Responsible production and consumption, 13th – Climate action, 14th – Life below water, 15th – Life on land, and 17th – Partnership for the goals (UNDP, 2019).

Thailand is also known as an agricultural country; the agricultural sector contributes to 9.9% of the country's GDP, 43% of the land is agricultural area, and it involved about 49% of the labor forces (FAO, 2021; International Trade Center, n.d.). It also has the advantage of having a fertile soil and tropical climate, which is good for agriculture. In 2020, the country has exported almost 200 billion euros of agricultural goods (OPS, 2021). Among the crops, banana is one of the top five exported fresh fruits of the country with 1.12 million tonnes produced in 2019. On the downside, banana also generates a lot of organic wastes, as only the fruits – which account for 12% of the whole plants – are fully utilized, while almost 88% of the rest are discarded (Sakharkar, S., 2019). In addition, there are studies related to value addition of the banana by-products including utilizing as a raw material for bioplastic production.

With the information provided, it leads to the approach of this study to understand the value chain and to investigate the feasibility of utilizing by-products obtained from banana cultivation as an alternative raw material for bioplastics production, replacing bio-based feedstock that is otherwise used as food in Thailand.

1.2 Research purpose and questions

To be able to analyze the operational feasibility of utilizing banana by-products in bioplastic industry, the main task is to capture the broad picture of the banana cultivation and bioplastic value chain, including the involved stakeholders. The main purpose of this study is therefore:

> *To explore the operational feasibility of utilizing banana cultivation by-products as an alternative raw material in bioplastic production, replacing bio-based feedstock that is otherwise used as food in Thailand.*

Based on the main purpose as stated above, to further understand the banana cultivation and bioplastic value chains, and to explore the activities and stakeholders involved, the following research questions (RQs) are asked:

1. *Who are the stakeholders involved in the banana cultivation value chain and the bioplastics value chain?*
2. *What are the by-products obtained from banana cultivation and how are they handled?*

3. *How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?*
4. *What are the barriers and success factors in using banana by-products to produce bioplastics that can be used as food packaging in Thailand?*

1.3 Scope and delimitations

The aim of this study is to determine the operational feasibility of utilizing banana by-products in replacing fossil-based plastics by using it as an alternative raw material in bioplastics production, replacing feedstock that is otherwise used as food in Thailand. It is an exploratory qualitative study through on-site and off-site interviews with involved stakeholders in the banana cultivation and bioplastics supply chains from the producers (banana farmers and bioplastics manufacturers) to the end-consumers in Thailand, using a combination of semi-structured interviews and secondary research. The obtained information was translated, interpreted and analyzed to be used for conducting a value chain map to illustrate the value chain of banana by-products and how it can be linked to the bioplastic industry in Thailand.

With the pandemic of Coronavirus Disease 2019 (Covid-19) during the time of study (January 2021 – June 2021) and a limited time constraint of 20 weeks due to state quarantine and social distancing policy launched by the government, there was a concern of difficulty in information gathering as there are many approaches in the study of value chain and limited access to the stakeholders of interest for interview and observation. To be able to obtain all the data required, the research plan needed to be flexible and adjustable to the upcoming situations. The plan of this project can be seen in the Table 10, Appendix A. As requested by some study participants, a few names of interviewees and companies are kept confidential as stated in Table 7. In addition, the information from secondary sources such as literature studies, reports, and publications, were used to complement with the data that were unable to obtain from the interviews.

There are also limitations in the value chain map as the information was visualized as a snapshot of a time when the study was made, while the information can change over time. Moreover, the information provided by the map does not go deep into the details, e.g., the map itself cannot express the dynamics, changes, trends, market requirements, and opportunities of the market being studied (Marketlinks, n.d.). With these limitations in mind, a detailed explanation to help in visualizing the missing information on the map – such as dynamics, trends, market requirements – were mentioned in the later part to help improve the understanding of the readers.

The topic is an exploratory study, based on the information that has not yet been studied in depth before. It is difficult to identify the right stakeholders that are involved in the value chain. Moreover, due to the exploratory nature of this study, the consideration of using banana byproducts in bioplastic industry is still in its very preliminary stages. Detailed financial discussions in relation to its feasibility are not included in the scope of this thesis.

1.4 Thesis structure

The thesis contains five chapters. This Introduction chapter is followed by four chapters, as summarized below:

Chapter 2 - Provide a frame of references from secondary research as a background and provide supportive information to the whole report.

Chapter 3 - Explain the thesis methodology, i.e., details on the research approach, data collection, and analysis done in this study.

Chapter 4 - Present the results and discuss these based on the frame of references in order to provide answers to the research questions.

Chapter 5 - Summarize the overall findings of the thesis and provide recommendations for further studies.

2 Frame of reference

This chapter will give the readers a relevant background of the bioplastics in general and an introduction of the Thailand bioplastic industry. It also includes information about banana cultivation and possibilities to utilize banana by-products in the bioplastics value chain.

2.1 Bioplastics

Bioplastic, by the definition of European bioplastics (2018) refers to the group of plastic materials derived from either bio-based of fossil-based resources. It consists of carbon building blocks as a main structure, which can be biodegradable or non-biodegradable depending on the material's properties. Figure 1 illustrates the coordination of the bioplastic system according to the biodegradability of material and the nature of material. This study will only focus on the bio-based material, both biodegradable and non-biodegradable group, as illustrated in the first and second quadrant of the plot.

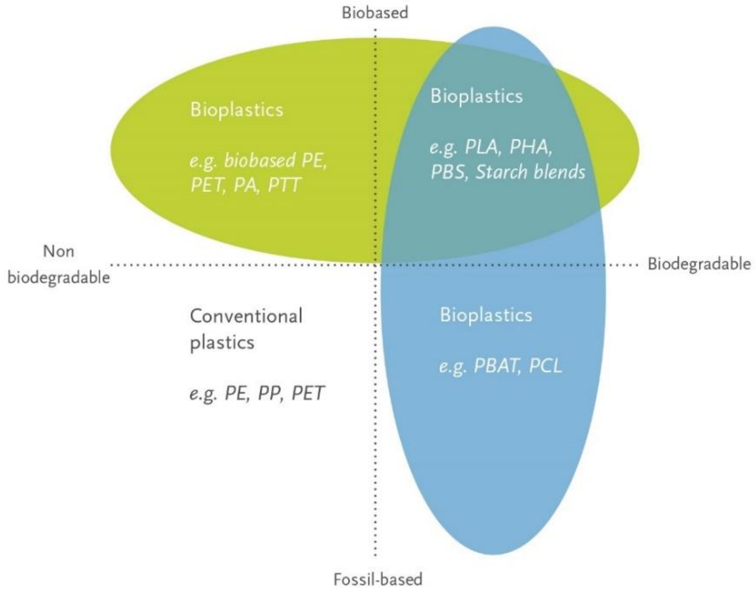

Figure 1 Material coordinate system of bioplastics (European bioplastics, 2018).

The term “bio-based” refers to the materials that are derived from plants or biomass as a source of raw materials such as corn, sugarcane, cassava, etc. To claim the material or product as bio-based, the standardized test method of American Society for Testing and Materials (ASTM) code ASTM D6866 using the radiocarbon dating method to determine the bio-based content of the material is used as reference (Ashter, 2016).

In terms of production, the demand of bioplastics is increasing annually, and it is expected to reach 2.87 million tonnes by 2025. Asia is known as the main producer with 46% of the global bioplastic production (European bioplastics, 2020). According to the data from European bioplastics (2020), the current proportion of biodegradable to non-biodegradable bioplastics are 40% and 60%, respectively. The top three major applications are flexible and rigid packaging, and consumer goods. The reasons why non-biodegradable material is more favorable might be because the recyclability of the material is similar to those that are fossil-based. While biodegradable and compostable materials are easier in terms of waste handling and management, but it may require specific condition or substrates to help in decomposing the materials. Otherwise, the degradation time will be longer, and there is a high possibility of ending up as a pollutant to the environment (Zang-Schwartz, 2019).

2.1.1 Bio-based non-biodegradable plastics

This group of bioplastics can be categorized into two main sub-groups. The first one is called ‘drop-in,’ which has identical structure and properties to the fossil-based plastics but derived from bio-based sources such as Bio-Polyethylene (Bio-PE), Bio-Polypropylene (Bio-PP) and Bio-Polyethylene Terephthalate (Bio-PET). The major applications of drop-in bioplastics are packaging, especially for Bio-PET-bottles. Such bottles are widely used in beverage industry. The materials can be recycled and utilized for a new bottle as recycled-PET (rPET) which is considered to be food-contact grade. However, it has to undergo the process of approved recycling and manufacturing standards (Höög, 2021).

Another group belongs to the larger portion of polymers such as polyamides (PA), Polyesters like polytrimethylene Terephthalate (PTT), polyurethanes (PUR) and many more. This group of bioplastics is considered to be durable and can have several years of operation time. There is a variety of applications of this group like textile fibers, automotive parts, etc.

2.1.2 Bio-based biodegradable plastics

Bio-based biodegradable plastics are the group of starch blends (combination of modified starch and biodegradable polymers) or polyesters like polylactic acid

(PLA) and polyhydroxyalkanoate (PHA). This group of bioplastics has been available in the market for a few years and still has a gap for innovation and potential to grow in the market. As the material is biodegradable, it is preferable for uses as packaging of a short shelf-life product due to its faster rate of degradation compared to conventional or non-biodegradable groups.

The degradation can be done by the activity of microorganisms to obtain nutrient-rich biomass which can be beneficial for the plants. However, the degradability varies depending on types of polymer, composition, and environmental condition. Not all biodegradable bioplastics can completely decompose in nature; some of them may need specific conditions and facilities to fully break down the plastics back to its origin (Zhu and Wang, 2020)

A summary in section 2.1 about bioplastic materials and their possible applications by NaturePlast (n.d.) are illustrated in Table 1. These materials are derived from renewable resources. However, one major drawback is that there are numbers of people who still suffer from hunger and lack of access to proper food. It would be better to use these materials as food for consumption instead of utilizing it as feedstocks for bioplastic production.

Table 1 Summary of characteristics and applications of various bioplastics (NaturePlast, n.d.)

Materials	*Origin / End-of-life*	*Resources*	*Properties*	*Applications*
Sustainable (BioPET, BioPE, BioPA, etc.)	20–100% biobased / Non-biodegradable and non-compostable	Sugarcane, Molasses, Vegetable oils	Equivalent to traditional polymers, Remain recyclable, Non-biodegradable, Ease of use	All types of packaging Technical parts
PLA	100% biobased / 100% biodegradable and compostable	Starch (Maize), Sugarcane, Sugar beet, Tapioca, etc.	Transparent, Rigid, Low thermal resistance, Low barrier properties	Agro-food packaging, Cosmetics, Injected parts, Biocomposites
PHAs	100% biobased / 100% biodegradable and compostable	Starch (Maize), Sugar (sugarcane, sugar beet), biomass, etc.	Opaque to translucent, Rigid to elastomeric, Good thermal resistance, Good barrier properties	Biocomposites, Injected parts, Packaging film
Biopolymers	Partially biobased / 100% biodegradable and compostable	Sugarcane, Starch, etc.	Opaque to translucent, Rigid to flexible, Good thermal resistance	Bag manufacturing, Mulching film, Vails, Injected parts

Materials	*Origin / End-of-life*	*Resources*	*Properties*	*Applications*
Cellulosic derivatives	Mostly biobased / May be biodegradable and compostable	Wood pulp	Transparent, Rigid, Good thermal, mechanical and barrier properties	Agro-food packaging (film), Injected parts
Bioelastomers	Partially biobased / 100% biodegradable and compostable	Different biobased polyols (vegetable oils, sugars, etc.)	Very flexible, Good mechanical properties, Easily transformable	Primarily technical and injected parts
Starch-based compounds	Partially biobased / May be biodegradable and compostable	Starch flours (corn, potato, etc.)	Flexible, Sensitive to moisture, Controlled biodegradation	Bag manufacturing, Mulching film, Horticulture
Biocomposites	Partially biobased / May be biodegradable and compostable	Wood fibers, hemp, flax, bamboo, and bioplastics or conventional matrix	Rigid, Good mechanical and thermal resistance, Easily transformable	Primarily technical and injected parts

It is mentioned by Colwill et al (2012) and Momani (2009) that the increase in bioplastics production will have an impact on the food supply chain. This creates food shortages and price increases due to higher food and agricultural land demand. By looking to the future, the world population is rising with higher demands for everything. The innovation in the field of bioplastics is still needed and it is recommended to further investigate an alternative bio-based feedstock that does not compete over food supply (Thailand Board of Investment, 2019).

In addition, Elferink and Schierhorn (2016) mentioned that the world population would reach 9.7 billion people by 2050, causing an increase in global food demand by approximately 59% - 98%. Many attempts have been done on valorizing food waste as raw materials for bioplastics production such as wastewater, peels from crops, fats, etc.

2.1.3 Cellulose as potential source of biomass

Due to an increase in environmental awareness regarding plastic overconsumption, bio-based feedstocks have recently become alternative resources for packaging production. The feedstock mainly consist of cellulose that could be used in packaging material development. Thus, non-edible plants including wood, stalks of cereal crops and grass are used for cellulose extraction by many manufacturers.

From 2020 to 2026, Compound Annual Growth Rate (CAGR) of the cellulose market is estimated to reach up to 2.9%, affected by the increased number of cellulose implementations. Similarly, CAGR in Asia Pacific region is expected to reach over 3% within 2026 due to growing demand in various types of products including packaging (Pulidindi and Prakash, 2020). The study of Yaradoddi et al (2020) revealed that, by incorporating cellulose into the product, it could reduce the production cost and enhance the feasibility of biodegradable film. With an increase in world’s population, this will have a direct impact on the increased demand of resources, such as food and agricultural area.

Lignocellulosic biomass is a term used to define the residuals of plants or woods. It is predominated with a complex of cellulose, hemicellulose, and lignin, creating a structure of cell wall as shown in Figure 2. There are also other organic and inorganic components presented, such as proteins, water, carbonates, nitrates, etc. Thus, it has no effects on the plants’ structural formation.

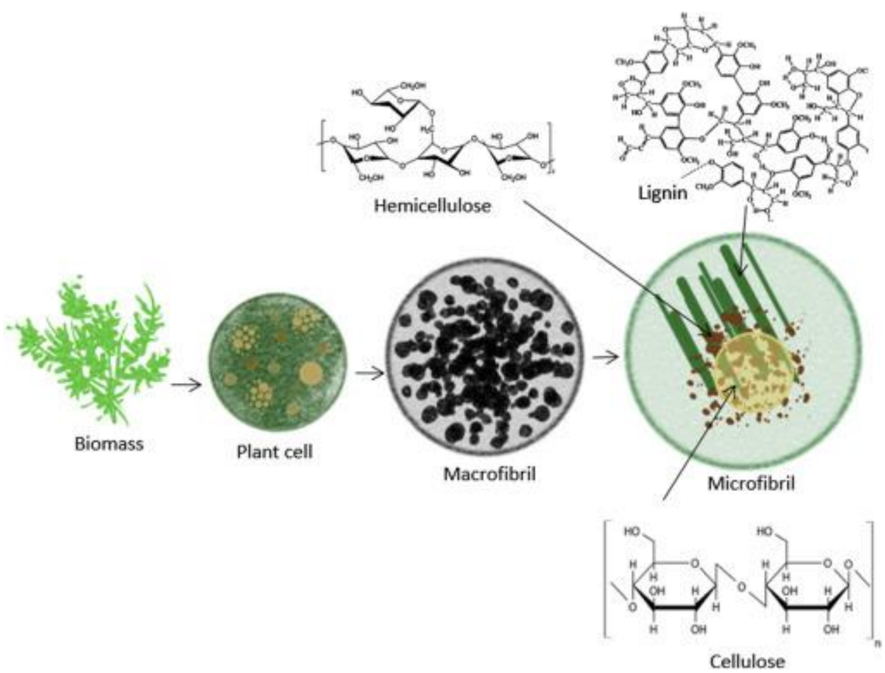

Figure 2 Main components of lignocellulosic biomass (Jędrzejczyk et al., 2019).

There are three components presented in lignocellulosic biomass. The first component is cellulose, which is the most abundant component of all. It provides a stiffness function and constitutes a core of a plant’s cells. The second component is hemicellulose, a low molecular weight polysaccharide providing structural formation of the plant. The last component is lignin, a complex structure surrounding the microfibril core, responsible for cell wall durability (Jędrzejczyk et al., 2019). With different types of plants, the composition of lignocellulosic biomass varies, as well as the structure and lengths of the polymer chains.

Barrett (2018) and Wilfred (2017) have classified bio-based feedstocks into three generations in Table 2, with cellulose and agricultural residuals belonging to the second generation.

Table 2 Three generations of bioplastics feedstock (Barrett, 2018; Wilfred, 2017)

Type	***Description***	***Sources***
First generation	Carbohydrate-rich plants or food crops, the most efficient bioplastics production feedstock where generates highest production yields with least required growing resources. However, they can also be used as food or animal feed, leading to competitiveness over the food supply chain.	Corn, Wheat, Sugarcane, Potato, Sugar beet, Rice, Plant oil, Natural rubber, etc.
Second generation	Group of feedstocks that is unsuitable as food for consumption. This can derive from either non-food crops or waste obtained from first generation feedstock.	Woods, Wheat straw, Bagasse, Corncobs, Palm fruit bunches, Switch grass, Waste lipids, Cellulose, etc.
Third generation	Group of biomasses obtained from algae, which utilizes wastes (CO_2 or methane) as raw materials and generates higher production yield and efficiency than first- and second-generation feedstock. It does not require any chemicals or land area for grow. The bioplastics obtained are having a faster degrade rate. However, it is more expensive compared to other bio- and conventional plastics	Algae, CO_2, and Methane

With an increase in demand on bio-based resources in replacement of fossil fuel, together with the approach to avoid the risk of food shortage while simultaneously providing value-added benefits to the residual wastes, the second-generation feedstocks which were previously considered valueless have come under the spotlight. Agricultural residuals and wastes, wood, empty fruit pulps and fiber from paper mills are full of cellulose and can undergo the processes of hydrolysis with acids or cellulolytic enzymes to convert into fermentable sugars. These residuals are used as a raw material for ethanol production which can be further utilized for bioplastics production as visualized in Figure 3.

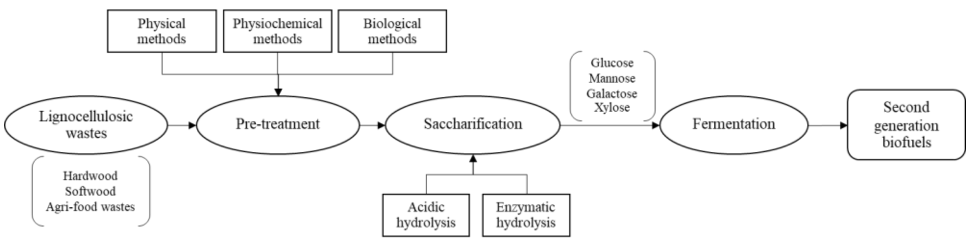

Figure 3 Second-generation biofuel production from lignocellulosic wastes (Laca et al., 2019; Patinvoh and Taherzadeh, 2019)

However, the treatment processes of cellulose as a second-generation feedstock are more complex than those in the first-generation. It requires four steps of treatments. The first step is the pre-treatment to break down the cellulose and lignin matrixes to enhance the enzymatic activity and increase production yield. This is followed by physical, physio-chemical, and biological treatments needed to break down the structure and removal of unwanted substances. The substrates then undergo fermentation and product recovery to obtain the biofuels (Saini et al., 2015).

2.1.4 Standards and Certifications

Standardization is a guideline which is voluntarily adopted by industrial stakeholders to define the general criteria of acceptance of products, services, or processes. It helps to enhance the commercializing ability and competition by setting barriers for specifications, introducing desirable quality requirements and prevention of fraud. There are two types of standards that often complement each other. First is the standard of test methods which define the methodological criteria and procedures to be followed. Another type of standard is for the specifications which define the criteria of pass and fail, required on the products or materials.

There are many standardization bodies existing on national and international levels, but the three main key bodies of standard accepted internationally are International Organization for Standardization (ISO), European Committee for Standardization (CEN) and American Society for Testing and Materials (ASTM). These standards are used to certify for certain properties of the products or materials, and are usually presented as a logo or label for recognition, as shown in Figure 4.

Figure 4 Logo of standard bodies; ISO (left), CEN (middle), and ASTM (right) (European Bioplastics, 2019)

These standards also apply to the categories of bioplastics. However, bioplastics are a group of many new plastic materials which have different properties and functions that are not easily defined by existing standards, although they can offer a basis assessment and claims which are a prerequisite of commercial success. The factsheet of list of standards from Bioplastics guide (n.d.) and European Bioplastics (2019) can be found in Appendix C.

2.2 Overview of bioplastics in Thailand

According to the data of Thailand Environment Institute (2020), due to the crisis of the Covid-19 pandemic, the approximate daily waste generated in the major tourist cities in Thailand has decreased by around 10 – 20% compared with data from before the pandemic. However, the portion of plastic wastes sharply rose more than 30-60% in all the cities. This is because of the expansion of food delivery services where consumers demanded for convenience and from the travel restrictions due to the pandemic situation. An average number of plastic packages is 5 pieces per order. The number of plastic wastes only in Bangkok have increased about 1.3 tonnes per day with 660 tonnes coming from recyclable plastics packaging.

As mentioned earlier, Asia is the main bioplastics producer of the world and from the report of Thailand Board of Investment (2019), Thailand is considered to be a suitable candidate to be a bioplastic hub of Asia. Due to abundant resources of two main types of bioplastic feedstock (e.g. PLA) which are cassava and sugarcane, the country is ranked second in cassava and fourth in sugarcane production of the world with the total of more than 42 million tonnes produced annually, and 17.5 million tonnes exported worldwide. Moreover, there is a capability in bioplastic production; Thailand was ranked 3rd in bioplastic resin – polylactic acid (PLA) export in the world, with the amount of over 18.5 million tonnes PLA being sent out in 2019.

In a presentation about Thailand's bioplastic industry, Jongkum (2013) described that since 2008, Thailand has tried to make the bioplastic industry the country's new wave industry. The initiation phase focuses on the production of PLA from cassava as its main product as shown in Figure 5. There are four strategies to drive the bioplastic industry of the country, which are (1) Development of the readiness of biomass raw materials, by conducting research and development to increase the cassava productivity and design of proper cultivation area. (2) Development of Research and Development to accelerate and create technology in the country provides the total funding of about 100 million Thai Baht (2.67 million Euros) on 87 projects collaborated with 17 universities from upstream of the producers down to the downstream of post-consumers activities. Examples are research on production of D-Lactic acid from selected strain of bacteria with high production yield and shorter time, the synthetic lactide with high productivity using new high performance catalyst, improvement of the biodegradability of the materials, etc. (3) Creation of industry and innovation business under the lead of Thai Bioplastics Industry Association (TBIA) with more than 50 business members, to drive the trend and create the demand for bioplastics in Thai society. (4) Set up of infrastructure for the bioplastic industry by establishing certified testing laboratories to test for material's biodegradability according to the standard of TIS 17088-2555, a modification version from ISO 17088:2008. This involves specifications for compostable plastics and enforcing a policy to provide incentives for investments in bioplastic industries.

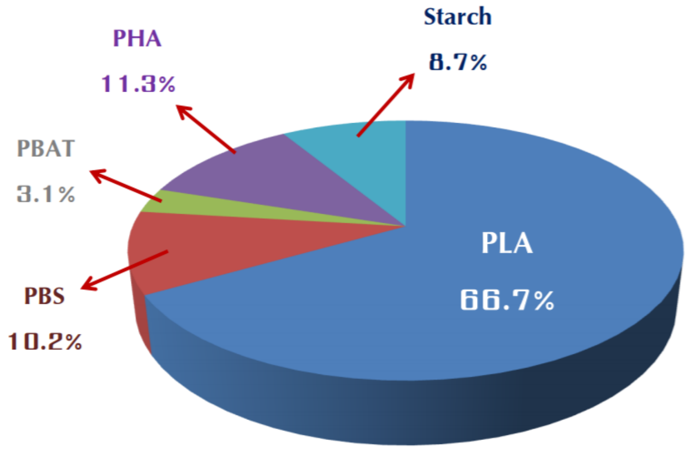

Figure 5 Financial support ratio by type of bioplastics provided by the Government (Jongkum, 2013)

Recently, the 20-year National Strategy was launched in 2018 by Thai government under the leadership of Prime Minister Prayut Chan-o-cha. It is a long-term strategy developed as a ground constitution, aimed to lead Thailand to achieve the vision of becoming "a developed country with security, prosperity and sustainability in accordance with the Sufficiency Economy Philosophy" along with happiness and well-being of Thai population as an ultimate goal (National Strategy Secretariat Office, 2018). There is a total of six main strategies; national security, national competitiveness enhancement, human capital development and strengthening, social cohesion and just society, eco-friendly development and growth, and public sector rebalancing and development, as shown in Figure 6.

Figure 6 Thailand's 20-year National Strategy from 2018 – 2037 (NSCR, 2019).

The fifth strategy of Eco-friendly development and growth is where the government has aimed to create a balanced sustainable development of three pillars - society, economy, and environment for the future generations - through the plan of establishing a governance system and a collaboration of partnerships in both domestic and international level (National Strategy Secretariat Office, 2018). In the context of bioplastics, the government has taken several actions to promote the use of bioplastics, such as the issuance of Royal Decree No. 702 - which allowed companies and juristic partnerships to gain a 25% incentive of tax deduction of the cost for utilizing biodegradable plastic products during the period of 1 January 2019 until 31 December 2021 (Deloitte, 2020). Another action was achieved via the policy of single-use plastics banning consisting of bottle cap seal, oxo-degradable plastics, and microbeads since 2019, and aimed to complete the ban of plastic bags, styrofoam boxes, plastic cups, and plastic straws by the end of 2022 (Pimthong, 2020).

2.2.1 Bioplastics production in Thailand

As mentioned earlier, Thailand is a main producer and exporter of sugarcane and cassava, together with the initiation in investing in bioplastic industry. Thailand Board of Investment (2019) reported that the two main bioplastics production in Thailand was Polylactic Acid (PLA) and Polybutylene succinate (PBS) from sugarcane and cassava due to their short conversion process compared to other starch-based crops which keep the production price low. Especially for PLA production, it showed a growth of over 300% from 2017 to 2018 and became the world's 3rd largest PLA exporter with 6.8% of the market share. A simplified bioplastics production flow from cassava and sugarcane can be seen as Figure 7.

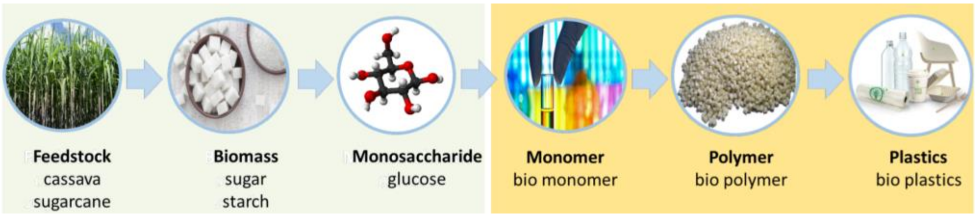

Figure 7 Simplified production flow of cassava and sugarcane in bioplastic industry (Yeetsorn, 2020)

From the figure, the process involves breaking down of feedstock into fermentable sugars which are later transformed into monomer and polymer, respectively, for bioplastics production by fermentation or conversion process. The description and a simple production process of PLA and PBS can be seen in Appendix D.

2.3 Banana

Banana, an herbaceous flowering plant of Musa genus and Musaceae family, produces one of the most popular edible fruits in the tropical regions. It is cultivated by over 130 countries and consumed worldwide. Banana is the world's second largest produced fruit, accounted for 16% of overall fruit production across the globe. Due to the tropical climate and fertile soil of the region, the continent of Asia is extremely suited for agriculture. The region has the highest banana production rate in the world of more than 50% with India, China and Indonesia as the top three exporters (Bakry et al., 2009).

Banana is popular for consumption because the fruit contains various beneficial phytochemicals. Many studies have claims of health benefits provided by the fruit. Its nutrients promote the function of neurotransmitters for hormonal regulation, antioxidants, lowering of blood cholesterol level, etc. (Vézina et al., 2021).

2.3.1 **Morphology**

Banana belongs to the group of herbs as the plant does not have woody tissue and the fruit-bearing stem will be wilted after the fruits have been harvested. Bakry et al., (2009) have illustrated the morphological diagram of the banana plant as shown in Figure 8.

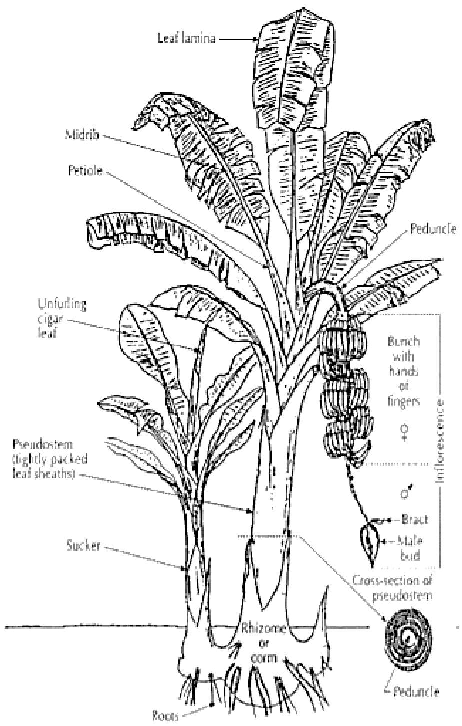

Figure 8 Morphological diagram of fruiting banana plant with sucker (Bakry et al., 2009)

The true stem consists of three main parts. The first part is the rhizome; the underground part responsible for generation of roots and production of clonal shoots. The second part is the aerial stem; the core stem that provides support of the plant. The last part is the peduncle; the top part of the aerial stem consisting of both male and female flowers. As the peduncle elongates, the outer layer made up of female flowers later develop into a bunch of banana fruits arranged in a hand shape. The fruit is green and horn-shaped, later turning to yellowish when mature. At the very end, the male bud is located.

The true stem covered with a layer of overlapping trunk-like part is called 'Pseudostem'. The very end part of the pseudostem is developed into leaves, with the center part functioning as a midrib that holds leaf blades together and is responsible for the photosynthesis activity (Bakry et al., 2009). Pseudostem is a major part of the banana plant which mainly consists of water and lignocellulosic components (Jayaprabha et al., 2011). Table 3 illustrates the composition of lignocellulosic contents based on dry weight and moisture content (based on wet weight) of banana pseudostem, comparing with other agricultural by-products.

Table 3 Lignocellulosic composition and moisture content of agricultural by-products

	Cellulose (dry)	***Hemicellulose (dry)***	***Lignin (dry)***	***Moisture (raw)***	***Source***
Banana pseudostem	49.3	12.04	13.88	96	(Li et al., 2010; Subagyo and Chafidz, 2020)
Rice straw	38	25	12	12 - 17	(van Hung et al., 2020)
Corn cob	45.6	39.8	6.7	5.3 - 7.2	(del Campo, 2010; Zhang et al., 2012)
Sugarcane bagasse	32 - 34	19 - 24	25 - 32	50	(Haghdan et al., 2016; Manickavasagam et al., 2018)

Banana can reproduce both sexually and asexually. Regarding sexual reproduction, the pollinated ovules are developed into seeds. This type of reproduction is usually found in the wild, while the asexual type is commonly found in agricultural cultivars where the lateral shoot called 'Sucker'. It develops from the same rhizome and emerges next to the parental plant. The sucker or shoot can be developed into a new plant which can also yield the fruits. The banana cultivated from asexual reproduction are seedless, with little visible black dots derived from the developed ovules (Bakry et al., 2009; Vézina et al., 2021).

2.3.2 Banana production in Thailand

Thailand is one of the agricultural countries whose income from this sector accounts for 670 million Baht (18.3 million Euros) or 9.9% of total Gross Domestic Product (GDP) (FAO, 2020). In terms of banana cultivation, Thailand has six main types of banana, which are *Cavendish*, Golden, *Pisang Awak*, *Musa balbisiana*, Lady finger, and *Saba* banana. The report from Department of Agricultural Extension (DOAE) shows that the total banana fruit production in 2019 was over 1.12 million tonnes as shown in Table 4.

Table 4 Total banana production in Thailand in year 2019 (DOAE, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f)

Banana type	***Total production (Tonnes)***
Pisang Awak banana	745,163
Cavendish banana	213,219
Golden banana	134,300
Musa balbisiana banana	27,458
Lady finger banana	10
Saba banana	660
Total	**1,120,810**

After fruit harvesting is completed, the fruit will follow the distribution chain as illustrated in the study conducted by Adisak (2014), shown in Figure 9. The bananas from farmers are distributed to three intermediate players, plus a channel directly reaching to consumers. Traders are the ones collecting bananas from farmers in order to resell to either consumers, processing plants or exporters. Farmer associations are organizations that are usually located nearby farms and provide support in supply input or loan offering to members. Lastly, cooperatives are larger organizations and can be located further away from the farms. By joining a cooperative, farmers will have a greater opportunity to access training and farmer's aid programs. Both associations and cooperatives act like a distribution point where it is easier to provide a larger portion of banana supply to processing plants and wholesalers. In the end, the bananas can be sold either fresh or processed, then transferred to distribution channels such as markets, then exported to other countries.

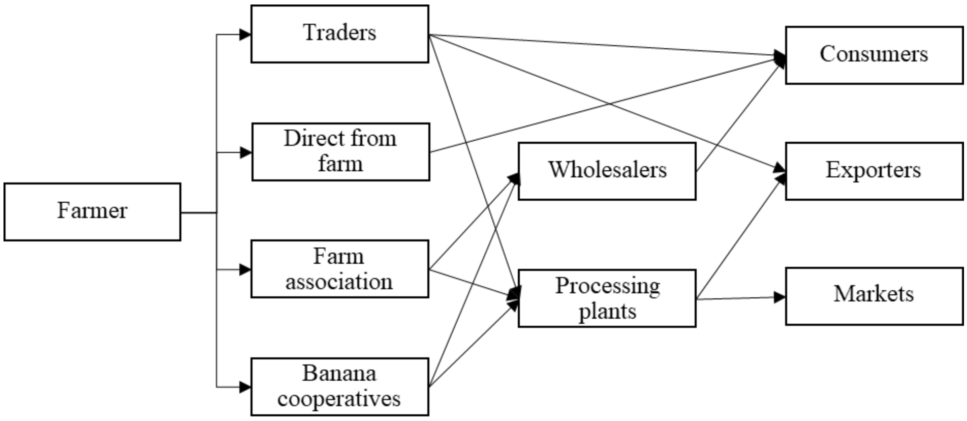

Figure 9 Banana market model in Thailand (Adisak, 2014).

2.3.3 Banana waste and its possible applications

Padam et al (2014) reported that waste from banana plantations (stem, leaves, fruit stalk, rhizomes, and damaged fruit) is about four times by mass of the product obtained. Furthermore, the mishandling in disposal of these wastes has a potential to cause global warming or human toxicity which create a great impact to the environment. According to Mohapatra et al (2010) and Padam et al (2014), on a global scale, more than 114 million tonnes of banana are produced annually. In addition, it requires a period of six months for the plant to fully grow to be able to bear fruit, and it takes another 85 – 100 days to develop the fruits that are ready to be harvested and consumed. However, only the fruits - which account for only 12% of the whole plant - are harvested and consumed (Sakharkar, S., 2019). Once the fruit is harvested, the plant will die, and only a small percentage of the leaves and trunks will be utilized as food wraps, textile fibers, or biogases. The rest would be discarded to landfill (Mohapatra et al., 2010; Padam et al., 2014). From a calculation based on information regarding banana fruit production quantity in Table 4, the total waste, comprises trunks, leaves, and peels generated from banana farming in Thailand is approximately 8 million tonnes per year.

Table 5 illustrates the summary of applications found in the study of Bhatnagar et al (2015), Mohapatra et al (2010), and Vigneswaran et al (2015) about the possible applications of each banana by-product part and the process applied.

Table 5 Banana by-product utilization matrix for food and non-food applications (Bhatnagar et al., 2015; Mohapatra et al., 2010; Vigneswaran et al., 2015).

	Peel	***Pseudostem***	***Leaves and sheaths***	***Male buds***	***Rhizome***
Extraction	Dietary nutrients Pectin Cellulose Micronutrients Bioactive compounds	Dietary nutrients Bioactive compounds Fiber & pulp Textiles Waxes	Bioactive compounds Fiber & pulp Textiles Waxes	Colorant Bioactive compounds	Bioactive compounds
Enzymatic treatment	Food flavoring	-	Food flavoring	-	-
Molecular modification	-	Heavy metal & Dye adsorbent	-	-	-
Densification	Briquettes production	-	-	-	-
Fermentation	Ethanol Biogas	Ethanol Biogas	Ethanol Biogas	-	-
Composting	Fertilizer	Fertilizer	Fertilizer	Fertilizer	Fertilizer
Microbial substrate	Cellulolytic enzymes & organic acids production Mushroom cultivation	Cellulolytic enzymes & organic acids production Mushroom cultivation	Cellulolytic enzymes & organic acids production	-	-
Non-processed	Animal feed	Animal feed Food ingredient Ceremony	Animal feed Food wrap Ceremony	Animal feed Food ingredient Ceremony	Animal feed

In Thailand, after the cultivation, other parts of banana are used for different purposes (see Figure 10). While banana leaves are commonly used for Thai traditional food and dessert wrapping, the unused banana blossom becomes an important ingredient in some traditional dishes such as *Pad Thai* and *Hua Plee soup*. Banana has also been rooted in the culture and lifestyle of Thai people for long time. Parts of banana trees are used for decoration in Thai traditional wedding ceremonies, as well as other religious ceremonies. In the northern part of Thailand, *Bai Sri tray*, made from folded fresh banana leaves and flowers, is a part of a spiritual ceremony which is believed to help console people's spirit to return to their body. Similarly, banana leaves and stems are used to make floating baskets as a tribute to the Goddess of Water according to Thai belief in *Loy Kratong* or full moon festival (Karnjana, 2019). However, comparing to the total wastes generated, the proportion of by-products reused is marginal.

(a) (b) (c) (d)

Figure 10 Figure 10 Figures of banana by-products applications (a) Bai Sri tray (Thai Language Hut, n.d.), (b) Pad thai with banana blossom as a side (The Market Experience, 2018), (c) Banana leaf used as food wrap (Yanukit, 2020), (d) Young banana shoots used in wedding ceremony (Pizarra Photography, n.d.).

2.3.4 **Banana in bioplastic industry**

Ma (2015) stated that the pseudostem is a major part of the banana plant and contains cellulose fibers as its dominant component. There are several studies on developing of products and materials from banana fibers such as; paper sheet, paper box, fiber mat, furniture, and fiber-based material for plastic production (Bhatnagar et al., 2015; Vigneswaran et al., 2015).

Moreover, there have been attempts to research and study about how to utilize waste from banana, such as the study of Ingale et al (2014) on the bioethanol production from banana pseudostem; using two fungal strains in breaking down of cellulose into reducing sugars and using fermentation process to obtain ethanol as a final product. Referring to the production of bioplastics material, sugar can be used in lactic acid fermentation for PLA production and ethanol is a substrate for PBS production. Two other projects conducted in Thailand by Liwthaisong (2013) and Singanusong et al (2014), studied about the potential of extracting food-grade cellulose and dietary fiber from banana peel obtained from banana production waste aiming to upcycle and increase the value of the byproducts. They have tested several applications, such as bioplastic film production from cellulose, fiber and cellulose as food additives, charcoal from banana trunk, etc. A recent study from Australia by Faradilla et al (2018) illustrated the potential of utilizing pseudostem of banana's trunk and leaf as a source of nanocellulose for food containing plastics and films production, which is biodegradable and does not create toxic substances when the food is consumed. Another study done by Shimizu et al (2018) found the conditions for extracting cellulose content from banana pseudostem using an acid treatment. Although these studies are preliminary research or in laboratory scale, they open the doors to new opportunities in utilizing agricultural wastes from banana plantation in biofuels and bioplastic industry (Jędrzejczyk et al., 2019).

Additionally, there is some evidence of incorporating cellulose into bioplastics to create composite materials to achieve certain properties. A Japanese company named Green Science Alliance Co., Ltd. has invented novel bioplastics cutlery. The company overcame the fragility of PLA materials by incorporating nanocellulose into the mix to improve the mechanical strength of the finished product to match with the performance of conventional plastics and preserve biodegradability function (Schelmetic, 2019).

2.4 Value chain map

A value chain, by the definition of Kaplinsky and Morris (2001), refers to the description of all activities involved in transformation of product or service from conception to reality through different stages of production, alteration, including inputs from service providers. The final product then delivers to the consumers and enters the disposal phase after being used. The Food and Agriculture Organization (FAO) also defined the value chain as an economical system that involves all the values of a similar family of products distributed and supplied by and for all stakeholders from producers to consumers (Fourcadet and Attaie, 2003). A tool that helps to visualize the systematic scheme of all the identified components and their relationships within the value chain, including the external influences is called a value chain map. From the report of Trienekens (2011), the basic players involved in the value chain, consist of producers, traders, processors, and consumers.

Whereas governmental and non-governmental organizations, financial institutions, and other involved service providers belong to the non-player group in the value chain.

The map demonstrates two dimensions of relationships between the stakeholders; horizontal dimension and vertical dimension. The vertical dimension shows the relationship between stages of function and physical flow of commodity products, as well as information and services from producers through the destination of sales or consumers. The horizontal dimension shows the interaction between stakeholders within the same function stage (Kaplinsky and Morris, 2001; Trienekens, 2011). The netchain concept developed by Lazzarini et al., (2001) as illustrated in Figure 11, shows the interrelationships between different stakeholders in vertical and horizontal dimensions. In the suppliers' level, horizontal dimensions could refer to the transfer of assets or interactions between two or more suppliers, while the vertical dimension refers to the linkage between suppliers and traders where one supplier can interact with many traders. However, a value chain in reality can be very complex, as a single source of raw materials can branch into various final products (Tetnowski, 2015).

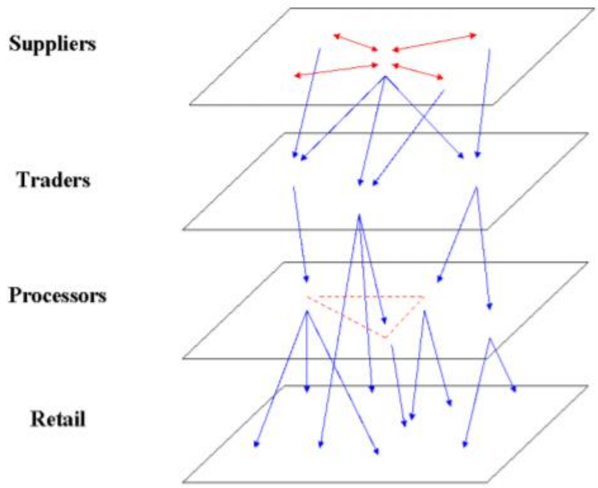

Figure 11 Netchain concept (Lazzarini et al., 2001)

3 Methodology

This chapter will walk through the approach and methods to obtain information that were used to answer the research questions. As this study is a qualitative, exploratory research, the main information was obtained from semi-structured interviews of each identified stakeholders involved in banana by-products and bioplastics value chains, combined with secondary sources data. The data obtained then visualized as a value chain map and analyzed for operational feasibility as stated in the research purpose.

3.1 Research approach

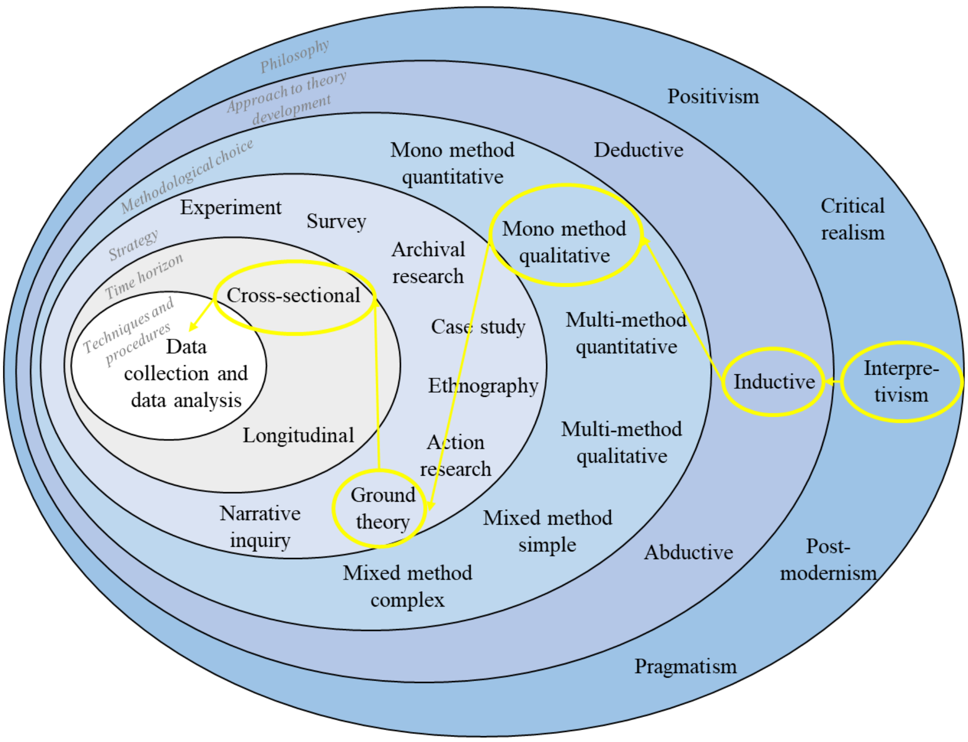

Figure 12 Research onion - adapted version based on the study by Saunders et al (2019).

Starting from an interest towards the utilization and value addition of agricultural wastes, this research followed an exploratory research route illustrated by the research onion of Saunders et al (2019) as in Figure 12. At the time that this study was conducted, there were no activities in Thailand regarding the utilization of banana by-products for bioplastics in an industrial scale. This was surprising considering there have always been a lot of bananas present in Thailand's landscapes, both industrial and natural. The research approach generally followed the interpretivism or constructivism philosophy using an inductive approach. The research began with a research purpose instead of a hypothesis and aimed to report the findings based on knowledge of those who have experienced (Dudovskiy, 2018; Mills and Birks, 2014). A qualitative exploratory research refers to how information is obtained through qualitative data collection and observation method of a specific period of time during the study. The information is then reviewed, coded, categorized into groups, and analyzed which is later developed into the findings of this study (Mills and Birks, 2014).

This exploratory research to helps improve understanding of the situations and provides new set of data and insights. The approach started from the secondary research to obtain a general background on bioplastics, banana cultivation, and the situation of both industries in Thailand and global scale. Further steps were aimed to explore more details with the actual stakeholders through qualitative interviews. The obtained information was intended to be used for analyzing the feasibility of the approach statement as stated in the research purpose (Nassaji, 2015). The rest of this chapter will explain in more detail the methodologies done in this study.

3.2 Data and data collection

The information in this report was obtained from primary and secondary sources. Collection of multiple sources to address the same research question is recommended to improve the quality of the research and to strengthen the credibility of the evidence (Hox and Boeije, 2005). This study started with secondary research to gain some backgrounds related to the topic, enabling the construction of the interview guide for the qualitative primary research. This was followed by series of qualitative interviews and observations. Both are considered to be an excellent source of information. A combination of primary research as interviews and observations with a valid and credible secondary research can be complemented with each other. In this case, data obtained from the primary research may not be presented in a complete form due to the candidates or researchers' biases or confidentiality issues (Hox and Boeije, 2005).

The effectiveness of the analysis depends on the quality of data collection. Different types of data and research methods have different strengths and weaknesses. It is also mentioned by Dudovskiy (2018) that the qualitative information obtained from individuals may be prone to bias as they tend to adapt their perception to plead with the research topic and could result in misleading of the outcome. A well semi-structured interview questionnaire and good facilitating skills are required. The information from secondary sources can also help in complementing the data from interviews as supportive evidence. It substantiates the completed qualitative primary research and fills in the missing gaps unaddressed by the interviews.

3.2.1 Secondary research

Data obtained from secondary research were from various sources available on databases. This report used five sources for searching of secondary data mentioned in the paper of Martins et al (2018). The first source is from the governmental and their related agencies that are trustworthy. Most surveys conducted by the government are usually done in a large scale and could be a representative of the population. This also applies with international agencies, such as UN. The second source comprises private entities and agencies which can give similar quality of information as governmental agencies. The information was carefully read and understood before being adopted into the report. The third source is data from private international research projects, such as those commissioned by European Commission (EC), which presents a pool of data. The forth source is from the scientific journals and research databases from databases available in the university. The last source refers to searches through other databases using Google scholar and Google Books.

The relevant search terms used for accessing to the articles were: *banana, by-products, bioplastics, value chain, bio-based,* and *Thailand*. As the research was carried on, more keywords were obtained and used to further extend the secondary research. The process was over when the information has reached a saturation point with similar results (Baum and Bintliff, 2001).

3.2.2 Interviews

In this study, the main primary source of information is in the form of interviews. A total of thirteen (13) interviews were conducted from six groups of stakeholders. Table 6 describes the purpose of the interview of each stakeholder in this study.

Table 6 Stakeholder's role and objective of an interview

Stakeholder's role	*Objective of interview*
Farmer	To get insights of the banana cultivation process and the management of the materials (banana by-products).
Farmer's cooperative	To understand the function and relation between the organization with its members and other stakeholders.
Transformer, Extractor, Converter, Packaging manufacturer	To understand the requirements and limitations of the bioplastics and packaging industries and to see the possibility of utilizing by-products from banana cultivation.
Food manufacturer	To understand the limitations and requirements from the food manufacturing aspect and the connection between the food manufacturer and other stakeholders.
Researcher from academic sectors and research institutes	To understand the technical feasibility aspect, the contribution to the banana cultivation and bioplastic value chains, and relationship between the institute or researcher with other stakeholders.
Government sector (Local and national level)	To understand the role, national goals, limitations, and existing legislation that could support or prohibit the approach of utilizing banana by-products into bioplastics value chain.

Before every interview session, to ensure confidentiality during interviews with the stakeholders, the researcher conducted a self-introduction and provided a brief background of the research. This is followed by asking for permission to record the interview for later study and for summarizing of the interview. The interviewees were also informed about the disclosure of the information and the publication of the final report. In case of confidentiality concerns of some parties, both the name of some interviewees and name of company are stated as anonymous (Wallace Foundation, n.d.).

3.2.2.1 Contacting and scheduling

The candidates for farmers, institutions, experts/researchers, bioplastic industries, and government sectors were reached out in an initial stage. The list of potential interviewees was obtained from the researcher's own connections and through the research from secondary sources. The referred candidates were suggested by the interviewees during the interview session. A call to introduce the general idea of the project was made to each candidate. This was followed by a written e-mail after the candidates agreed to participate in the interview while the date and time of interviewing were discussed later by both parties (Wallace Foundation, n.d.).

3.2.2.2 Questionnaire formulation

This research was conducted in Thailand. The language used in the interviews was Thai and later translated into English for research documentation. Semi-structured interview questions for each group of stakeholders can be seen in Appendix B. With the approach of qualitative interview, the form of open interview was used. The questions were constructed based on "How" rather than "Why" or "Yes/No" to allow the interviewees to have a free flow of answer formulation without any restrictions, where the interviewees can reflect their own opinion based on their experiences. They were also constructed based on the stage of the stakeholder and ranged from basic to more specific questions. A guideline remarks or keywords are listed under each question where the development of probing questions may be added during the interview session in case it was not mentioned (Harvard, n.d.)

3.2.2.3 Interview guideline

Most of the interviews were expected to be conducted on-site to help understand the working environment and conditions of the target stakeholders better, as suggested by Braun and Clarke (2006). However, some of the interviews could not be conducted face-to-face as the interviewee preferred to have the interview from distance due to the pandemic, or they lived far away in others region of the country (e.g., more than 3 hours by driving). These interviews were completed via online platforms like Zoom and Microsoft Teams or phone calls.

Three interviewing skills mentioned by Palys and Atchison (2014) for having an effective interview, were applied. The first skill is to be an active listener and make sure that the information obtained was correct. The second is to be patient; do not rush or push for the desired answers, allow the interviewee to freely express their response while gently guiding the direction of the interview. The last skill is to be flexible; always keep in mind that different people have different backgrounds, social status, generations, etc. Thus the interviewer may require flexibility in modifying of interview questions to fit with the situation, and formulation of new questions may need. Each interview session lasted around 45 – 90 minutes. The interviewees are the main speaker, and the researcher took the role of facilitator to conduct the free flow of information and encourage the interviewee to speak freely while keeping the discussion on track.

During the interview, in case the interviewee has not mentioned some of the information needed for the research, follow-up questions or keywords were asked to probe the direction of the interview and to explore into the topic of interest. At the end of the interview session, the researcher summarized all the main points mentioned during the interview to confirm that the data obtained is corrected, following by additional ending questions asking about suggestions or comments on the related topic (Griffee and Hitchcock, 2005; Harvard, n.d.).

3.2.2.4 Documenting the data collected

Data collection in this study was done via voice recording, as well as written notes both in physical and electronic formats including follow-up e-mails with additional questions after an interview, and summary of interviews, or reports. During the interview, the responses from the interviewees, as well as observations of feelings, gestures, mood, and voice tone during the interview were noted down. All the interviews were conducted in Thai as it is the main communication language. A translation of information based on the concern of a precision and correct choice of words and a complete summary of each interview was done within a day of the interview with a playback of the recordings to avoid the missing of the main points and misleading of the information (Griffee and Hitchcock, 2005).

The collected data was organized using a Gantt chart (see Appendix A) in a chronological manner and the notes files were kept in electronic form (Microsoft Word and Excel), so that the researcher could easily track and trace the progress, from raw data to the conclusion. The advantages of having data organization are that it helps to prevent loss of information, provides stable resource which does not alter over time and can be accessed repeatedly.

3.3 Data analysis

In the data analysis phase, the information obtained from data collection step from both qualitative interviews and secondary research was used to construct the value chain map. Later, an analysis was conducted to identify the answer to the research question regarding feasibility in utilization of banana by-products as an alternative feedstock for bioplastic industry.

To prevent error and confusion in value chain analysis, a clear scope and boundary of study must be defined. This helps in selecting the focus of the study and prevent loss of track during investigation of the value chain. The approach is based on neutral researcher position to prevent bias from researcher's opinion, and focuses on the aim of research to answer the research questions (Grbich, 2012).

3.3.1 **Analysis of interviews**

The analysis of interviews follows the six steps of qualitative data analysis in the thematic analysis framework explained by Maguire and Delahunt (2017), as illustrated in Figure 13.

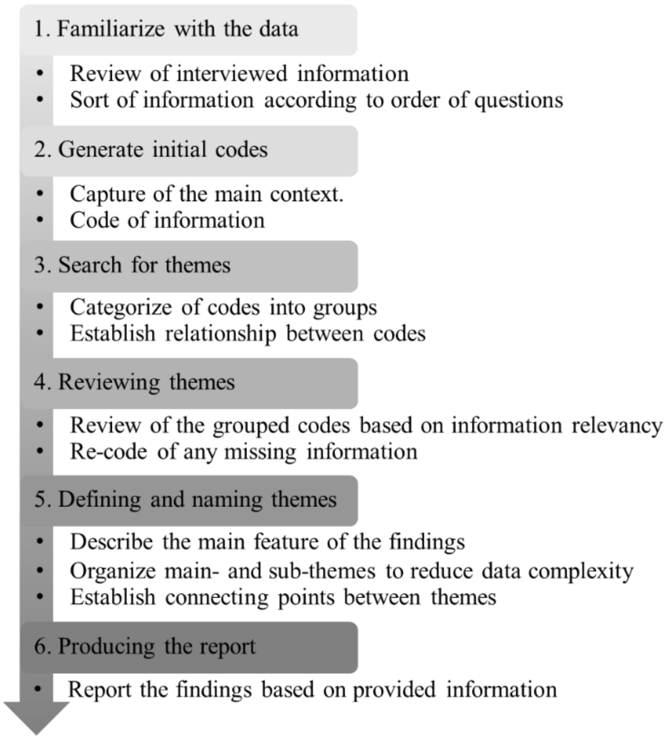

Figure 13 Thematic analysis framework by Maguire and Delahunt (2017).

The data obtained from the interviews in both audio recordings and written notes were reviewed and generated into codes in a Microsoft Word file in bullet points, to make sure that all the key information mentioned were presented. The codes represented the set of ideas focusing on the frequency and extensiveness of the information mentioned by the interviewees. It is recommended by Maguire and Delahunt (2017) to use the exact same word or description as mentioned by the interviewee. However, to prevent the biases from the interview, the notes taken from observation on the interviewee's feelings and interactions towards the topic was taken into account. The codes listed in the file are sorted according to the order of questions being asked. In case of answers from an impromptu question, the answers were placed together with the answers from other logically related questions.

All the generated codes were then grouped according to their relevance to the research question. For example, the codes about difficulties during work of the stakeholders are grouped together. Some codes were presented in more than one groups in case the information is relevant to those groups. Themes were defined after the codes were put together in a group or sub-group; this can reduce the complexity of information and a mind map was used to help visualize the connections between the information. For the codes that ended up into other minor themes which did not initially fit with any of the main themes, they are grouped under a "miscellaneous" theme as a temporary space. Those in miscellaneous theme were later brought back to be either re-analyzed or discarded (Soto E., 2019). The themes were assigned with names according to their relevance such as main activities, influences, and direct support with a sub-theme categorized by level of the stakeholders. An example of the thematic map done in this study is illustrated as Figure 14. Farmers performed activity of harvesting, selling and managing by-product, after the products were sold to manufacturers. Similarly, researchers conducted research, product development and provided supports to farmers and manufacturers.

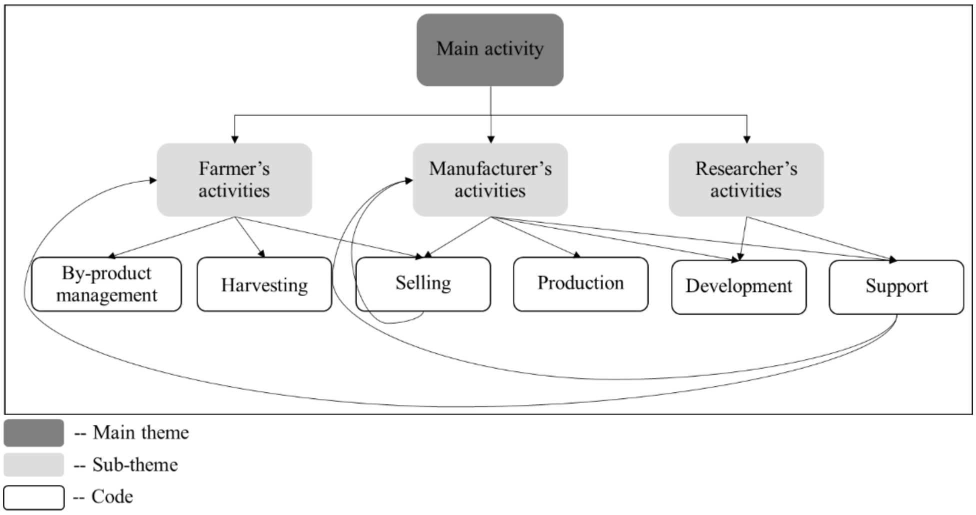

Figure 14 Sample of thematic map from the study (by author)

Once all the information was sorted and linked together, the narrative report to express the important aspect and the whole mapping scheme of the findings related to the research questions was produced.

3.4 Value chain mapping

Since there is no existing value chain for utilizing banana by-products for bioplastic industry in Thailand at the time of the study that could serve as a reference, the value chain had to be constructed. The data-based construction was based on the information obtained from the interviews, observations, and data collected on transformation of banana by-products from farmers to bioplastic (food) packaging industry. The mapping procedure relied on MEDA (n.d.), and six out of nine steps from the article were applied in this study and listed as below:

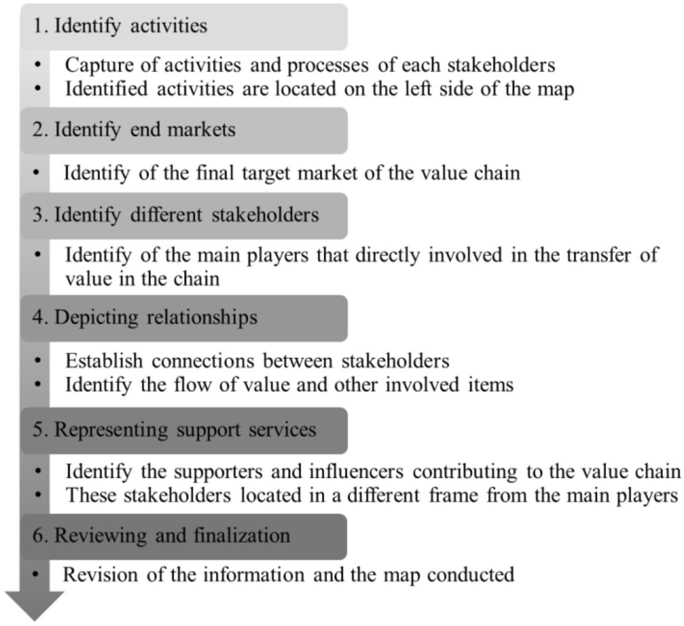

Figure 15 Flow of conducting value chain map (MEDA, n.d.).

The data obtained from interviews with stakeholders was also used to generate the value chain map with an addition of secondary sources to complement the missing information (Hox and Boeije, 2005). Before mapping the value chain, there are five elements of the value chain to be identified. The first element is the stage of activities, which refers to the stage where changes in the value of the object in focus - which in this study is the banana by-products - occurs. The second element is the main stakeholders who are directly involved or handle the by-products physically from the producer to end-user level. The third and fourth elements are the supporters and influencers; external players who provide support or have an influence on the value chain. They can have an engagement at a specific point or throughout the map. The last element is the flow of physical, information, and financial transaction value discovered during the study. Text boxes and arrow lines with different shapes and colors including the structuring of the map layout were used to differentiate the data and reduce the confusion that may happen to the readers.

After all the identified components were placed and connected with indicators, a cross-checking of the information and final revision was done to prevent any missing information that might be left without being mentioned. What was missing from the map was the additional overlays as quantifier to indicate the input and output of the physical flow, such as quantity of by-products generated and supplied, or how much in numbers the item was distributed. This includes gender factors and market research missing from the map due to the fact that this information is unable to be obtained. However, these are recommended to be carried out in future studies.

3.5 Analysis of feasibility

The feasibility study is report is defined as “operational feasibility”, as it aimed to explore the possibility in introducing banana by-products into bioplastic industry. According to definition by Giorgini (2003), operational feasibility relies on the question “If the system is developed, will it be used?”. The analysis focuses on the importance of the issue and the acceptability of the solutions. This includes internal issues such as people oriented, organizational conflicts, operation ability, etc., as well as external issues like government related issues and market acceptability of the new system.

To be able to answer the last research question which is about the success and barrier factors of the approach of utilizing by-products obtained from banana cultivation for bioplastic industry in Thailand, the DEFT framework by Gordon (2010) was used as a tool to analyze for the operational feasibility of the approach. It is recommended by Pearson (2010) to use DEFT as tool for early assessment of a trend. In this case, it is the operational feasibility of the approach in this study. Gordon also explained that DEFT is a tool to help pointing out the hidden probe of the trend, and it consists of four parts representing the abbreviation DEFT.

Drivers - The forces that drive the trend to make an incident to happen and sustain it.

Enablers - The factors that support or catalyze the drivers. It is often confused with drivers, but a main distinguish point between drivers and enablers is that the enabler will have no effect without a presence of drivers, while driver can sustain itself without any support needed.

Frictions - The resistance forces that slow down the changes of trend. It is mostly occurred with the innovation approaches where it must overcome the financial, educational, and other limitations that resist to the adaptation.

Turners - Sometimes called as ‘Blockers’, the forces that stop or turn the approach into the opposite direction. It also refers to the counter-drivers where it creates a new trend that opposes to the drivers presented.

The analysis was done via the scheme of the benefits distributed among all the stakeholders in the value chain; activities performed by the stakeholders, opportunities, and difficulties defined by the interviewees and secondary research, and role of the governance and supportive players within the value chain (Kaplinsky and Morris, 2001). The success factors were determined by the identified drivers and enablers while the barrier factors were based on frictions and turners, which are all further discussed in more detail in the next chapter.

3.6 Effects of existing pandemic

This research was conducted during the outbreak of Covid-19 across the globe. There are limitations related to the rules of social distancing and changes in the work location and schedule. It is quite difficult to schedule and conduct a face-to-face interview with all the stakeholders, where they tend to work from home and when the schedule can be changed all the time. To be able to obtain the required information, a confirmation call or e-mail prior to the time of interview was done. Mode of interview also varied depending on the suitability of interviewee schedule and location, some were done via phone call, online meeting applications, or an on-site visit. Moreover, many interviews were unable to carried out as expected, resulting in limited numbers of interview conducted. Consequently, the information in this study might not fully represent the actual picture of the value chain.

4 Results and Discussion

This chapter illustrates the value chain mapping and all the key findings from data obtained from secondary research and interviews with identified stakeholders involved in the value chain of banana by-products in relation to the bioplastic industry in Thailand. Then, using the DEFT framework, the chapter aims to analyze and discuss the operational feasibility of utilization of by-products obtained from banana production for bioplastic industry as an alternative raw material to replace fossil-based plastics and bioplastics feedstock.

The research purpose of this thesis was *"To explore the operational feasibility of utilizing banana cultivation by-products as an alternative raw material in bioplastics production replacing bio-based feedstock that is otherwise used as food in Thailand."*

Based on the main purpose above, to further understand the banana supply chain and to explore the activities and players involved, the following research questions were then asked:

1. *Who are the stakeholders involved in the banana cultivation value chain and the bioplastics value chain?*
2. *What are the by-products obtained from banana cultivation and how are they handled?*
3. *How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?*
4. *What are the barriers and success factors in using banana by-products to produce bioplastics that can be used as food packaging in Thailand?*

To be able to address the research purpose and the subsequent research questions, 13 qualitative semi-structured interviews were completed with 14 respondents. A summary of all interviews conducted in this study including the key takeaways from each interview is shown in Table 7 as shown below.

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Due to confidentiality concerns, the names of some interviewees and companies were kept anonymous. Acronyms are used for naming the anonymous interviewees to help readers easily identify the respondents, as stated in the table; these are used throughout the chapter

Table 7 List of interviewees and key takeaways from the interview

Interviewee	***Position***	***Stakeholder's role***	***Key takeaways***
Mr. Veera Souseng	Banana farmer in Karnchanaburi	Farmer	- Banana cultivation process and requirements. - Obtainable by-products. - Interactions between farmers with other stakeholders.
Mr. Ann	Banana farmer in Petchaburi	Farmer	
Respondent F	Banana farmer and owner of banana snack owned label.	Farmer	
Mrs. Jintana Srasamang	Head of banana cooperative and owner of Siam banana brand	Cooperative	- Role of cooperative and interactions with other stakeholders.
Assoc. Prof. Amporn Sanae	Professor and researcher of Department of Packaging and Materials Technology, Kasetsart University	Researcher	- Role of researcher and contribution of the academic sector to the value chain. - Information of bioplastic-related research. - Possibility of agricultural wastes utilization.
Asst. Prof. Suthaphat Kamthai	Professor and researcher of Faculty of agro-industry, Chiangmai University	Researcher	
Mr. Sataporn Spanuchart and Mr. Thanaphong Lertpiriyasakulkit	Manager and Analyst from plastics intelligent center, Plastics Institute of Thailand	Institute	- Role of the research institutes and interactions between other stakeholders. - Insights of bioplastic industry.

Interviewee	*Position*	*Stakeholder's role*	*Key takeaways*
Respondent BM	Business development manager & application at a leading PLA manufacturing company	Bioplastics manufacturer	- Role of bioplastics manufacturer and relationships with other stakeholders. - Requirements and limitations in manufacturing.
Mr. Thanakorn Sodsai	Banana farmer and owner of Tanee Brand, value added banana byproducts	Converter	- Alternative perspective of banana by-products utilization. - Requirements and limitations in manufacturing. - Possibility of agricultural wastes utilization.
Respondent C	Packaging manufacturer from natural plant fiber	Converter	
Respondent FM1	General manager of packaging department in food manufacturing company	Food manufacturer	- Requirements of food manufacturers, food products, and consumers. - Relationships between food manufacturers and other stakeholders.
Respondent FM2	R&D Director of a food manufacturing company	Food manufacturer	
Mr. Satien Macharoenrungreung	Head of provincial farmer federation of Karnchanaburi province	Government sector	- Relationships between government sectors and farmers. - Farmer's requirements. - Government related activities.

4.1 Value Chain map

This study takes into account all the discovered stakeholders involved in the banana by-products and bioplastics value chains (to the researcher's knowledge). This encompasses the very beginning of the value chain at the producer level all the way following the flow of materials to the retailer level which is the last gate before reaching to the consumers. All information obtained from the interviews was analyzed and visualized into a value chain map as shown in Figure 16. The activities and data illustrated only focus on the relations between banana by-products and bioplastics and its connections with the food packaging industry. This also addresses the RQ1 – looking stakeholders involved in the banana cultivation value chain and the bioplastics value chain.

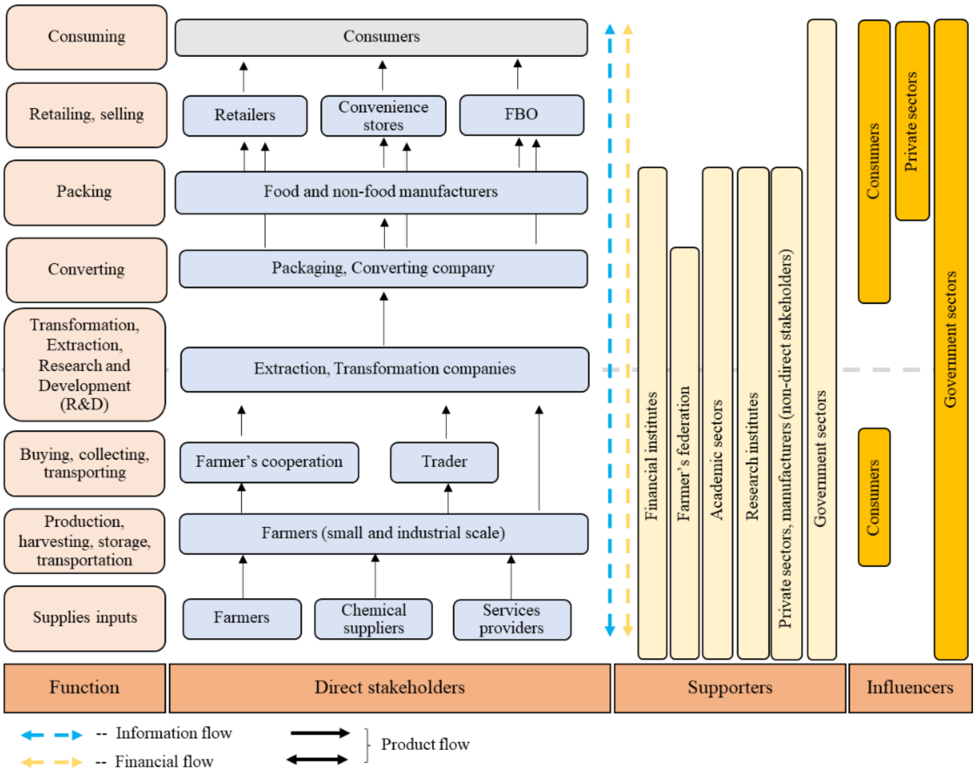

Figure 16 Value chain map illustrating the flow of utilization of banana by-products into bioplastics and food packaging industries (by author).

As seen in the value chain map, there were eight identified function stages (shown in light orange in Figure 16) throughout the chain, with direct stakeholders, supporters, and influencers placed accordingly to their activities or stage of involvement. Since an actual connection between banana cultivation and bioplastics is yet to be discovered, there is a grey dashed line dividing the boundary between the banana cultivation value chain and the bioplastics value chain. There are three main flows identified in this system, illustrated with broken and solid arrow lines in the diagram. The first is the flow of the physical form of materials and products (shown in solid arrow lines). The flow can either move in a downstream direction from producers towards consumers or as a transfer of material within the same function stages between research institute, academic sector, and material transformation companies. The second and third flow refer to the flow of movement of financial transaction and information as colored in yellow and blue respectively. Both are moving in both upstream and downstream directions and this is applied throughout the value chain map. As the banana by-products or manufactured products was moved towards the downstream, the money and information was also delivered back to the upstream side. However, there are also cases such as farmers paying the researchers or manufacturers for plant's strain development or manufacturers conducting a focus group testing on the new developed product, where the attended consumers may receive incentives and the company gets the information. The transfer can occur within the same, between one or more pre- and post-stage functions.

The first four stages of the value chain map have revealed the direct stakeholders involved in banana cultivation value chain to answer for RQ1 which are the supply and service providers, farmers, traders, farmer's cooperation, and extraction and transformation manufacturers. This part also addresses to RQ2 - What are the by-products obtained from banana cultivation and how are they handled? With a transition point at "Transformation, Extraction, and Research & Development (R&D)", this could establish the connection between banana cultivation value chain with the bioplastics value chain. Followed by the remaining four stages until consuming functions, these stages thereby address RQ3 - How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?

4.1.1 Supplies input

The supplies input stage covers all the necessary materials needed for pre- and post-harvesting activities like soil plowing to prepare for the new banana cultivation or new plants as a crop rotation, weeds removal, and the cultivation of banana for fruits and other products like leaves, trunks, buds, etc. To start a banana farm, the farmers have to purchase banana shoots from other banana farms or digging up the shoots from existing banana trees (Souseng V., personal communication, 4 March 2021). More details of the shoots supply will be mentioned in 4.1.2.

4.1.2 Production, Harvesting, Storage, and Transportation

It takes approximately one year for the banana to complete the cultivation cycle from planting to harvesting of the fruits (Mohapatra et al., 2010; Padam et al., 2014). By the second to the third month of cultivation, trimming damaged and old yellowish color leaves and small new shoots processes takes place. The trim helps prevent the competition over nutrients between main plant and its shoots. The cut leaves and shoots are usually left on site to decompose without any further uses, while some farmers collect them in a compost bin and use them as raw material for making organic fertilizer. The shoots of a selected plant that are considered to be a good strain will be dug out and planted as a new banana tree in a farmer's own land or sold to others as a seedling.

In the flowering and fruiting phases, farmers usually allow 5-6 hands of flowers to develop into fruits while the rest including male bud are removed. Only some strains like *Pisang awak* banana have buds that are tasteless and have less wax. It can be used as raw material for food and beverages, or as a dish decoration. As for other types of banana, the buds have a bitter and astringent taste and are fibrous in texture, which is not preferable to be consumed and thus are discarded in the field.

In the harvesting period, farmers usually hire workers on a daily basis to help with collecting of the fruits and cutting down the plants. Only a small portion of leaves is used as a protective layer in the plastic crates during the packing of bananas. The harvested fruits are still unripe and green, meaning that it will take around two more weeks before they are ready to be consumed. The remaining unsold bananas will be sold to a local market through the farmer's contact or by selling themselves. For the other unwanted parts obtained from all activities mentioned in this stage, these also get treated with the same manner as mentioned earlier; some farmers just leave the whole cut trees on site and let it decay over time, while some farmers remove the leaves and use the trunk parts to mix with rice bran as animal feeds, fermenting them into organic fertilizers, or processing them into charcoal (Souseng V., personal communication, 4 March 2021; Ann, personal communication, 10 March 2021; Srasamang J., personal communication, 4 March 2021).

On the other hand, *Musa balbisiana* is a special type of banana whose fruit is not consumed by Thai people, due to its seeds and the bitter taste. Mr.Thanakorn Sodsai said during his interview on 27 March 2021 that this type of banana is commonly used for its trunk and leaves, traditionally used in ceremonial, spiritual, and ritual occasions because the leaf has high flexibility, and the trunk is tasteless. Farmers usually harvest the leaves and compile these into bundles and sell them to the market. Trunk parts are occasionally used for ritual ceremonies like weddings, ordination, or alms offering, and some are transformed into fibers for making rope. The rest end up as waste with no further use.

To summarize, the banana cultivation cycle takes around nine months to one year period with routine caring activities. Harvesting of the fruits is usually done by farmers, but there are cases where the customers or farmer's cooperatives do the job, depending on the contracts. This stage could address RQ2 regarding the by-products of the banana plant after the fruit is harvested. The rest of the whole plant consisting of rhizomes, trunks, leaves, and buds are all considered as by-products or wastes. Some of the by-products mentioned were used for consumption, wrapping things, animal feeds, fertilizers, or religious ceremonies. Most of the by-products were discarded on-site as there is no intended use.

4.1.3 **Buying, Colleting, and Transporting**

The activities in this stage are usually performed by traders who purchase products from the farm and resell them to the desired customers or a farmer's cooperative established by a group of farmers. However, there are some cases where the farmers have signed a contract with a company or a farmer's cooperative to solely sell the whole fruits produced in the addressed area to them. Those parties are the ones responsible for harvesting and transporting the products, although cutting down the trees is under the farmer's responsibility. While on the other side, farmers can also sell their products to a cooperative. By doing this, it benefits the members as there is stronger negotiation power with the customers and there are better chances of contacting government sectors as a group compared to as individuals. The cooperative can help in bridging farmers to government sectors for support and information, as well as to broaden the customer's connections (Ann, personal communication, 10 March 2021; Srasamang J., personal communication, 4 March 2021).

4.1.4 **Transformation, Extraction, and Research & Development (R&D)**

This stage is a transition phase where the banana cultivation value chain and bioplastics value chain could potentially be connected. The main stakeholders are the manufacturers who performed extraction, transformation, and R&D activities. Academic sectors and research institutes also play an important role in this stage, but more of a supportive role which will be discussed later in the supporting part. The practice of utilizing the by-products from banana cultivation into the bioplastic industry, and the legislation to support the commercialization – does not yet exist in Thailand. However, due to increasing demand for reduced production cost and more sustainable solutions, there has been significant research done in the field of bio-based and bioplastic products in Thailand. Based on Table 5, there are many substances that can be extracted from different banana by-product parts which can be used in both food and non-food applications. As this study aimed to explore the utilization of banana by-products for bioplastics production, the main focus could be on the extraction of cellulose from pseudostem and leaf sheaths for bioplastic films application as in the study of Faradilla et al (2018). In addition, the organic acids and ethanol obtained from microbial activities and fermentation could potentially be used for PLA and PBS production Ingale et al (2014). The raw materials could be obtained directly from farmers or with the support from suppliers, academic partners, and research institutes Liwthaisong (2013) and Singanusong et al (2014), while some of the manufacturers also perform R&D activities on their own. The activities performed by manufacturers are similar to the academic and research institutes, but more focus is placed on the business development side, and rely on the customer's requirements like cost reduction, less material use, upcycling of production wastes, etc. However, the current activities performed in the bioplastics value chain were based on the theme and trend of the national development plan, which currently focuses on the PLA-based material from the fermentation processes of sugarcane or cassava (Weerathaworn, 2019).

As mentioned earlier, this is the transition point between the two value chains. The first part revealed the relationships in the banana cultivation value chain from the upstream between farmers, suppliers, and their clients to the mid-stream level of extractor, and transformer companies. Furthermore, this stage could be the connecting point to a downstream side in the existing bioplastics value chain. However, it should be noted that there is no evidence to support the existence of such banana by-products activities on a commercial scale. Also, if banana by-products were to be developed into useable raw material for the bioplastic industry, involvement of academics, institutes, potential manufacturers like extractors and resin producers will be necessary. Moreover, governmental support will most probably also be required.

4.1.5 **Converting**

From this stage onwards, the discussion will be related to the bioplastics value chain based on existing feedstocks such as sugarcane and cassava. As aforementioned, the usage of cellulose from banana by-products in bioplastic film production is only presented in lab-scale experiments. It is yet to exist in reality (Faradilla et al., 2018; Singanusong et al., 2014). Therefore, from this stage onwards, the discussion is presented only a proposal or a hypothetical continuation of the earlier stages involving the banana by-products value chain, using what we know from value chains of existing bioplastic feedstocks.

At the conversion step, the main stakeholders in this stage are the packaging and converting companies who transform monomers and resins obtained from extractor or transformer companies into compounds by blending the pure resins with other materials and additives to achieve desirable properties of the final product. According to an interview on 22 February 2021, respondent BM from a plastic resin manufacturing company, has given an example of the relationship between his company and the converter company, which is his client. The supplied resins could either be purely used without the presence of any other additives or will be mixed into compounds with additives like plasticizers to enhance the flexibility and temperature resistance property. In addition, based on the secondary research, there are possibilities that cellulose can be applied for plastic films or for food packaging applications to increase bulk property and reduce cost (Yaradoddi et al., 2020; Kamthai S., personal communication, 23 March 2021).

The resin or compound materials are then formed into a flatted sheet of bioplastics using heat. The sheet is handled using different processes depending on the expected final product. Thermoforming is for trays production, hot extrusion is for straws, blow molding is for bags, and injection molding is used for utensils and other solid piece products. The formed products are distributed to the food and non-food manufacturers to serve as a package for their products, or in the form of single-use packages such as straws, utensils, and bags. They may be directly passed on to the retail and selling stage.

4.1.6 **Packing**

This stage relates to the food manufacturer level and existing packaging. The packages received are not only used for packing of finished products but also used in intermediate activities in the production line. Examples include bags for transferring between areas, storing of samples for quality checking, storage as bulk pack before transferring to individual pack, or sealing of package as a form of film seal. The common requirements on packing of food products are good moisture and gas barrier, resistance to high and low temperature from cooking and freezing processes, rigid enough to protect the food content during storage and transportation, transparent to reveal products inside, or opaque to prevent light transmission. The packed products are then distributed to distribution centers and designated selling points across the country using truck as a main mode of transportation under ambient, chilled, or frozen storage conditions (Respondent FM1, personal communication, 23 February 2021; Respondent FM2, personal communication, 1 March 2021).

4.1.7 **Retailing, Selling**

At the retailer's level, there are various types of products and are handled differently depending on the respective scenario. For the packed food products from food manufacturers, these are usually presented in supermarkets and convenience stores where the products are either displayed on the shelf in a form of tray or box in ambient, chilled, or frozen conditions, depending on the content inside the package. While the single-use products from converters that do not contain any food products at the point-of-sell like straws, cutlery, and utensils are available in a packed package as well. This also applies to the case for Food Business Operators (FBO) where they may display some of the packed products on shelves. However, they mostly buy single-use plastics or bioplastics to serve to the consumers or to pack foods as takeaway or delivery services.

Due to the policy of plastic banning in the country, every modern trade channel like supermarkets, hypermarkets, or minimarts are implementing a no-bag policy wherein the customers have to bring their own bags or pay for the bag, as opposed to receiving it for free (Thammasujarit, 2020). This also applies to convenience stores where they have changed from conventional plastics bags to compostable bags. The stores will now always ask customers whether they need a plastic bag or not for every purchase (TNN, 2020). FBOs are adapting to the policy and trend of sustainability as well; many businesses especially beverages have changed their packaging such as cups from PET to PLA, or they use paper or compostable straws instead of conventional ones (Prachachat, 2019).

4.1.8 Consuming

The consumption stage's main stakeholder is the end consumers, where they purchase the products or packages from point of sale. In recent years, with the ongoing trends of sustainability and climate change issues, consumers have become more active and more concerned on their individual actions that could impact the environment. This has been reflected in the wider variety of environmentally friendly products available on the retailer's shelves. The food and packaging manufacturers also stated that they have received many requests from their clients tasking for a sustainable packaging solution (Respondent BM, personal communication, 22 February 2021; Respondent FM1, personal communication, 23 February 2021; Respondent FM2, personal communication, 1 March 2021). Once the consumers are done using the package, the package would enter the post-consumer stage which is beyond the scope of this study.

To summarize, in this first part of the discussion, the first four stages in Figure 16, from 4.1.1 to 4.1.4 illustrated the relationship between stakeholders in banana cultivation value chain addressing to RQ1 and thereby address RQ2 about the by-products obtained from the cultivation steps. Apart from the fruit being harvested and sold for consumption, only a small portion of the banana plant parts goes towards traditional utilization e.g., food and food wraps, usage in religious activities, compost for fertilizers, and animal feeds as stated in Table 5. The rest of the wastes are unused and discarded to landfill. There are also attempts in R&D to utilize and add value to the banana by-products in bioplastics and other applications, as in the study of Faradilla et al (2018), Ingale et al (2014), Liwthaisong (2013), and Singanusong et al (2014). There is no evidence to claim that banana by-products are being used in bioplastic production on a commercial level. The stage 4.1.4 could be a transition point in connecting the banana cultivation value chain to the following four stages of the bioplastics value chain. The later parts of the value chain map illustrated the relationships among the stakeholders in bioplastics value chain in the context of existing bio-based feedstock like sugarcane and cassava. However, the information obtained could answer RQ3. Even though the utilization of banana by-products does not happen in reality yet, interviews and secondary research support the view that the raw materials for bioplastic production such as sugars and cellulose are also presented in banana by-products. Moreover, by utilizing the wastes, it could provide certain benefits in terms of cost-efficiency and sustainability. The raw materials previously considered as valueless could potentially reduce the competition over consumable source of materials.

The previous part has discussed the main stakeholders identified in the map. However, there are also groups of supporters and influencers that could potentially be involved in the banana cultivation value chain and bioplastics value chain, as shown on the right part of Figure 16. This will be discussed in the following section.

4.1.9 **Supporters**

Supporters are the ones who provide direct or indirect help to the stakeholders. In this study, six identified supporters which are financial institutes, farmer's federation, academic sectors and researchers, research institutes, government sectors, and private sectors and manufacturers (non-direct stakeholders) could contribute to creating a value chain for banana by-products if decided of interest are as below.

4.1.9.1 Financial institutes

Farming is considered to be an informal job which is not required to pay income taxes. Thus, the majority of the farmers have a limited access to the welfare provided by the government, which is not sufficient and still live at the most bottom of the poverty line (NESDC, 2019). This also connected to other factors like the lack of education, not owning any assets, having huge debt, and having a lot of expenses. It has been passed on from generation to generation.

The financial institutes serve the role of financial supporter as well as an advisor on financial management to the farmers. The Bank for Agriculture and Agricultural Cooperatives (BAAC) is a special financial institute established to support agricultural related businesses. They provide loan services for farmers to start their cultivation. After the crops have been harvested, the money must be returned to the bank with a low rate of interest (BAAC, 2019). Other financial institutes provide credits and loans for small and medium businesses with support from the government as guarantor for the loan (FPO, 2020).

4.1.9.2 Farmer's federation

This is an organization that is under the direct supervision of Thailand's Office of the Prime Minister (OPM). The members of the farmer's federation are representatives of the farmer communities from all over the country, working voluntarily to advise, educate, and bridging the gap between farmers and government sectors. They also provide consultancy services as well as information related to farmers and agriculture to the government. The foundation's main role is to gather all the problems and requests of the farmers; the selected issues based on the severity and urgency are then presented to the OPM and forwarded to the council meetings where the issues raised will be discussed for proper action and possible solution, then assigned to the responsible person. Once the action plan is set up, one or several ministries may be assigned a role according to the type of problem (National farmers council, 2017).

Apart from gathering and proposing problems to the council, the federation also seeks help in alternative ways like connecting farmers to manufacturers and academic researchers to work together on solving the farmer's problems through the form of research, experiments, or introducing potential suppliers and buyers (Macharoenrungreung S., personal communication, 16 February 2021).

4.1.9.3 Academic sectors and researchers

Researchers and academic institutes take part in supporting the farmer and manufacturer levels by conducting research to develop new product designs and innovations, to improve the productivity and production yield, and to offer education and training programs. A request is made by the producers as farmers and manufacturers who need academic support in research and development to solve their problems. Ms.Jintana Srasamang from a farmer's cooperative mentioned during the interview on 4 March 2021 that she once contacted the university for help in cultivating the plant tissue of a new banana strain with high production yield. Another case is explained by Assoc. Prof. Amporn Sanae (personal communication, 1 March 2021) where the university is contacted by packaging manufacturers seeking support in research and development of new materials. This can result in two scenarios depending on the agreement made between the academic institute and the investor. In case the investor fully funded the research project, such person or firm can have the ownership of the findings and claim this for their assets. On the other hand, if the project is a joint funding between the two parties, the research knowledge will be under the ownership of the academic research, while the investor, despite the benefits obtained from the knowledge discovered, can also benefit from governmental enablement such as tax reduction policies.

Another approach takes the form of a request made by the government, asking for support from academic institutes in solving problems or requests made by the producers. An example given is about a pest and disease problem in sugarcane raised by the farmer's federation, where the government decided to solve the problem by assigning the Ministry of Agriculture and Cooperatives (MOAC) to be responsible for this task. The ministry then contacted the academic institute for assistance in solving the problems. As a result, the researchers together with a representative from the MOAC performed a site visit to conducted a study, and finally solved the problem (Macharoenrungreung S., personal communication, 16 February 2021; Souseng V., personal communication, 4 March 2021).

4.1.9.4 Research institutes

The research institutes perform a supportive role for farmers, manufacturers, and government as examples given in the previous parts. Moreover, with an interview on 5 March 2021 with Mr.Sataporn Spanuchart and Mr.Thanaphong Lertpiriyasakulkit from the data analytic department of Plastics Institute of Thailand (PIT), one of the research institutes under the supervision of the Ministry of Industry that plays important role in the plastics value chain. There are six main tasks performed by the institute listed as follows:

1. *Information database* - Provide a database of market studies and data analyses on both domestic and international levels. The reported information is to support industrial management and to help develop suggestions for policymakers.
2. *Design and development of solutions* - Starting from the fundamental background and consulting services for new businesses through the design and development of prototypes both virtually and physically. In addition, they also experiment on new compound materials according to a customer's requirements.
3. *Manufacturing development* - Provide business and management consulting services such as management of cost, material flow and management, and manufacturing best practices. This also involves giving suggestions to help in connecting the right investors to the right solution providers.
4. *Material testing and analysis* - A services on material properties according to the certified testing standards. However, the institute only provides the results according to the test. To certify materials and products, the manufacturers have to contact the Thai Industrial Standard Institute (TISI) for the certification of the materials and packaging, or the Thai Food and Drug Administration (Thai FDA) for food-contact material or uses as packaging for food stuff certifications.
5. *Training courses* – Courses for plastics manufacturers and academic partners on machine utilization and demonstration of new machines presented by suppliers.
6. *Sustainability programs* - Public-Private Partnership for Sustainable Plastic and Waste Management (PPP Plastic), a collaboration between the institute, government, and private sectors.

According to the websites of other research institutes such as National Metal and Materials Technology Center (MTEC), National Center for Genetic Engineering and Biotechnology (BIOTEC), and other institutes under the supervision of Ministry of Higher Education, Science, Research and Innovation (MHESRI), there exist similar supportive roles related to research and development of packaging materials and design.

4.1.9.5 Government sectors

The government together with research institutes provides both direct and indirect supports to the identified stakeholders. Generally, at upstream side, the registered farmers in the government's system will receive many direct benefits such as crops insurance at approximately 30% of the estimated product price for the damaged crops from natural disasters, gain access to the supportive programs and equipment provided by the government, get an invitation to training courses, exhibitions, fairs, and study trips. It aims to generate knowledge sharing among the members. Moreover, the government also supports the sales of crops and agricultural products with the help of the Ministry of Commerce (MOC) (Souseng V., personal communication, 4 March 2021; Srasamang J., personal communication, 4 March 2021).

In terms of research supports and funding for academic and research institutes, it depends on the themes of the development for each year and each government team. Assoc. Prof. Amporn Sanae (personal communication, 1 March 2021) mentioned that the funds are distributed to the ministries and research institutes according to the planned strategy. An example of support can be referred to the policy of driving Thailand's bioplastic industry by increasing the PLA production from cassava performance as mentioned earlier. The first phase between 2008-2010 focused on improving the supply performance of cassava production along with education and raising awareness about bioplastics and sustainability throughout the value chain with a budget of 300 million Baht (7.98 million euro). The second phase continued from 2011-2015 and concentrated on the development of technology and innovation, together with an establishment of new production facilities. The new facilities were anticipated to increase the competitive performance and promote the utilization of sugarcane as an alternative source of raw materials under the budget of 1,000 million Baht (26.67 million euro) (NIA, 2010). Therefore, the research topics related to the development of these interests are easily being funded.

For the manufacturing level, the government support has drawn strategic plans and policies to support the activities of manufacturers involved in the bioplastic industry. Referring to the bioplastic industry development plan from NIA (2010), there are many policies launched to support the production and utilization of bioplastic materials and promote the growth of bioplastic-related businesses such as tax reduction on import and purchase of bioplastics materials, policies to give benefits to investors who invest in the bioplastic industry, and establishment of legislations and testing centers to support the commercialization of bioplastics in the country.

The government has provided support to all stakeholders in every stages through direct support via local governance, or policies and strategies to drive the country forward. However, it should also be noted that the current focus of the government is to promote the PLA production using sugarcane and cassava as the main feedstock, and that the use of banana by-products is not part of the current approach.

4.1.9.6 Private sectors and manufacturers (non-direct stakeholders)

The private sector and manufacturers can be presented in the form of suppliers, customers, partners, or investors of the value chain's stakeholders. However, these groups of supporters are not considered as direct stakeholder as they are not directly involved within the value flow of bananas or bioplastics. The support can be in the form of training courses provided to the food manufacturers by the converter about new packaging materials and techniques, presenting and demonstration of new products and technologies by the fertilizer company including free trial or sample offered to the farmers, introducing trends and innovations by the suppliers to their clients. Support may include funding and participating in the research and development projects between private sectors and academics, research institutes, or among two companies working together to achieve their goal benefits (Kamthai S., personal communication, 23 March 2021; Spanuchart S. and Lertpiriyasakulkit T., personal communication, 5 March 2021).

Another form of support is in a form of Corporate Social Responsibility (CSR) which mainly provides financial and human capital to the upstream part of the value chain in alleviating poverty of the farmers. Many private companies use CSR activities for marketing purposes, but they also gain benefits like tax reduction through CSR activities such as donations and providing services or establishment of facilities for public use (Mongkolvanich, 2016).

4.1.10 **Influencers**

The influencers are the agents with the potential to drive or create a shift in the trends. They are different from the supporters as they do not provide support to the stakeholders, but create an influence that could impact the value chain instead. In this report, consumers, government sectors, and private sectors were the identified influencers that have the potential to influence the banana by-products and bioplastic value chain.

4.1.10.1 Consumers

Although the consumers have been identified as one of the main stakeholders who participate in the consuming part of the value chain map. However, they also have influences on other parts of the value chain apart from consuming or using the packages. All the interviewees have mentioned that consumers play a very important role in influencing market demand. Farmers want to produce and sell everything that consumers need and are willing to buy. On the farmer's and cooperative's side who are dealing with fresh bananas and raw by-products, the consumers influence the popularity of banana cultivation. During the interview on 4 March 2021, Mr.Veera Souseng, an interviewee who worked as a banana farmer, said that there is a continuous increased in the demand for banana consumption annually. The growing demand has pushed the farmers to grow more banana trees and to improve their productivity.

The same concepts are also applied to the food and packaging manufacturers as well as retailers in the case that consumers became more aware of the climate change crisis and the need for more sustainable solutions. These concepts drive an increase in the demand for eco-friendly solutions. The interviewee from the food manufacturing sector mentioned that they have received many requests from customers asking for a sustainable or biodegradable packaging solution to serve the demand of end-consumers (Respondent FM1, personal communication, 23 February 2021).

4.1.10.2 Government sectors

The government, together with research institutes, plays an important role in determining the direction to move the country forward. The institutes and government staffs are the ones who gather all information, perform analysis, and pass on suggestions to the council. The council then determines the information and develops the policy. The influence from government sectors was generally from the strategies and policies published. This has a significant influence on all stakeholders as it can permit or prohibit their business activities. One good example that can visualize the impact of influence from the government sector on the upstream side is as followed. A new sugar tax since 2017 has caused a decline in sugar demand from the beverage industry. Therefore, many farmers have shifted from sugarcane cultivation to other alternative crops such as corn and cassava (Macharoenrungreung S., personal communication, 16 February 2021). While on the downstream side, due to the policy of plastics banning, the retailers, as well as food and packaging manufacturers were forced to shift from utilizing conventional plastics to an alternative bio-based solution. From this policy, it provides an opportunity for business in the field of bioplastics and eco-friendly packaging to substitute their products for the conventional single-use plastics. On the other side, from the perspective of conventional plastics manufacturers, it is a huge loss for them. From the analytic report by the Thai Military Bank (TMB), approximately 400 plastics producers were disadvantaged due to the plastics banning policy. Moreover, 250 of those producers were in small and medium-sized enterprises (SME) which do not have the flexibility in adapting to the changes in the policy (Prachachat, 2020). In addition, this also has impacted the lifestyles of consumers as they have used more reusable cloth bags and have become more aware of sustainable approaches (Vassanadumrongdee et al., 2020).

4.1.10.3 Private sectors

This addressed to all private sectors in general, the sustainability campaigns and CSR programs do not only benefit the companies, but they also change the attitude of the employees which later can spread the environmental awareness to society. Respondent FM1 (personal communication, 23 February 2021) and Respondent FM2 (personal communication, 1 March 2021) mentioned that both of their companies and others have implemented waste sorting systems and installed a composting facility to change the habit of their employees, and that a similar concept also exists in many other companies.

To summarize, in this section (4.1 value chain map), Figure 16 maps the value chain answering the RQ1-3 that was based on the information gathered during the period of study from February until May 2021. Sections 4.1.1 to 4.1.8 explained the identified flow of banana by-products that can be potentially linked to the bioplastic industry, including the activities performed by each stakeholder at different stages. There were eight function stages together with direct stakeholders, supporters, and influencers identified as shown in the figure. Apart from the small portion of banana trunks and leaves of specific strains of banana that goes towards traditional utilization, e.g., food and food wraps, religious activities, and animal feeds, the rests of the wastes were unused and discarded to landfill. In section 4.1.9 and 4.1.10, the government sector together with other identified players play an important role in supporting and influencing throughout the idea of using banana by-products for bioplastic industry and initiating an evaluation of its feasibility. Even though, there is no evidence that banana by-products have crossed over for utilization in the bioplastic industry, at least not beyond preliminary research activity. However, the stage of extraction, transformation, and R&D could be a connecting point to link between the value chain of banana cultivation and bioplastics. Moreover, by looking into examples shown in Figure 7 of how other biomass feedstock like cassava and sugarcane have been used, we can have some references of how to potentially introduce banana waste into the bioplastic value chain.

4.2 DEFT Analysis

In this part, DEFT analysis is used to address RQ4. The collected information for this study came from in-depth interviews with potential stakeholders from the value chains of banana by-products and bioplastics, as well as from the secondary research from various sources including research journals and government reports. A summary of the DEFT analysis and the identified points are visualized in Table 8.

Table 8 Summary of DEFT Analysis

DEFT	***Factors***	***Details***
Drivers	Government	Supportive policies and legislations in utilizing bio-based and bioplastic products. Offered education and training programs.
	Producers	Higher production leads to higher by-products generation. Demand for solutions in by-products utilization. Act in response to government policy and consumer's demand
Enablers	Consumers	Trend of sustainability. Demand for sustainable solutions and alternative bio-based options.
	Raw materials	Insufficient current biomass feedstock. Reduction of current biomass feedstock production. Increase in banana production and cultivation. Utilization of waste instead of potential food source.
Frictions	Government	Lack of supportive legislation. Limited access to proper support from the government sectors. Limited access to proper education and training
	Raw materials	Uncertain supply of raw materials. Cost competition over conventional and major group of bio-based materials due to complexity in processing. Limitations related to material properties and applications. Alternative applications of banana by-products (i.e., not bioplastic production)
	Technology	Lack of access to technology
Turners	-	-

4.2.1 Drivers

There are two main drivers in the feasibility of utilizing banana by-products for the bioplastic industry. The first enabling force is from the government sectors. This can be divided into three points, strategy, policy, and legislation. Regarding the strategy, like other countries, the Thai government has pledged to the UN Committee on achieving the UN-SDGs by using the 20-year National Strategy as a framework in directing the country (United Nations, 2017). This is reflected in the fifth strategy of eco-friendly development and growth, apart from the conservation of resources, promoting climate-friendly growth, and sustainable growth of society. There are many components that could promote the feasibility of value-adding activities to agricultural wastes. One of the goals written in the strategic plan is to promote a bio-based economy and the development of environmental-friendly infrastructure of both private and public sectors (NSCR, 2019). This strategy has led to the development of many projects and programs such as support for research and development projects related to the green economy. The main policy that could be a potential driving force is the policy of banning conventional plastic bags, which has been applied to all supermarkets, retail stores, and convenience stores since the beginning of 2020 (Thammasujarit, 2020). The banning of single-use plastic straws, bags, cups, styrofoam boxes, and microplastic beads is expected to be implemented on a national level by the end of 2022 (Pimthong, 2020). The other policy is the offer of a 125% tax reduction for the manufacturers for the utilization of biodegradable plastic packaging starting from 2019 until the end of 2021 (Sidarn, 2019; Thansettakij, 2019). Furthermore, the government also helps in the development of the grassroots economy level, where it offers an opportunity for investors to help in increasing the performance of rural businesses and organizations. In return, the investors can gain benefits from tax reduction or exemption (Plastics Intelligence Unit, n.d.; Sanae, personal communication, 1 March 2021).

The second driver is the push from the producers (farmers and plastics resin and packaging manufacturers). Banana is a fruit-bearing plant that gives high profits when compared to durian, mango, and other fruits in terms of cultivation and resources required. With continuous growth in the demand of banana consumption, it has pushed the farmers to cultivate more trees and improve the growing productivity and quality (Souseng V., personal communication, 4 March 2021). Furthermore, the consequence of government legislation can indirectly enhance the production of bananas. From the land and building tax act, effective in January 2020, it has pushed landowners to turn their vacant land into agricultural farming in order to avoid paying the higher tax rates. Banana is one of the most popular plants that Thai people choose to grow due to the fact that it is easy to grow, does not require special care, and produces edible and marketable fruits (Ministry of Finance and Ministry of Interior, 2020). With an expected increasing demand and production of bananas, this means that there will be more by-products generated, which could be a potential alternative source of raw materials for bioplastics production.

Another factor is due to the economic and financial issues of the farmers: more than 50% of farmer families in Thailand have household debt and are living under poverty (Chanrat et al., 2020). An insight from the farmer’s cooperative and representative mentioned that the farmers are willing to do anything that they could to earn extra income and they are seeking an opportunity to add value to their products and wastes. It is a concern that is often brought up during conferences (Macharoenrungreung S., personal communication, 16 February 2021).

On the other side, the packaging and food manufacturers are trying to act in response to the National Strategy and global trends of sustainability by changing their packaging into a more sustainable alternatives such as using paper or bioplastics instead of conventional plastics, or by reducing material use. They also take action in response to consumer’s demand for sustainable or biodegradable packaging solutions from the end-consumers (Respondent FM1, personal communication, 23 February 2021). Moreover, the academic sectors have revealed that many manufacturers have contacted them for joint research and development of new packing solutions from bio-based or bioplastics. It is believed that manufacturers might have developed several new products which are still waiting for the enforcement of the legislation in commercializing products making from new bioplastic materials into the market (Kamthai S., personal communication, 23 March 2021).

There are two drivers identified. The first driver is the government factor; through the government policies and strategies that support and promote the usage of sustainable and bio-based resources such as tax deduction and those that prohibit the use of single-use conventional plastics. Another factor is the pushing forces from the farmers and manufacturers involved in banana cultivation and bioplastics supply chains. The rising in demand of banana consumption is expected to lead to higher numbers of banana cultivation, thus increasing of by-products generated. The farmers were seeking a way to earn more income and value-added to their products; therefore, by-products is one of the options. The packaging manufacturers are also working on sustainable packaging solutions in response to government strategies and consumer demand.

4.2.2 Enablers

From the information obtained, there are many factors that can support the feasibility of utilizing by-products from banana cultivation. First is the enabling force from the growing consumers' demand for sustainable solutions, as well as higher consumption of bananas leading to higher volume of by-products or waste generation. This is somehow linked to the initiations of the government, thus creating the trend of sustainable solutions and plastic alternatives from bio-based sources. Nowadays, people are becoming more aware of the climate change crisis and are more concerned about the negative impacts of their actions on the environment. Together with the global movement towards more environmentally friendly practices, consumers are now looking for alternative options to plastic and might be prepared to pay an additional cost of up to 30% if the product offers a sustainable value (Spanuchart S. and Lertpiriyasakulkit T., personal communication, 5 March 2021). Due to this increasing demand for bioplastics, European bioplastics (2020) predicted that the global production capacity of bioplastics would increase almost 150% in the next five years. This information was supported by the interviews from both the bioplastic resin manufacturer and researchers - the demand for bio-based and bioplastic products is increasing constantly, through the requests of retailer stores asking for a more sustainable packaging solution, and not only with PLA-based products but also from other bio-based sources (Respondent BM, personal communication, 22 February 2021; Sanae A., personal communication, 1 March 2021).

The second enabler is from the raw material perspective, which is the banana by-products. According to European bioplastics (2020) the supply of bioplastic material is still insufficient comparing to the demand on a global scale. Bioplastic manufacturers in different regions are trying to scale up and increase their production capacity to reach 2.87 million tonnes by 2025. Plus, the banning of plastics policies in many countries accelerates the rise in demand even more (Goldsberry, 2020). However, climate change plays a big role in the decline of the production rate of raw materials. In the case of Thailand, the potential biomass feedstock like cassava and sugarcane are the main source of raw materials in PLA production. According to climate forecast during 2046-2055, the production amount of cassava, as well as the harvested area, are predicted to be reduced by 12.49–16.05%, resulting in the reduction of cassava production in Thailand by approximately 14.74–21.26% from the baseline. About a half-million cassava farmers and those who take part in the cassava global supply chain will be directly affected by climate change (Pipitpukdee et al., 2020; Prasertsri and Chanikornpradit, 2019). With the mismatched supply-demand balance, cellulosic materials are expected to be a potential alternative source of bio-based feedstock for bioplastics production as they can be broken down into fermentable sugars - but this requires more complex extraction and conversion processes compared to the conventional ones (Coppola et al., 2021).

Apart from the insufficient supply of bio-based feedstock, there is also competition over the current biomass feedstock like sugarcane and cassava, due to an ongoing crisis of food shortage affecting more than three billion people in the world. The current major bioplastics production like PLA is made from sugarcane and cassava which are considered to be a main source of carbohydrates. There is a concern on the competition over the agricultural land between bioplastics production and food-feed for consumption (Bioplastics guide, n.d.; Wilfred, 2017). It would be a better option to utilize valueless resources, such as waste materials, instead of using the ones that is consumable as food, to address this concern of raw materials sourcing. Coppola et al., (2021) mentioned lignocellulosic material as a promising alternative source of biomass for bioplastic production, which many manufacturers are focusing on to avoid the food crops conflicts. From Table 3, banana could be an interesting alternative choice due to its cellulose content.

To summarize, in this section, two major enabling factors that were presented could support the feasibility of utilizing banana by-products for bioplastics production. The first one comes from the consumer’s response to the trend of sustainability and the driving demand for alternative solutions from bio-based and bioplastic. While raw material is considered as the second enabler. This is due to the current mismatch in demand and supply of biomass feedstock for bioplastics production, with the forecast of declining sugarcane and cassava productivity. In addition, there are concerns about the competition over the raw materials to use as food for consumption or other applications. Cellulosic-derived biomass could be a potential candidate as alternative feedstock options, because it is available in large quantity, derived from waste which is valueless and does not affect the food supply.

4.2.3 Frictions

There are many identified factors that can delay the feasibility of utilizing banana by-products in bioplastic applications. Even though the government policies and strategies are considered as the main driver as mentioned earlier, these could still prove to be insufficient. The lack of proper supportive legislation is the first identified friction that prevents the feasibility of the approach. Similar to other countries, Thailand has its own standards for bioplastic materials and products. Based on the current database of TISI as shown in Table 9, there are six standards of bioplastic products allowed in the Thai market.

Table 9 Standards for bioplastic products in packaging industry (TISI, 2020a, 2020b, 2020c, 2019, 2018, 2017)

Types of bioplastics	*Definition and applications*	*TIS no.*
Bioplastic bag	Compostable plastic bag for waste	TIS. 2793-2560
	Compostable plastic bags (non-food contact)	TIS. 2995-2562
	Biodegradable plastics nursery bags (seedling cultivation)	TIS. 2996-2562
Bioplastic film	Biodegradable plastics mulch films for agricultural use	TIS. 2997-2562
Bioplastic straw	Biodegradable, single use for food application	TIS. 2744-2559
Bioplastic packages and utensils	Single-use compostable plastic packages and utensils for food part 1 poly (lactic acid)	TIS. 2884 Book 1-2560

The list in Table 9 mainly addresses the products made from PLA or PLA-composite with PBS or Polybutylene Adipate Terephthalate (PBAT) materials which is safe for food-contact applications. However, these standards are still limited to a small group of materials, products, and applications and the work to develop new standards to cover a wider range needs to be done (Kamthai S., personal communication, 23 March 2021; Respondent FM2, personal communication, 1 March 2021; Spanuchart S. and Lertpiriyasakulkit T., personal communication, 5 March 2021).

In order to develop a new standard or claim of new materials, packaging, or packed products, it must follow the route as illustrated in Figure 17.

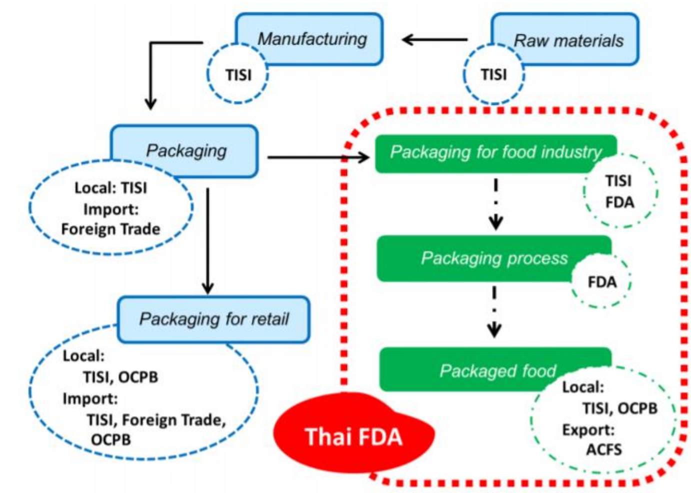

Figure 17 Workflow of legislation approval for new materials and packed foods and the responsible organizations in Thailand (Poovarodom, 2018).

In general, most of the approval for new materials and packages are done by TISI, as can be seen that it exists in almost every step of the flow. However, as for food for consumption products, the Thai FDA has an important role in this scope. However, when it comes to the topic of bioplastic materials certification, currently there is no assigned responsible organization to support and approve the commercialization of bioplastic materials for food-grade contact. From this barrier in legislation, the packaging manufacturers have pursued an alternative track of applying for the regulations of the most similar packaging materials such as plastics and paper, or they perform the tests and claims for the certifications abroad. For example, the PLA tray for fresh meat products or compostable cups and utensils referred to the regulation of food-contact grade plastics, and for bioplastics laminated cups and bowls made from sugarcane bagasse were referred to paper packaging regulations. Asst. Prof. Suthaphat mentioned that he has raised a concern regarding the lack of legislation for the commercialization of new bioplastic materials during a meeting with government representatives. Still, there is no response from any parties regarding the responsibility for the approval of the new bioplastic materials.

Even though there are many campaigns and programs provided by government sectors to help producers and manufacturers to run their businesses smoothly and gain access to the resources needed, it seems that there is limited accessibility to official supports. Mr. Ann, who is a banana farmer said in his interview on 10 March 2021 that he never receives any support or training offers from the government or municipality. He studied and learned about the cultivation of different crops and solving problems through experimenting by himself. Another case was from a group of farmers and cooperatives who explained that they have formed a group for some times and worked hard to gain a reputation before they were contacted and received support from the government sector. In the beginning, the group has asked for support from the government sector, but they received no response then. In some cases where there was a budget available for expensive equipment. The farmers have to form a group and register as a company in order to own such equipment and share it among the members (Souseng V., personal communication, 4 March 2021; Srasamang J., personal communication, 4 March 202). This will be a disadvantage for communities with poor collaborations among the members and those who have little to no access to connections for these forms of support. Moreover, with no proper support provided on the producer level, the chance of utilizing agriculture wastes is still far from being successful.

With insufficient support provided, this also led to limited access to proper knowledge in education and training. Referring to the value chain map, there are many approaches to educate different levels of stakeholders in the value chain. For example, the local municipality together with researchers, experts, or suppliers usually has on-site visits to educate or present new technologies that can improve or solve the problems of the farmers. On a provincial scale, the representative of the community or head of cooperatives is invited to join conferences where they can learn from experts and share knowledge with each other. This knowledge is later distributed by the representative during periodic meetings within each community. There are also product and packaging development programs such as *One Tumbon One Product* (OTOP), a program that promotes the locally unique products from each community in Thailand (Royal Thai Embassy, n.d.). The supports provided are still not accessible by everyone. According to an interview with many farmers and producers, they want to utilize their wastes in a more useful way. However, they only have agricultural knowledge such as production yield maximization, prevention of crops from pests and diseases, farming management, etc., and have little to no knowledge when it comes to processing or adding value to their products. Requests from farmers for suggestions and questions regarding value-added crops or by-products were often raised during the periodic meetings in the local community. Which in return, one of the common questions that was asked by the municipality or researchers back to the farmers was "What kind of improvements or value-adding initiatives do you prefer?" which in the end no one could answer, and the solution was postponed and left behind (Macharoenrungreung S., personal communication, 16 February 2021; Souseng V., personal communication, 4 March 2021).

The second friction is from the raw materials regarding the performance and limitations of the materials in the aspect of supply quantity, cost, properties, and applications. Both academic researchers and packaging manufacturers have mentioned the concern of insufficient raw material supply. Even though it is predicted to have at least 8 million tonnes of banana by-products generated annually in Thailand. However, this number can be converted to less than 3 million tonnes of cellulose-derived products, which is considered to be lower in production capacity compared to those derived from wood pulp. According to the interview with a university researcher and information analysts from PIT, they all agree that the current banana cultivation in the country is not likely to be sufficient to satisfy demands on a commercial scale. It also requires high logistics costs to timely transfer all the raw materials to one manufacturing plant as the main component of the plant is water (Subagyo and Chafidz, 2020). Moreover, by looking at the availability of feedstock supply, rice straw and corn cobs are more promising in terms of supply. From the statistics provided by the Department of Alternative Energy Development and Efficiency (DEDE), under the supervision of the Ministry of Energy, in 2013, the biomass generated from rice and corn plantation accounted for more than 27 and 10.5 million tonnes respectively (The Bangkok Insight, 2021a, 2021b). This makes by-products from rice and corn more attractive for utilization.

Even though biomass or cellulose from agricultural waste could be considered valueless. But the complexity in the current production process including the use of chemicals to achieve desirable final properties and limited production capability together, caused the price of bio-based and bioplastic products to be more expensive, compared to conventional plastics (WindMill, 2019). The existing attempts in using banana by-products were only done in a laboratory scale and utilizing banana by-products for bioplastics production by manufacturers is currently not yet being done. The main material that can be obtained from banana by-products is cellulose as it is the main component in trunks and leaves. Technically, from Figure 4, cellulose can be broken down into fermentable sugars and can be used as a raw material for bioplastics production such as PLA and PBS as an alternative to sugarcane or cassava. Even though cellulose extraction is not a novel method, extracting cellulose from bananas is more complicated than from other agricultural wastes. This is because the main component in banana's parts is water with a presence of natural waxes, extra processing steps in the removal of the waxes and other unwanted components including dehydration of moisture could lead to more expensive in the final price. A good example of friction from material's cost can be observed from the current Pandemic situation where the consumption habits have been highlighted up.

Thai consumers have the habit of using a lot of plastic bags and containers during grocery shopping, due to advantages in the properties, cost, and convenience. Ever since the government requested Thai people to work from home during the Covid-19 outspread, food delivery service has become even more popular throughout the country. Most of the restaurants deliver food with single-use plastic packages, resulting in highly increasing numbers of plastic waste. On a national level, the number was reported to increase by 15% during 2019-2020, while the number was raised by 60%, solely in the Bangkok area (Boonsrangsom, 2020). Furthermore, food businesses and consumers choose conventional plastics due to concerns about hygiene and transmission of disease. Mr.Sataporn and Mr.Thanaphong (personal communication, 5 March 2021) have said that hygiene is one major concern from consumers particularly during this time of the pandemic. The other factor is the cost, as more delivery services are used. The food businesses use packaging made from conventional plastic materials since the cost is much cheaper when compared with bioplastics or paper packaging. Even though the trends are moving towards sustainability, in the end, consumers and vendors always look for good quality and low-price options and it is difficult to change their perception. Therefore, the majority of the consumers will still choose price over sustainability. Mr.Sataporn and Mr.Thanaphong added that it is possible to shift the perception of consumers to the opposite side, but it takes time and effort from every stakeholder involved in the value chain to make it happen.

With the purpose of utilizing the banana by-products for bioplastics for food packaging, the physicochemical attributes of the materials and requirements from the products are also considered. The main features required by food products on the packaging are good moisture and gas barrier, good mechanical properties, and good temperature resistance (Coppola et al., 2021; Respondent FM1, personal communication, 23 February 2021). However, from a food producer's perspective, the performance of current bio-based and bioplastics solutions that can be used for commercial applications does not yet reach a satisfactory level that meets the requirements of the products to be packed. In addition, researchers have tried to utilize cellulose in plastic packaging but still far from being successful. Asst. Prof. Suthaphat Kamthai (personal communication, 23 March 2021), has researched and studied the extracting and value-adding of by-products from agricultural crops. According to his research on plastics bag composite with cellulose extracted from rice bran and corn cob, adding cellulose can improve heat stability and lower the production cost. But the drawbacks are that it is lower in flexibility and there is a loss of the material's transparency, which affects the production capability and is also not desirable by consumers. The maximum amount of cellulose suggested to be added to the mixture was no more than 8% or else the mix would be too viscous and cannot be blown-molded into a bag. Moreover, with different strains of bananas, these might have slight differences in the properties of the fibers or cellulose obtained, which could be an issue for quality control until more research and standardization is done. In response to the quality concern, the manufacturers could instead cultivate their own crops with better-controlled conditions. However, this still does not address the issue of utilizing the by-product wastes (Kamthai S., personal communication, 23 March 2021; Spanuchart S. and Lertpiriyasakulkit T., personal communication, 5 March 2021).

From the limitation being mentioned, it might be better to apply cellulose in food, textile, or other applications. Because there is an existing food-grade extraction method, and the addition limit is higher in food application than bioplastics (Kamthai S., personal communication, 23 March 2021). Another finding during this study is that banana by-products can be used in the textile industry instead of being utilized for bioplastics production. An example is the work of Mr. Thanakorn Sodsai (personal communication, 27 March 2021), the owner of "Tanee Brand", a business that utilizes almost 100% of banana parts such as upcycling banana leaves and trunks into bags and decorative stuff, while the rest of the parts can be used to make paper pulp. This approach has turned the valueless banana wastes into a high-value product that could cost up to 7,000 Thai Baht (185 Euros). Instead of competing over the existing and potential competitor biomass, processing these by-products into innovations could be one of the other options for adding value to banana wastes, one that provides additional income to the local community.

Figure 18 Mr.Thanakorn Sodsai (right) and the products from Tanee Brand made from banana by-products (Post Today, 2019).

The third friction is from the lack of access to technology. It is one of the limitations mentioned by Respondent C (personal communication, 21 April 2021) that his company is a food packaging manufacturer using waste from rice straws and bagasse from sugarcane and bamboo to make fiber-based bowls, plates, trays, or cups. With the existing packaging production technology that the company has, it is only compatible with several types of raw materials that the company currently uses, as the other raw materials including banana leaves and trunks have a limitation in terms of removal of impurities. The final product contains contamination that is not yet approved with the existing testing methods that ensure safety for consumer use. Moreover, the technological advancement in agricultural wastes extraction is much lower in terms of production capacity and performance, compared to the commercialized PLA production process. This could relate to the financial friction being discussed.

In short, there are three identified frictions that would slow down the feasibility of utilizing banana by-products for the bioplastic industry. The first friction is about the lack of legislation which leads to only a small group of bioplastic materials and products being marketed. Another reason is the lack of proper support from the government sectors -- it is a disadvantage for farmers and small manufacturers who have little to no connections and do not have access to the support needed, to improve their business, including education regarding value adding to their products. The second friction relates to the raw material from an uncertain and insufficient amount of supply, being less competitive in cost than conventional plastics and existing bio-based feedstock, limitations on the properties of materials and requirements from the applications, and other alternative solutions that seems to be more promising. The third friction is the lack of access to technology, making it difficult to scale up the production capacity and to compete with existing bioplastic and conventional plastic feedstocks. These are the factors that could decrease the rate of the feasibility of the approach but do not completely obstruct it. This means that there is a chance that this approach could still be pushed forward, but it would take time and will not likely happen in the near future.

4.2.4 **Turners (Blockers)**

From the information obtained during this study, there is no turner that could be identified. Some of the frictions like utilization of banana by-products for food or textile applications seem to be a turning factor as suggested by Kamthai S., personal (communication, 23 March 2021). This could delay the approach of utilizing banana by-products in the bioplastics scope. However, it does not actively oppose or push the approach to a stopping or turning point. Moreover, there are no identified stakeholders who have disadvantages from the utilization of banana by-products into bioplastics production, at least from the information obtained in this study.

To summarize section 4.2, the analysis on feasibility of utilizing banana by-products in the Thai bioplastic industry and to answer to RQ4 was completed via a DEFT analysis. Based on data from interviews and secondary research, there are drivers from the government sectors through policies and strategies in supporting the utilization of bio-based and bioplastic products, as well as the upstream sides of producers and manufacturers acting in response to the government's plan and market needs. The drivers receive support from the two enabling factors which are the trend of sustainability and demanding for more sustainable solutions from the consumers. The other enabler is the material factor from the mismatch of biomass demand and supply, reduction in the main biomass feedstock production, increase in the cultivation, and conflicts over the food supply chain, which makes the banana by-products could potentially be an alternative of interest as it is a waste which could be utilized into something valuable.

On the other hand, there are some obstacles that may negatively affect the feasibility, such as lack of proper support in legislation, education, and training from the government sectors. This makes a big impact on the feasibility of the approach, as the by-product from banana is not currently in the focus of the government. More time is needed for the new legislation to support the utilization of new materials to be carried out. Other obstacles from the raw material side include insufficient and inconsistent supply of the raw materials, competition with existing or other bio-based alternatives in terms of cost, and limitations from the material properties and applications. Other alternative agricultural wastes like rice straws, corn cobs, or sugarcane bagasse seem to be more attractive in the aspect of supply, as well as research and production technology. Lastly, there are no stakeholders identified to be strongly in the opposing position to banana by-products utilization in bioplastics. Taking everything into consideration, utilization of banana by-products in Thailand as bioplastic feedstock could be possible, but will not likely happen in the near future.

5 Conclusion

This is a study that explores the operational feasibility of utilizing by-products obtained from banana cultivation for the bioplastic industry as an alternative raw material in order to replace fossil-based plastics, as well as bioplastic feedstocks which can be used as food in Thailand. The study was done using a secondary research in combination with semi-structured qualitative interviews with stakeholders. Even though this study has faced some obstacles due to the Covid-19 pandemic causing difficulty in contacting and scheduling for interviews, the data collection process went well and the information obtained was insightful.

In this study, thirteen interviews were conducted with identified stakeholders involved in the banana cultivation value chain, as well as stakeholders from the bioplastic industry addressing *RQ1-Who are the stakeholders involved in the banana cultivation value chain and the bioplastics value chain?* The collected data was used to construct a value chain map that illustrated eight stages of activities. The three identified groups of stakeholders consists of direct stakeholders, supporters, and influencers. The value chain begins with suppliers who supply chemicals such as fertilizers and services to farmers. Farmers are the ones who grow, harvest, and sell banana fruits, small shoots, and their sellable by-products, while the rest were discarded. The products can either pass through traders and farmers cooperatives or directly be forwarded to manufacturers for by-products extraction and transformation into useful cellulosic, CMC-derived, or fermentable sugars substances which can later be converted into packaging material like films and other products. The formed or converted packages are either sent to food manufacturers for packing food products or can be sold directly in the form of single-use bioplastics like straws and cutlery. The products are displayed in many sales channels like supermarkets, convenience stores, and food business operators which have the consumers as the end-user. This value chain is supported by financial institutes, farmer's federation, academic sectors, research institutes, non-direct player private sectors, and government sectors throughout different stages of activities. Moreover, the consumers, private sectors, and government sectors also exert a certain influence on the value chain concerning trends, demand, or directions of the approach.

Regarding the interest towards banana by-products and to answer *RQ2 - What are the by-products obtained from banana cultivation and how are they handled*, the findings indicate that the current practice after the fruits are harvested, about 80% of the banana plant parts are likely to be considered as waste. This includes rhizome (root-like part), pseudostem (trunk), leaves, stalks, and buds. Only a small portion of these wastes (and of specific strains of banana) can be used in other applications such as food for human consumption, animal feeds, wrapping material, or in religious ceremonies. The rest of the waste ends up in landfills. However, the stage of extraction, transformation, and R&D could be a connecting point to the link between the value chains of banana cultivation and the bioplastics, leading to the answer for *RQ3 - How can the banana by-products be used in the bioplastic industry as an alternative to the current bio-based feedstock?.* It should be noted that there are no existing activities regarding the utilization of banana by-products for bioplastic industry yet in Thailand, at least not on a commercial or industrial scale. Based on the collected data, there are research conducted to explore the use of banana by-products as a raw material for bioplastics production, such as the work of Faradilla et al (2018). By reference to how other biomass feedstocks like cassava and sugarcane have been used in the bioplastic industry, we could say that banana by-products could also be introduced into the system as an alternative source of raw materials.

For the analysis of the operational feasibility, DEFT was used as the framework to help address *RQ4 - What are the barriers and success factors in using banana by-products to produce bioplastics that can be used as food packaging in Thailand?* Considering all the information obtained in this study, it is therefore concluded that utilizing banana by-products in Thailand as bioplastic feedstock could be possible, but will not likely happen in the near future. There are identified drivers and enablers from the government sectors, producers (farmers and manufacturers) and consumers, as well as promising evidence from the academic research. However, the limitation in the current legislation states that only small numbers of materials (mostly PLA) and applications are allowed to be marketed in the food-contact category. Furthermore, the lack of access to proper technology, the limitations of raw materials, and the requirements from different applications can strengthen the point that it will take times before this approach comes to reality, despite no actively opposing stakeholders found.

5.1 Recommendations for future work

While there is no existing linkage between banana by-products and the bioplastics value chain at the moment this study was conducted, we can see that there are approaches in trying to utilize agricultural by-products into the bioplastic industry. A follow-up activity on the progress of legislative development between TISI, Thai FDA, and other responsible parties is recommended, as it can increase the opportunity for the new bioplastic materials to be marketed. Furthermore, a further investigation can be done to identify any hidden stakeholders and activities that may get involved in the future, as well as an analysis of economic and financial feasibility, as the value chain can evolve over time (Faße et al., 2009).

In parallel to the continuous study of the value chain, the method for improving extraction and production of banana by-products to produce more cost-efficient products that have potential in competing with existing bio-based feedstock like sugarcane, cassava, and the conventional fossil-based feedstock is recommended. Moreover, a study of properties of cellulose and other materials that can be extracted from domestic banana strains is recommended as it can lead to an opportunity to utilize these materials efficiently.

Even if the utilization of banana by-products might not seem feasible in the near future, other alternative bio-based feedstocks, e.g., rice and corn should be taken into serious consideration as they have a better quantity in supply and do have some business models developed by Kamthai S. (personal communication, 23 March 2021). Lastly, another interesting topic could be the operational feasibility of utilizing banana by-products in other countries that have greater numbers of banana cultivation such as India, China, and Indonesia (FAO, 2020) where the supply issue will not be a challenge.

6 References

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Appendix A Work distribution and time plan

Table 10 Project's Gantt chart

			Dec-20					Jan-21				Feb-21				Mar-21					Apr-21				May-21				Jun-21				
Step	Start	End	49	50	51	52	53	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Draft Thesis proposal	1/12/2020	18/1/2021																															
Literature research	14/12/2021	12/5/2021																															
Approved Master thesis proporsal	18/1/2021	18/1/2021																															
Start of Master Thesis	18/1/2021	18/1/2021																															
Fly to Thailand	24/1/2021	25/1/2021																															
Quarantine	25/1/2021	9/2/2021																															
Interview with stakeholders	January	April																															
Contacting and Scheduling	27/1/2021	19/4/2021																															
- Banana farmer	16/2/2021	16/2/2021																															
- Karnchanaburi farmer federation	16/2/2021	16/2/2021																															
- Bioplastics company	22/2/2021	22/2/2021																															
- Food manufacturing company	23/2/2021	23/2/2021																															
- Food manufacturing company	25/2/2021	25/2/2021																															
- Academic researcher	1/3/2021	1/3/2021																															
- Banana farmer	4/3/2021	4/3/2021																															
- Banana farmer cooperation	4/3/2021	4/3/2021																															
- Thai plastics institute	5/3/2021	5/3/2021																															
- Banana farmer	10/3/2021	10/3/2021																															
- Academic researcher	23/3/2021	23/3/2021																															
- Tanee brand	27/3/2021	27/3/2021																															
- Biobased package manufacturing company	19/4/2021	19/4/2021																															
Midterm presentation	12/3/2021	12/3/2021																															
Conclusion and report writing	May	June																															
Presentation of Master Thesis	4/6/2021	4/6/2021																															
Poster Feedback session	10/6/2021	10/6/2021																															
Master Thesis approved	17/6/2021	17/6/2021																															
Poster and Executive summary	29/6/2021	29/6/2021																															

Appendix B Interview questions

B.1 Interview guideline for Banana farmers

1. **Could you please introduce yourself?**
2. **Please explain about the background of your business**
    a. How do you come up with this business?
    b. Business process.
    c. What are the raw materials? (quantity)
    d. What are the outputs? (quantity)
    e. Waste and how you handle them?
    f. Who gets involved in this business?
    g. Any value adding to the waste?
    h. Alternative source of income?
    i. Transaction flow
    j. Information flow
3. **Have you ever had problems in growing bananas? How do you solve it? Do you seek or receive any help?**
    a. From whom?
    b. What kind of help?
4. **What are the challenges and opportunities in this business?**
    a. Any trend changes in recent years?
    b. Pulling/demand forces from customer's
5. **Have you ever heard of bioplastics, any idea what is it about?**
6. **How do you foresee the trend of banana consumption in the next 5-10 years?**
7. **Do you have any recommended person that I could interview next for this project?**
8. **Any final thoughts / comments to share?**

B.2 Interview guideline for Farmer’s cooperative

1. **Could you please introduce yourself?**
2. **Please explain about the background of your business**
    a. How do you come up with this business?
    b. Business process.
    c. What are the raw materials? (quantity)
    d. What are the outputs? (quantity)
    e. Waste and how you handle them?
    f. Who gets involved in this business?
    g. Any value adding to the waste?
    h. Alternative source of income?
    i. Transaction flow
    j. Information flow
3. **Have you ever had problems in growing bananas? How do you solve it? Do you seek or receive any help?**
    a. From whom?
    b. What kind of help?
4. **What are the challenges and opportunities in this business?**
    a. Any trend changes in recent years?
    b. Pulling/demand forces from customer’s
5. **Have you ever heard of bioplastics, any idea what is it about?**
6. **How do you foresee the trend of banana consumption in the next 5-10 years?**
7. **Do you have any recommended person that I could interview next for this project?**
8. **Any final thoughts / comments to share?**

B.3 Interview guideline for Researchers from academic sector and research institutes

1. **Could you please introduce yourself?**
    a. Experience / field of expertise
2. **Please describe the role your institute/department**
    a. Activities, tasks?
    b. Particular to farmers and bioplastics industry (producer and manufacturer)
    c. How did you get research or project's funding or incentives?
    d. Relationships to other stakeholders
3. **What is your opinion on utilizing cellulose extract from banana waste like trunks and leaves as an alternative raw material?**
    a. Which is upcycling of waste rather than using a potential source of food like sugar cane and cassava for bioplastic production?
    b. Possible applications?
    c. Requirements
    d. Opportunities
4. **In your opinion what are the success factors, barriers, or requirements for the initiative of utilizing agricultural waste in bioplastics industry?**
    a. Particular to banana by-products
    b. Any other source of agricultural wastes you have come across?
5. **How do you foresee the situation/trend of bioplastic in Thailand in the next 5-10 years?**
6. **Do you have any recommended person that I could interview next for this project?**
7. **Any final thoughts / comments to share?**

B.4 Interview guideline for plastics and bioplastics converter and manufacturers

1. **Could you please introduce yourself?**
2. **Please explain about the background of your business**
    a. How do you come up with this business?
    b. Products and process.
    c. What are the raw materials? (quantity)
    d. What are the outputs? (quantity)
    e. Waste and how you handle them?
    f. Who gets involved in this business?
    g. Challenges
    h. Opportunities
    i. Any value adding to the waste?
    j. Alternative source of income?
    k. Actors involved and their roles.
    l. Transaction flow
    m. Information flow
3. **What are the success factors for your business?**
4. **Are there any restrictions or barriers in your business? What are they and how do you solve it? Do you seek or receive any help?**
    a. Financial
    b. Legislation
    c. Consumer acceptance
    d. Market demand
    e. From whom?
    f. What types of help?
5. **How do you foresee the situation/trend of bioplastic in Thailand in the next 5-10 years?**
6. **Do you have any recommended person that I could interview next for this project?**
7. **Any final thoughts / comments to share?**

B.5 Interview guideline for Food manufacturers

1. **Could you please introduce yourself?**
2. **Please explain about the background of your business**
    a. How do you come up with this business?
    b. Products and process.
    c. What are the raw materials? (quantity)
    d. What are the outputs? (quantity)
    e. Waste and how you handle them?
    f. Who gets involved in this business?
    g. Challenges
    h. Opportunities
    i. Any value adding to the waste?
    j. Alternative source of income?
    k. Actors involved and their roles.
    l. Transaction flow
    m. Information flow
3. **What are the success factors for your business?**
4. **Are there any restrictions or barriers in your business? What are they and how do you solve it? Do you seek or receive any help?**
    a. Financial
    b. Legislation
    c. Consumer acceptance
    d. Market demand
    e. From whom?
    f. What types of help?
5. **How do you foresee the situation/trend of bioplastic in Thailand in the next 5-10 years?**
6. **Do you have any recommended person that I could interview next for this project?**
7. **Any final thoughts / comments to share?**

B.6 Interview guideline for Government sectors

1. **Could you please introduce yourself?**
2. **Please describe the role your position and the department**
    a. What are the activities / tasks?
    b. Involvement with other stakeholders
    c. Information and financial transaction flow
    d. Organization structure
    e. Case example
3. **As a government or state agency, please describe an influences/drives that you have done on agricultural sector or bioplastic industries.**
    a. In what aspects?
    b. Case example
4. **In the context of utilizing banana waste for bioplastics industry, are there any resources or supports that could contribute to this supply chain?**
    a. Policy and legislation
    b. Financial and equipment
    c. Education and training
    d. Collaboration with other stakeholders
5. **What are the current challenges you are facing in related with agricultural and bioplastic industries?**
6. **In national scale, what are the numbers of inputs and outputs of both banana and bioplastic industry?**
    a. In case of the information not available, do you have any recommendation for me to look for these numbers?
7. **How do you foresee the situation/trend of Thailand in the next 5-10 years?**
    a. Banana cultivation
    b. Bioplastic industry
8. **Do you have any recommended person that I could interview next for this project?**
9. **Any final thoughts / comments to share?**

Appendix C List of standards

Table 11 Lists of international bioplastics standards and certifications (Bioplastics guide, n.d.; European Bioplastics, 2019; Weerathaworn, 2013).

Category	***Sub-category***	***Standard code***	***Description***
Relevant standards for bio-based plastics	Determination of the bio-based content	EN 16640	Bio-based products - Bio-based carbon content -Determination of the bio-based carbon content using the radiocarbon method.
		EN 16785-1	Bio-based products - Bio-based content - Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis.
		EN 16785-2	Bio-based products - Bio-based content - Part 2: Determination of the bio-based content using the material balance method.
		ASTM D6866-21	Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis
		CEN/TS 16137:2011	Plastics - Determination of bio-based carbon content
	Sustainability and Life Cycle Assessment (LCA)	ISO 14040	Environmental management - Life cycle assessment - Principles and framework
		ISO 14044	Environmental management - Life cycle assessment - Requirements and guidelines
		EN 16760	Bio-based products – Life Cycle Assessment
		EN 16751	Bio-based products - Sustainability criteria
		ISO 14067	Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
Relevant standards for biodegradable plastics	Standards for industrial composting and anaerobic digestion	EN 13432:2000	Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging

	EN 14995	Plastics. Evaluation of compostability. Test scheme and specifications
	ISO 18606	Packaging and the environment – Organic Recycling
	ISO 17088	Specifications for compostable plastics
	ASTM D6400 - 19	Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities
	OECD 301C	Ministry of International Trade and Industry (MITI) biodegradation test
	JIS K 6950 (ISO 14851)	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium - Method by measuring the oxygen demand in a closed respirometer
	JIS K 6951 (ISO 14852)	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium - Method by analysis of evolved carbon dioxide
	JIS K 6953 (ISO 14855)	Determination Of The Ultimate Aerobic Biodegradability And Disintegration Of Plastic Materials Under Controlled Composting Conditions - Method By Analysis Of Evolved Carbon Dioxide
Standards for home composting	AS 5810	Biodegradable plastics – biodegradable plastics suitable for home composting
	TÜV AUSTRIA Belgium	OK compost home certification scheme
	NF T 51-800	Plastics — Specifications for plastics suitable for home composting
Biodegradability in soil	TÜV AUSTRIA Belgium	Bio products – degradation in soil
	EN 13432	Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging
	EN 14995	Plastics. Evaluation of compostability. Test scheme and specifications
	EN 17033	Biodegradable mulch films for use in agriculture and horticulture – Requirements and test methods

	Biodegradability in marine environments	ASTM D6691	Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum
		ASTM D6692	Standard Test method for Determining the Biodegradability of Radiolabelled Polymeric Plastic Materials in Seawater
		ASTM D7473	Standard Test Method for Weight Attrition of Plastic Materials in the Marine Environment by Open System Aquarium Incubations
		OECD 306	Biodegradability in sea water
		ISO 16221	Water quality – Guidance for determination of biodegradability in the marine environment
		TÜV AUSTRIA Belgium	OK biodegradable MARINE
Bioplastics – Communication standards	-	EN 16848	Bio-based products - Requirements for Business-to-Business communication of characteristics using a Data Sheet
		EN 16935	"Bio-based products - Requirements for Business-to-Consumer communication and claims
		ISO 14020	Environmental labels and declaration
		ISO 14021	Environmental labels and declarations Self-declared environmental claims (Type II environmental labelling)
		ISO 14024	Environmental labels and declarations - Type I environmental labelling - Principles and procedures
		ISO 14025	Environmental labels and declarations - Type III environmental declarations - Principles and procedures
		ISO 14063	Environmental management - Environmental communication - Guidelines and examples
		ISO 14067	Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification

Appendix D

D.1 Polylactic Acid (PLA)

PLA is a polymerized chain of lactide, which is a derivative of lactic acid from the fermentation of sugars. It is one of the popular bioplastic materials as it has quite similar properties to the fossil-based plastics such as PET and PP, but derived from renewable resources. However, PLA has weaker mechanical strength than conventional plastics. In order to match the mechanical strength, higher mass utilization is needed, although this can have an impact on the cost structure (Coppola et al., 2021; Nagarajan et al., 2016). A simple production flow of PLA is illustrated in Figure 19.

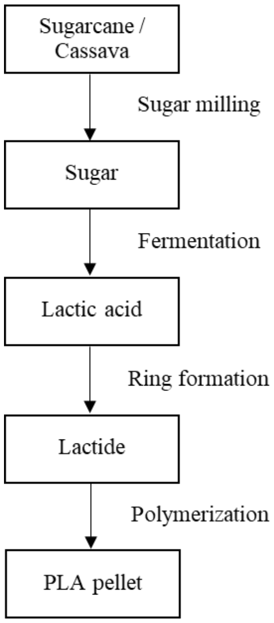

Figure 19 Simple production process of PLA pallet (Coppola et al., 2021).

D.2 Polybutylene succinate (PBS)

PBS is a polyester built up on a combination of succinic acid and 1,4-butanediol monomers derived from the processed renewable source of carbohydrates such as sugarcane and corn. It has similar properties to PP and have wider range of applications than PLA as it can be used in textiles, sport devices, automotives, etc. However, the drawback of PBS is due to the relatively high cost of production which still needs further improvements (Chen and Yan, 2020). The process flow from Cheroennet et al., (2017) is shown in Figure 20.

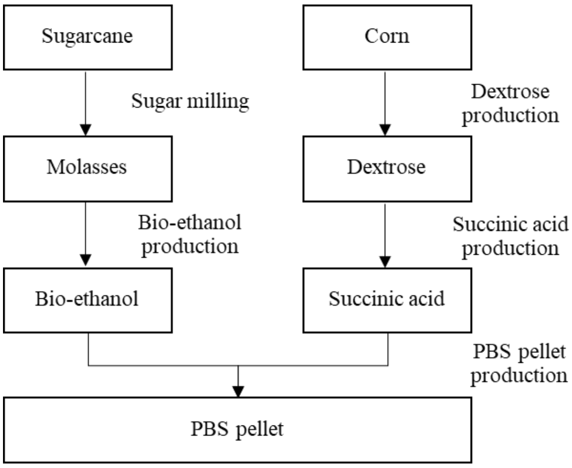

Figure 20 Simple production process of PBS pallet (Cheroennet et al., 2017).