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Development of a Supply Chain Management Platform for Rubberwood Biomass in Southern Thailand

Sirirat Pungchompoo, Nikorn Sirivongpaisal, Sirirat Suwatcharachaitiwong, Dollaya Buakum

Faculty of Engineering, Prince of Songkla University, Thailand

Abstract

This research aims to manage biomass raw materials in line with industrial needs by developing a platform that links stakeholders in the rubberwood biomass supply chain in southern Thailand. Geographic Information System (GIS) technology was applied to build a database and estimate rubber plantation areas. The trees were grouped by age into three categories: 14–20, 21–27, and over 27 years. The platform also provides information on garden and factory locations, including sawmills, rubberwood processing plants, biomass production plants, and biomass power plants in 14 southern provinces. The system, available on Android and iOS, supports users in making decisions about transportation costs such as distance, time, and fuel. Results from the technology transfer show that the platform is practical, matches user requirements, and is used effectively. The average user satisfaction scores were 4.538 for function and 4.504 for overall use, reflecting the platform's usefulness and acceptance among stakeholders.

Keywords

Rubberwood supply chain, rubberwood biomass, rubberwood biomass platform.

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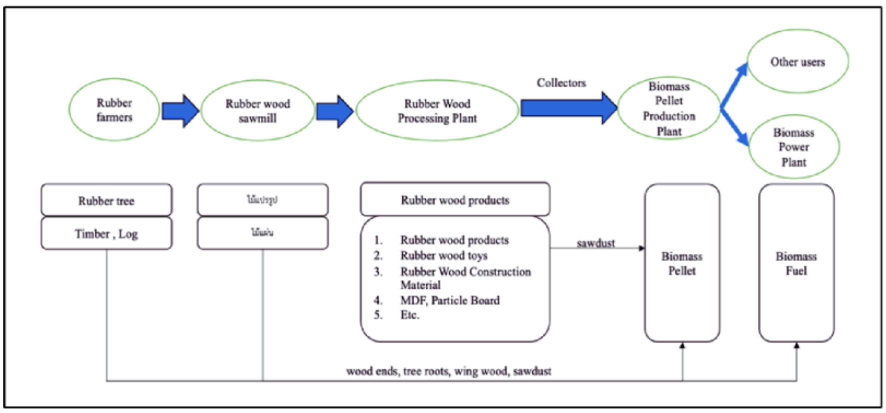
Introduction

Thailand has a policy to promote the production of electricity from renewable energy sources, including the production of electricity from biomass to maximize the use of resources in the country and enhance energy security. Support is provided for the purchase of electricity from private sector renewable energy power plants, both small power producers (SPP) and very small power producers (VSPP). This has led to an increase in the number of small and very small power plant projects selling electricity to the commercial grid, reaching a total of 226 projects in the year 2021 from 1,000 companies. These companies produce electricity from biomass, which is derived from the agricultural process, including oil palm, rice, rubberwood, and fast-growing trees planted specifically as an energy source, such as giant reed, eucalyptus, and Napier grass. Normally, these biofuels are used in various general industries for heat energy production, which may not be sufficient if they are utilized in the energy sector. Therefore, the management of biofuels and their allocation, both for the industrial sector and bioenergy power plants, is a problem that impacts the raw material management for the bioenergy production chain as per the PDP2018 plan. Regarding the electricity system's reliability, for example, in the year 2037, the estimated maximum electricity demand in the southern region is 5,264 megawatts, with an anticipated capacity to generate electricity from power producers totaling 8,662 megawatts. Of this, 29% comes from small, very small, and community power plants operated by private companies. This illustrates that the quantity of biomass available for electricity production is a crucial factor to consider (Ministry of Energy, 2020). At the same time, data on distributed biomass resources is lacking, and stakeholders cannot access timely and connected information, posing challenges in predicting biomass availability for biofuel use, both directly and indirectly, in the rubberwood industry. This includes rubber plantation farmers and rubberwood processing businesses, totaling 290 factories that use rubberwood branches, roots, and sawdust as biofuels for bioenergy power plants. In the year 2020, the total capacity was 196.8 MW (Office of Industrial Economics, 2020). However, bioenergy power producers are not aware of precise information about biomass producers, including estimating production costs, which are affected by transportation costs. Another significant issue is that bioenergy power plants are distributed across various regions and have increased in number in each region, yet there is a lack of regional management, planning, and access to digital resources. For example, the cost of biomass feedstock for small bioenergy power plants is high because they cannot directly access biomass from local producers. Transportation costs have also increased due to sourcing from distant areas. Moreover, the price of biomass feedstock is determined by large-scale biomass producers who serve as both producers, distributors, and transporters of biomass. This results in inadequate supply, price fluctuations, and instability in biomass feedstock prices.

As a result of the aforementioned problems, the objective of this research is to develop a suitable service model for stakeholders involved in community-based bioenergy power plant projects, including farmers, biomass producers, intermediaries in biomass procurement and distribution, power plant operators, and rubberwood processing factories, through a digital platform that utilizes information technology and the internet of things, enabling access to user requirements within the system. This aims to support and facilitate decision-making in the efficient management of domestically produced biomass resources in Thailand, ensuring cost-effective raw materials and efficient transportation services. Additionally, it aims to establish sustainability within the bioenergy supply chain. Therefore, this research aims to establish an intelligent information-sharing service model through a digital platform among stakeholders in the Thai rubberwood industry. It will highlight the key components of the supply chain connecting rubber plantation farmers, rubberwood processing factories, biomass producers, and bioenergy power plants. This will be achieved by implementing a geographic information system that displays location and transportation routes, facilitating calculations for rubberwood resource estimates, distances, and transportation costs concurrently. Therefore, the literature review details are as follows:

Biomass supply chain from para rubber wood

The rubber wood industry is related to farmers who wish to cut down old rubber trees for replanting or rubber trees that have been damaged or are more than 25 years old. They offer rubber wood for sale at the garden location, and buyers from farmers will cut down the old rubber trees after reaching a mutually satisfactory price agreement. In the process of cutting down one acre of rubber trees, only 50% of the logs obtained can be used. Normally, rubber wood that is cut is divided into three parts: roots or tree stumps, wood ends with a central diameter of 3 inches or less, and log sections with a central diameter of 4 inches or more. The log sections are cut to a length of 1.5 meters for delivery to sawmills and furniture factories. The remaining 50% consists of wood scraps, branches, and sawdust, which are considered waste. This waste was not used in the past but is now used in the wood industry, especially for manufacturing MDF (Medium Density Fiber Board) and particle board in the wood processing industry, such as fiberboards and particle boards. Currently, most of the processed wood panels come from the processing of rubber wood because there are not enough other types of log sources in large quantities for industrial use. Additionally, the waste from production, such as wood ends and tree root, comes from rubber tree gardens, wing wood, and sawdust from rubber wood sawmills, and tree branches, as well as toadstool waste from rubber wood furniture factories. This waste is converted into biomass fuel pellets for use in other industries or as biofuel in electricity production plants. Therefore, the above process can be illustrated in the form of a biomass supply chain from rubber wood, as shown in Figure 1 below.



Source: Authors' own work.

Figure 1: Biomass supply chain from para rubber wood.

Renewable energy and biomass potential in Thailand

From the complete report of the Ministry of Energy in the year 2022, which gathered data on energy crops with agricultural practices covering 21.75 million rai, or 49.20 percent of the total area. Key economic crops include rubber and oil palm (Department of Agricultural Economics, 2019). Rubber is of significant economic importance to the southern region, generating income for the local population and providing employment opportunities on a large scale. According to data from the year 2019, the southern region exported rubber with a total value of 130.18 billion Thai Baht, comprising 80.84 billion Thai Baht in natural rubber products and 49.34 billion Thai Baht in rubber products. Therefore, rubber is the most important export commodity in the southern region and has a higher export value than other product categories. (Bank of Thailand, 2563) However, the rubber tree cultivation area in Thailand continuously decreased during the period from the year 2014 to 2018, with a decline of 0.99 percent in the year 2018 compared to the year 2017. In the year 2018, the rubber tree cultivation area was 22,626,277 rai, a decrease of 0.99 percent from the year 2017 when it was 22,852,178 rai. Even though the southern region had the largest rubber tree cultivation area in the country, accounting for over 60 percent, in the year 2018, the rubber tree cultivation area in the southern region was 13,584,115 rai, with a decrease of 1.56 percent compared to the year 2017 when it was 13,800,212 rai. When considering the provinces in the southern region, in the year 2018, the group of provinces on the Gulf of Thailand side, consisting of 5 provinces including Chumphon, Nakhon Si Thammarat, Surat Thani, Phatthalung, and Songkhla, had the largest rubber tree cultivation area, totaling 7,550,875 rai, a decrease of 1.48 percent from the year 2017 when it was 7,664,168 rai. The next group was the provinces on the Andaman Sea side, including Ranong, Phang Nga, Phuket, Krabi, Trang, and Satun, which had a rubber tree cultivation area of 3,425,331 rai in the year 2018, a decrease of 2.41 percent from the year 2017 when it was 3,509,800 rai. The southern border provinces group, consisting of Pattani, Yala, and Narathiwat, had a rubber tree cultivation area of 2,607,912 rai in the year 2018, a decrease of 0.64 percent from the year 2017 when it was 2,624,737 rai. This decrease was due to the impact of drought and low agricultural product prices, which discouraged farmers from rubber and led some of them to cut down rubber trees to plant other crops suitable for the area. Additionally, they received support from the government to reduce cultivation area and switch to other crops. As a result, the rubber tree cultivation area decreased every year, including in the present year. Regarding the rubber tree's biomass, cutting down one rai of rubber trees produces a total biomass of 59 tons per rai, divided into 1) rubber tree logs: 30 tons of biomass, 2) tree branches: 12 tons of biomass, 3) rubber tree branches/stems: 9 tons of biomass, 4) tree roots: 5 tons of biomass, and 5) sawdust: 3 tons of biomass. This biomass from rubber trees has the potential to be used as biofuel for electricity generation, consisting of tree branches, rubber tree branches/stems, sawdust, wood scraps, and tree roots, accounting for 49.20 percent of the biomass from rubber trees per rai. (The Association of Rubber Wood Business, 2015, as cited in Chaiya Kongmani and colleagues, 2017)

Geographic Information Systems and digital platforms

Currently, Geographic Information Systems are widely used in both agriculture and industry. There is ongoing research that applies Geographic Information Systems and technology in various aspects, including production planning, site selection, transportation, and overall cost analysis. For example, a study by Akarariya, Siriwongpaisarn, Kongkaew, and Preechaveerakul (2018) investigated the establishment of collection points to create a balance between areas for oil palm cultivation and palm oil extraction factories. The study focused on logistics for inbound transportation and the current state of palm oil transportation in the southern palm oil industry. It also explored strategies for establishing collection points (known as 'Lan Te') in the southern region to achieve a balance between planting areas and production capacity of palm oil extraction factories, using mathematical models. This included determining the position and quantity for setting up representatives for sub-farmer groups growing oil palm. The study addressed the procurement and distribution of fertilizer to cultivation areas within Surat Thani province under the large-scale agriculture promotion policy. The goal was to minimize the overall cost, including procurement, setup and operation expenses, and delivery costs, within the service area of representatives for sub-farmer groups. These representatives were determined based on sub-farmer groups growing oil palm in each sub-district of Surat Thani province, totaling 121 sub-districts (Siriwongpaisarn and Kongkaew, 2018). Janarthanan et al. (2023) reviewed recent developments in GIS applications, highlighting their role in solving complex socio-economic engineering problems, which supports the integration of GIS into various aspects of agriculture and industry. Mennecke and Crossland (1996) provided an introduction to GIS and a research framework for information systems researchers, emphasizing the importance of GIS in data acquisition, interpretation, and decision support. Li at al. (2024) highlighted the use of GIS for geographic information data elements on the basis of enumerating and summarizing the spatial data infrastructure, which support the construction of digital China and economic and social development.

Furthermore, the application of information and communication technology (ICT) and Internet of Things (IoT) in the biomass supply chain for the development of Industry 4.0, there is the utilization of the ICT BIOCHAIN platform. This platform provides services, including a database and processing capabilities that can link data throughout the system, from the beginning to relevant producers. A survey of business groups in Europe found that 17% utilize the ICT BIOCHAIN for system management, while 15% still adhere to traditional management methods. The remaining percentage employs a mixed approach (Flak, 2020). Similar to the research by (Wajszczuk et al., 2008), the concept of building a biomass transportation network for communities connecting biomass markets with digital platforms for biomass power plants is introduced. The research reveals that challenges in the biomass market arise from the lack of anticipation of biomass demand due to insufficient data from cultivation areas, biomass quantities, data accessibility, and assessment of waste from wood processing or related industries. The cost of transporting biomass for biomass power production is another factor in establishing regional power plants. In this context, digital platforms serve as fundamental tools to connect producers and buyers to address the aforementioned challenges.

The role of GIS in Logistics and Environment also has a great impact. Eldrandaly (2023) explored the integration of GIS with decision support systems to model domain-specific contexts and enhance expert intelligence, which supports the development of digital platforms. Swain (2024) emphasized the role of GIS and remote sensing in revolutionizing logistics and supply chain management, which is essential for optimizing transportation routes and reducing costs. Barnett (2024) discussed the importance of GIS in environmental impact assessment, highlighting its role in providing spatial data, analysis, and visualization for informed decision-making. Atlan (2024) reviewed the significance of database management in GIS, focusing on the organized handling, storage, and retrieval of spatial data to ensure high data quality and accessibility. Goodchild (2022) explored the grand challenges in geographic information science, emphasizing the need for advanced GIS applications to address complex societal issues. Weiner et al. (2002) discussed the integration of community participation with GIS, highlighting its transformative potential in various social and environmental contexts. Sangeetha et al. (2024) reviewed the applications of remote sensing and GIS in precision agriculture, emphasizing their role in optimizing crop production and minimizing environmental impacts.

Platform development by applying GIS and mobile application display

The use of Geographic Information Systems (GIS) in platform development has become crucial in industries such as agriculture, logistics, and transportation. By integrating GIS into mobile applications, businesses can enhance decision-making, improve resource management, and optimize operations. These platforms enable users to estimate plantation areas, optimize transportation routes, and access real-time data via mobile devices.

In agriculture, GIS plays a critical role in estimating plantation areas, especially for crops like palm oil and rubber. For example, Lee et al. (2020) and Li et al. (2020) showed how GIS allows industries to monitor plantation growth in real-time, aiding in land use optimization, production planning, and scheduling. Furthermore, the ability to combine satellite imagery with spatial data makes GIS an essential tool for sustainable land management (Green et al., 2021). Brovelli and Magni (2020) explored open-source mobile GIS solutions, highlighting their versatility across various application fields, which supports the integration of GIS into mobile applications for enhanced decision-making. In addition, GIS is vital in precision agriculture, where analyzing large datasets helps improve land use and sustainability (Jones and Smith, 2019; Wang et al., 2023). Sarbazvatan and Karimi (2023) developed a mobile GIS application called LandInfo for land use and land cover field data collection, demonstrating the practical applications of GIS in real-time agricultural monitoring.

Similarly, GIS is indispensable for optimizing transportation routes in logistics. By factoring in distance, traffic, fuel consumption, and environmental impact, GIS-based platforms help businesses reduce transportation costs. Brown et al. (2019) demonstrated how GIS improves biomass transportation in rural areas, an approach particularly relevant to industries like palm oil and rubber (Kim et al., 2020). Takahashi (2021) introduced Geo-Log Mobile, a mobile GIS application based on a new database framework, which enhances real-time data access and decision-making in agriculture and logistics. Additionally, GIS's real-time capabilities allow businesses to adjust routes dynamically, enhancing delivery efficiency and reducing environmental impact (Miller et al., 2020; Parker & Van Alstyne, 2020). Nitin Liladhar Rane (2023) explores the integration of mobile GIS applications in precision agriculture to enhance crop management practices. The findings indicate that mobile GIS tools significantly improve the efficiency of monitoring and managing agricultural fields, leading to increased crop yields and better resource management.

The growing importance of mobile technology has led to the integration of GIS into mobile applications. These platforms provide real-time travel data, allowing users to optimize routes and estimate travel times and costs (Zhang et al., 2019). Prastacos (1991) discusses the integration of GIS technology in urban transportation planning to address traffic congestion and improve spatial analysis and decision-making, and highlights that GIS significantly enhances the efficiency and effectiveness of urban transportation planning. In agricultural supply chains, mobile GIS applications help transport materials like rubberwood or palm oil to processing facilities. For instance, Li et al. (2020) developed a mobile platform for real-time route optimization, benefiting smallholder farmers by reducing costs and fuel consumption. Giuffrida (2024) presents a GIS-enhanced Real-Time Spatial Delphi approach for spatial participatory planning in urban logistics, and indicate that involving logistics experts in the decision-making process through this participatory method significantly improves the location and efficiency of urban logistics facilities, leading to reduced traffic congestion and environmental impacts. Furthermore, recent advances have integrated predictive analytics into GIS applications. White et al. (2022) explored mobile platforms that predict route changes based on traffic and weather forecasts, enhancing decision-making (Smith et al., 2018). Brown and Affum (2022) developed TRAEMS, a GIS-based environmental modelling system that integrates transport planning outputs with land use information, enabling transportation planners to assess environmental impacts alongside traffic efficiency for more sustainable decision-making. These developments, along with environmental monitoring capabilities (Li et al., 2021; Wang and Zhao, 2023), continue to transform industries that require real-time operational adjustments.

Lu et al. (2024) developed an integrated approach combining Bayesian networks (BNs) and Geographic Information Systems (GIS) to assess flood disaster risks in Yinchuan, China. Their findings demonstrate that the BNs-GIS method effectively evaluates hazard, vulnerability, and exposure, offering a robust framework for comprehensive flood risk management. Chen et al. (2024) investigate the application of GIS in environmental monitoring and risk assessment, with a focus on water, soil, and atmospheric conditions. Their study reveals that integrating GIS technology with remote sensing and spatial data analysis significantly improves the monitoring of environmental changes and risk assessment. This integration leads to more informed decision-making and effective environmental management strategies. The study on GIS-based route optimization for waste management by Swadhin Das, Ankon Baral, Islam M. Rafizul, and Senta Berner found that optimizing waste collection routes using GIS reduced travel distance by 9.40% and fuel costs by 11.6%, significantly enhancing efficiency in Khulna City, Bangladesh.

Materials and methods

This research can be considered in three parts, namely Part 1: Study and data collection of biomass producers, Part 2: Data collection, preparation of data for the database, and study of the cost structure of biomass fuel transportation using GIS, and Part 3: Development of a biomass management platform with innovations using information technology and digital technology. The details are as follows:

Study and data collection of biomass producers

This study covered 14 provinces in the southern region of Thailand, including Chumphon, Ranong, Phang Nga, Phuket, Surat Thani, Nakhon Si

Thammarat, Krabi, Trang, Phatthalung, Songkhla, Pattani, Yala, Narathiwat, and Satun. The main purpose was to identify problems and define the requirements of the rubber wood biomass supply chain. This included cultivation areas, tree age, wood quantity, processing factories, middlemen or collectors, and regulations for establishing community biomass power plants. Another objective was to collect information on the demand and supply of biomass from industries and biomass power plants in the region, to support decisions on the size and location of new community power plants.

The main dataset consisted of plantation areas, rubber age, and production volume, together with information on four key stakeholder groups: sawmills, rubber wood processing factories, biomass production plants, and biomass power plants. Data for each group included their locations, type of operation, contact information, and production capacity. In addition, information on collectors, collection points, transportation methods, and structural factors such as regulations, distance from communities, road networks, and resource availability were also gathered. Secondary data were mainly taken from the Department of Industrial Works and the Ministry of Energy between 2020 and 2022, together with information from agricultural agencies, rubber associations, and satellite imagery. The preliminary verification was carried out using Google Maps, Street View, and official documents, while primary data was collected from field surveys. The survey included GPS-based location recording, photographs of sites, and interviews with stakeholders. The initial results showed that there were 450 sawmills, 30 rubber wood processing factories, 39 biomass production plants, and 82 biomass power plants across the 14 provinces.

To accuracy, the data were cross-checked with multiple sources, such as satellite images, orthophotos, Google Earth, and field observations. Records that were duplicated or incomplete were removed, and all updates were recorded in a data log. The database was developed in two forms: spatial data (points stored in GIS layers, separated by business type) and attribute data (tables including id, factory name, address, type, contact number, and capacity). All data were processed in ArcGIS, where spatial and attribute data were linked, and maps were generated with symbols and colors to distinguish business types. Finally, the database was exported as Shapefile and GeoJSON/JSON files for connection with a digital platform. Quality control was performed by random checking at least 10% of records in each group with field data and satellite images, which helped to improve data reliability for future spatial analysis and decision-making.

Data collection, preparation for database, and study of biomass fuel transportation cost models using GIS

This part entails studying and collecting topographic data in the 14 provinces of the southern region, such as cultivation areas (referenced from the Ministry of Agriculture and Cooperatives and the Thai Rubber Association), production, orchard age, the number and locations of collectors, transportation patterns, the number and locations of biomass production factories, and the number and locations of biomass power plants. Geographic Information System (GIS) is utilized as a tool to display cultivation areas, collector locations, transportation patterns, factory locations, and power plant locations. Field surveys are conducted, and samples are collected from relevant parts of the supply chain to verify the data. The methodological procedures are explained step by step in the following subsections.

Data and tools

The satellite images used in this study consisted of Landsat 8 OLI/TIRS (2013–2015) covering Path 127–130 and Row 51–56 (13 scenes), Landsat 5 TM (2005–2007) for time series analysis, high-resolution Google Earth imagery (2008–2015), and orthophoto maps at a scale of 1:4,000 (2002 and 2010). Institutional and industrial data were obtained from the Ministry of Agriculture and Cooperatives, the Thai Rubber Association, the Department of Industrial Works, and the Ministry of Energy. Data processing relied on ERDAS Imagine for image processing, ArcGIS for spatial analysis, and a high-performance computer system for large-scale data handling.

Image pre-processing

The selection of satellite imagery was carefully controlled to avoid the leaf-shedding period of rubber trees, which occurs around February in the upper South and March in the lower South. Images with the least cloud cover were prioritized, and when necessary, supplementary images from nearby years were included. For provinces that required mosaicking of multiple scenes, images from the same season or acquisition date were selected to minimize differences. Geometric correction of Landsat 5 TM data was performed using topographic maps at 1:50,000 scale (UTM/WGS84) with an image-to-map approach and evenly distributed ground control points (GCPs). Mosaicking and histogram matching were applied to normalize tonal differences across scenes. Image enhancement techniques, such as brightness–contrast adjustment and radiometric enhancement (equal percentage and Gaussian methods), were also applied to improve visual interpretability according to land characteristics.

Bands and composites

Spectral analysis employed bands 1–7 of Landsat 8. Bands 5, 6, and 7 provided the best tonal contrast for land cover differentiation. Composite images were generated to support visual interpretation and training data identification. The false color composite (5-6-3, RGB) was effective in highlighting vegetation, where young rubber appeared orange, mature rubber pink, and oil palm dark orange. The natural color composite (6-5-4, RGB) and the true color composite (4-3-2, RGB) were also applied to support discrimination of rubber plantations from other land covers.

Area of Interest (AOI) and training areas

Training areas were identified to cover at least 30 plots, with a minimum of 10 plots for each age class, and each plot larger than 100 rai to ensure homogeneity. Four categories were defined: rubber aged 7–14 years, 14–20 years, over 20 years, and other land covers such as oil palm, forests, agricultural preparation areas, wetlands, mangroves, water bodies, settlements, and cloud shadows. In provinces where small rubber plots (<100 rai) were predominant, additional training areas were selected to compensate for size limitations.

Supervised, pixel-based classification

The classification process used the Maximum Likelihood algorithm with several combinations of spectral bands and training areas tested to obtain the best results. Class separability was evaluated using Transformed Divergence (TD), ranging from 0 to 2000. A TD value above 1900 indicated clear separation, values between 1700 and 1900 showed good separation, while values below 1700 suggested overlapping classes. The results showed that rubber plantations could be clearly distinguished from other land uses. However, some overlap occurred among the three rubber age groups, especially between the 14–20 years category and adjacent classes, due to the similarity in spectral signatures of rubber leaves.

Field survey and accuracy assessment

Field surveys were conducted after the leaf-shedding period and before the rainy season. Survey points were distributed across the 14 provinces, where GPS coordinates, photos of tapping marks, and environmental context were recorded. Interviews with landowners were also carried out to verify plantation age. Classification accuracy was evaluated using an error matrix and overall accuracy was calculated based on 477 reference points. The classification was accepted only when overall accuracy reached at least 85%.

Post-processing and GIS integration

The classification results in raster format were converted into vector polygons. Small polygons (<3 rai) caused by misclassification were eliminated or merged, and boundaries were smoothed to better match real-world patterns. Polygons were further converted into points to facilitate system integration, and the data were exported into JSON format for use in digital platforms.

Facility database for four stakeholder groups

The database was also developed for four stakeholder groups: sawmills, rubber wood processing factories, biomass production plants, and biomass power plants. The process began with filtering facility lists from the Department of Industrial Works and the Ministry of Energy to remove duplicate or incomplete records. Facility status and locations were verified using Google Maps, Street View, and supporting documents. Geocoding was performed to convert addresses into geographic coordinates, and when possible, field surveys with GPS were conducted for higher precision. All locations were standardized to WGS84/UTM and imported into ArcGIS to create point layers by facility type. Attribute tables including id, facility name, address, type, telephone, and production capacity were linked to spatial data. Symbolization by color and shape was applied to represent different facility types, and summary maps were generated to show their distribution across the 14 provinces. The final database was exported as Shapefile, GeoJSON, and JSON formats for platform integration. Initial results showed 450 sawmills, 30 rubber wood processing factories, 39 biomass production plants, and 82 biomass power plants.

Quality control procedures included random checks of at least 10% of records in each group using base maps, satellite images, and field surveys. Facility types were cross-verified against official definitions, and missing information such as contact details and production capacities was updated from government sources or direct communication. All modifications were recorded in a data log to ensure transparency. As a methodological note, secondary data may be subject to changes such as facility closures, relocations, or ownership transfer; therefore, database updates are recommended at least once a year. Ethical considerations regarding the publication of commercial contact details were also taken into account.

Spatial–attribute update for 2020/2563

To update the database to 2020, spatial boundaries from 2015 were maintained, while attribute data were recalculated. The area of each polygon was expressed as a proportion of the total district area in 2015, then multiplied by the updated district-level plantation area in 2020. This method allowed estimation of new plantation areas while reducing time and cost compared with producing a completely new land cover map.

Age-class re-class

The rubber age classes derived from 2015 classification (7–14, 14–20, and >20 years) were adjusted by adding five years to match the 2020 reference year. The updated classes were therefore defined as 12–19, 19–25, and >25 years. The recalibrated results were compared with official data from the Rubber Authority of Thailand at the district level to ensure consistency and reliability before integration into the platform.

Transport cost modeling – outline

To connect the database with logistics decision-making, a transport cost framework was designed. The analysis considered road networks, travel speeds, and the relationship between supply points (plantations, collectors, sawmills, and processing factories) and demand points (biomass plants and power plants). Network analysis was applied using shortest path, least-cost path, and cost-distance approaches. Cost parameters included transport cost per kilometer per ton, vehicle type, load capacity, loading/unloading costs, and travel time constraints. The expected outputs were minimum distance, time, and cost per route, the supply areas that each plant can serve, and efficient allocation of transportation routes. Numerical results of the cost model are presented in the results section.

Development of a biomass management platform with innovations using information technology and digital technology

The biomass management platform was developed by the research team in collaboration with key stakeholders in the rubber wood biomass supply chain. Its aim was to increase business value and improve the efficiency of information exchange between producers and consumers. The platform was also designed to support the sustainable use of biomass resources through digital connection, data visualization, and system performance evaluation. The development process was divided into five steps, as described below.

Design and development of the prototype

The development began with designing a prototype using Google Maps to display biomass sources from rubber wood. The prototype played a critical role in testing the main concept, collecting user feedback, and reducing risks before creating the full version. The design emphasized simplicity and usability, with appropriate use of colors, fonts, icons, text, and responsive buttons that allowed users to interact quickly and easily.

Application development on Android and iOS

A mobile application prototype was created for both Android and iOS platforms. Input was drawn from focus group discussions with stakeholders such as rubber plantation owners, sawmills, processing factories, biomass producers, and biomass power plants. The application included several functions: system login, display of plantation data by age and size within a 5–10 km radius, summary of plantation data by province and district, connection to Google Maps for navigation, and visualization of four key stakeholder groups.

Route and transport cost analysis

The application was also designed to calculate transport routes and costs. Users could select their own starting and ending points, either from plantations or facilities, to identify the lowest-cost route for buying, selling, or combined transactions. This function was intended to improve decision-making in biomass supply chain logistics.

System testing and evaluation

The prototype was tested using the Black Box Testing method to evaluate efficiency, accuracy, and user satisfaction. A questionnaire was designed with two main sections: efficiency and functional requirements, and usability. The questionnaire was validated by five experts through content validity checks (IOC $\geq$ 0.50) and revised based on their suggestions. Reliability testing was conducted using Cronbach's alpha with a pre-test on a small group before actual field use.

Stakeholder participation

Hands-on workshops were organized to present and test the platform with stakeholders. Participants were invited to use the application directly, explore key functions (such as searching and filtering plantations and facilities, summarizing data by province and district, connecting to Google Maps, and calculating transport routes), and then provide feedback through the validated questionnaire. Their comments and suggestions were used to improve the data structure, user interface (UI), and calculation modules of the platform before its wider deployment.

Results and discussion

The preliminary results of the platform development research, conducted under the specified research methodology, are as follows. Initially, the results include the development of a biomass database from rubber trees and databases for sawmills, rubber wood processing plants, biomass production plants from rubber trees, and bioenergy power plants. Subsequently, a prototype biomass platform was designed and developed using data from rubber trees and various plant databases for bioenergy power plants. Furthermore, a satisfaction evaluation was conducted among users who accessed and used the prototype platform application on mobile or tablet devices. Therefore, all results are presented as follows.

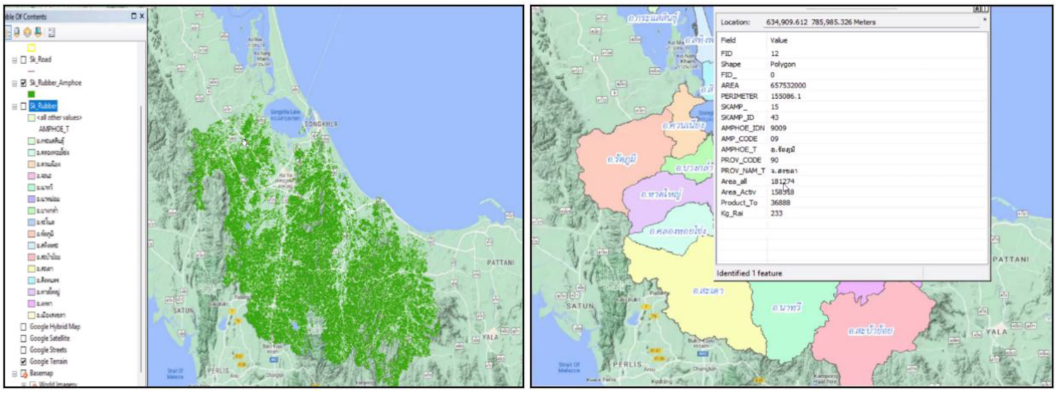
Study, collection, and data compilation for establishing a rubber plantation area database and assessing the age of rubber trees using geographic information system (GIS) have the following details:

The survey data from the Thai Rubber Authority in 2020 reveals changes in rubber plantation areas in the southern region over the past five years. Some districts have seen an increase, while others have experienced a decrease. Consequently, there is a need to update rubber plantation area data for each district to ensure its accuracy. The new area is calculated using descriptive data from the GIS database. However, the spatial data from the original rubber plantation areas in 2015 is retained due to the time and cost associated with updating it using satellite imagery. The area (in hectares) of each polygon for the 2015 rubber plantation areas is calculated as a percentage of the total planting area per district. This percentage is then applied to the total planting area for 2020, derived by multiplying the percentage from 2015 by the total planting area for each district in 2020. Subsequently, the age range of the new rubber trees is calculated by adding five years to the latest satellite imagery data in 2018. Age groups are divided into three ranges: 1) 7-14 years, 2) 14-20 years, and 3) >20 years. The age range of the new rubber trees is calculated in the GIS database as attributes, resulting in three age ranges: 1) 12-19 years, 2) 19-25 years, and 3) >25 years. The testing results are presented in Table 1, and this data is utilized to develop a database specifying rubber plantation areas and the age of rubber trees. Figures 2 to 4 depict this information, which is crucial for the development of a platform managing the rubber biomass supply chain in the next phase.

District	Data from the Survey Year: 2015	Age of Rubber Trees >27	Age of Rubber Trees 21-27	Age of Rubber Trees 14-21	Unclassified	Data from Estimation Year: 2020	RAOT Data Year: 2020
Krasae Sin	6,962.70	712.17	3,192.97	1,846.16	4,017.70	9,769.00	9,765.00
Khlong Hoi Khong	55,531.18	46,235.17	25,644.02	32,308.68	2,440.05	106,627.92	106,628.00
Khuan Niang	32,671.86	13,610.63	12,799.82	13,501.00	10,476.55	50,388.00	50,388.00
Chana	198,535.60	90,908.63	30,933.56	52,946.34	49,094.43	223,882.96	223,883.00
Thepha	213,643.85	172,441.80	39,108.15	46,065.63	6,355.39	263,970.97	263,971.00
Na Thawi	366,856.35	184,792.22	29,080.14	92,352.89	11,001.18	317,226.43	317,227.00
Na Mom	39,678.02	14,749.22	9,256.92	16,551.88	19,275.91	59,833.93	59,834.00
Bang Klam	27,030.63	16,291.11	6,781.16	9,659.55	1,976.22	34,708.04	34,798.00
Mueang Songkhla	32,208.75	15,235.41	4,134.40	5,022.95	8,048.26	32,441.02	32,441.00
Rattaphum	169,361.04	36,294.77	51,596.44	44,251.94	49,130.42	181,273.57	181,274.00
Sadao	380,919.13	279,264.37	73,229.59	74,657.36	8,809.20	435,960.52	435,961.00
Saba Yoi	269,963.30	160,603.70	39,059.55	76,851.71	22,165.19	298,680.15	298,680.00
Hat Yai	204,380.81	72,220.77	44,831.01	45,856.73	45,795.85	208,704.36	208,713.00
Ranot	-	-	-	-	-	-	30.00
Sathing Phra	-	-	-	-	-	-	172.00
Singhana-kron	-	-	-	-	-	-	491.00

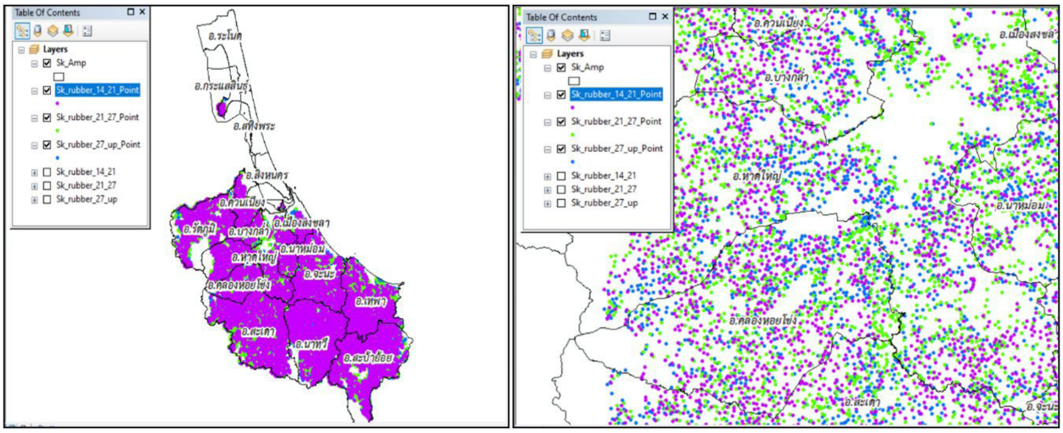
Source: Rubber Authority of Thailand (RAOT), 2020

Table 1: Estimation of rubber plantation area in 2020 based on 2015 data compared with Rubber Authority of Thailand (RAOT). Data for 2020.



Source: Authors' own work

Figure 2: Example data from the assessment of rubber plantation area and age of new rubber trees.



Source: Authors' own work

Figure 3: Spatial database in the Geographic Information System (GIS) showing rubber plantation areas in Songkhla Province.

Sk_rubber_14_21_Point

Shape	OBJECTID	NAME_T	PV_TN	AP_TN	Rai_63	Class_New	ORIG_FID	POINT_X	POINT_Y
Point	15295	ยางพารา	สงขลา	สะบ้าย้อย	53.82214	14 - 21 ปี	18	100.903918	6.353916
Point	15296	ยางพารา	สงขลา	สะบ้าย้อย	23.2373	14 - 21 ปี	19	100.89357	6.354916
Point	15297	ยางพารา	สงขลา	สะบ้าย้อย	18.69737	14 - 21 ปี	20	100.919022	6.354417
Point	15298	ยางพารา	สงขลา	สะบ้าย้อย	38.23104	14 - 21 ปี	21	100.889266	6.354899
Point	15299	ยางพารา	สงขลา	สะบ้าย้อย	26.91107	14 - 21 ปี	22	100.908081	6.355608
Point	15300	ยางพารา	สงขลา	สะบ้าย้อย	206.35801	14 - 21 ปี	23	100.916103	6.353126
Point	15301	ยางพารา	สงขลา	สะบ้าย้อย	46.83302	14 - 21 ปี	24	100.910329	6.357444
Point	15302	ยางพารา	สงขลา	สะบ้าย้อย	12.0368	14 - 21 ปี	25	100.904026	6.359826
Point	15303	ยางพารา	สงขลา	สะบ้าย้อย	119.41226	14 - 21 ปี	26	100.895938	6.358817
Point	15304	ยางพารา	สงขลา	สะบ้าย้อย	72.69871	14 - 21 ปี	27	100.923122	6.361924

Source: Authors' own work

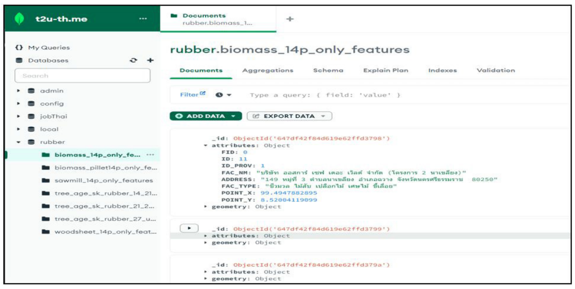
Figure 4: Descriptive database in the Geographic Information System (GIS) showing rubber plantation areas in Songkhla Province

Establishment of a database for wood sawmills, rubber wood processing plants, biomass production facilities from rubber wood, and biomass power plants

For data collection to establish a database for the four user groups in the biomass industry, namely wood sawmills, rubber wood processing plants, biomass production facilities from rubber wood, and biomass power plants, preliminary data has been gathered by obtaining geographical information from the Department of Factories and the Ministry of Energy. This data is then cross verified against business operations and locations using Google Maps. Upon examination, it was found that there is up-to-date information in the southern region across all 14 provinces. Specifically, the wood sawmill group has 450 factories, rubber wood processing plants have 30, biomass production facilities from rubber wood have 39, and biomass power plants have 82. The data is then visualized using coordinates obtained through the Global Positioning System (GPS) and imported into the ArcGIS program to create a comprehensive database. This allows the connection of attribute data for each group of factories with spatial data, and the presentation of this information is depicted on the map, as shown in Figure 5.

Design and development of a prototype for the platform

The Prototype, functioning as a platform displaying biomass data from rubber wood on Google Maps, is a crucial tool to support the development of Thailand's bio-based economy. It facilitates easier access for users to information about biomass from rubber wood, leading to more efficient and sustainable utilization of this resource. This software will be the initial version with tested functionalities, and the prototype design is a key step in the software development process. It allows the development team to test software concepts and address any shortcomings before proceeding with the development of the full version. In this process, various program components are created to build the prototype platform, showcasing the database system and data on the mobile application screen, as illustrated in Figures 6 and 7.

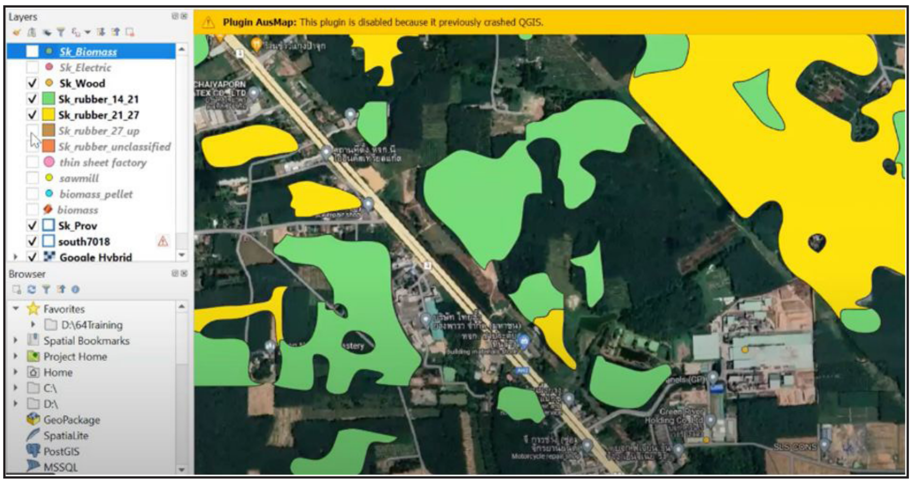


Source: Authors' own work

Figure 6: Database of the biomass platform from rubber wood.

Source: Authors' own work

Figure 7: Example of program code for the map generation to display data.



Source: Authors' own work

Figure 5: Example data and database development for wood sawmills, rubber wood processing plants, biomass production facilities from rubber wood, and biomass power plants.

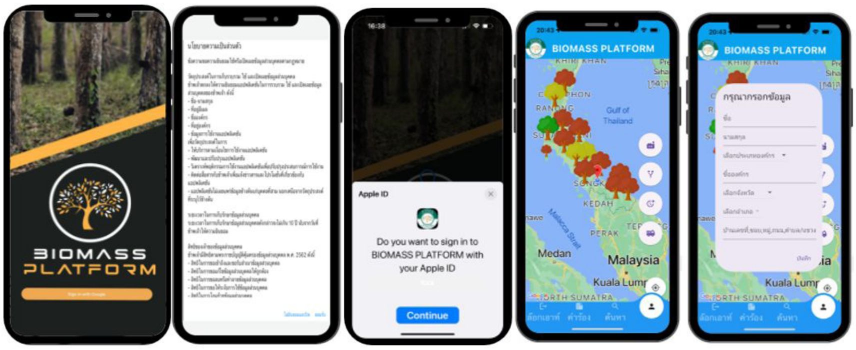
The data is displayed through the application on both Android and iOS operating systems. The operational results, as well as details regarding the application's design and functionality, are outlined as follows:

1. Initial access to the application during system. Testing Users can access the application on both platforms, as illustrated in Figure 8. Next, the initial screen displayed when users access the application on both Android and iOS platforms in Figure 9.

Source: Authors' own work

Figure 8: The logo representing the application, which is available on both Android and iOS operating systems.to display data.

For the user interface through the application, users can search for information on the types of industries they are interested in, specifically rubber plantations. These can be categorized into three sizes: 1) Small rubber plantations (rubber trees with a size of 1-50 rai), 2) Medium-sized rubber plantations (rubber trees with a size of 51-100 rai), and 3) Large rubber plantations (rubber trees with a size larger than 100 rai). Additionally, the system can categorize rubber plantations based on the age of the rubber trees, as illustrated in Figure 10. The application displays rubber plantations within predefined distances, initially set at 5 kilometers and 10 kilometers. It also estimates the transportation distances along actual transportation routes in Figure 11.



Source: Authors' own work

Figure 9: The initial screen displayed when users access the application.

Source: Authors' own work

Figure 10: Display through the application - information on the interested industry types, rubber plantations, and the age categories of rubber trees.

Source: Authors' own work

Figure 11: Display through the application - displaying rubber plantations within the defined distance and estimating transportation distances.

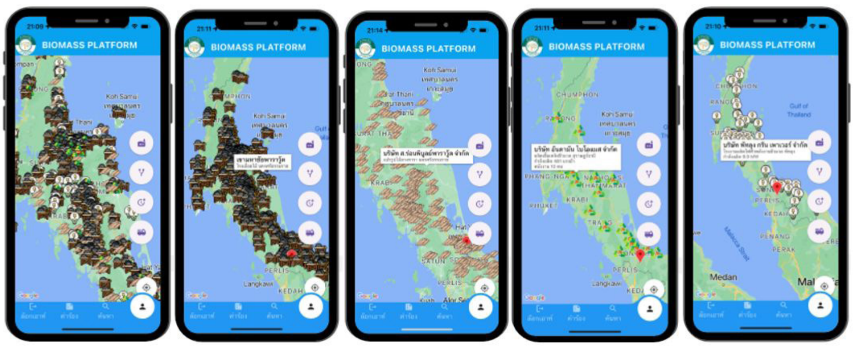
Moreover, data display of the four key business groups related to the rubberwood supply chain: This includes sawmills, rubberwood processing plants, biomass pellet production plants, and biomass power plants. The application is designed to display information specifically for sawmills and rubberwood processing plants, as illustrated in Figure 12.

Estimating transportation routes and optimal costs for managing rubberwood biomass fuel

In addition to displaying basic data based on the creation of the database, route identification, and cost estimation for transportation in accordance with the research project's objectives, the application should also allow users to estimate their own transportation routes. This feature would enable users to connect routes from rubber plantations and the four key business groups, allowing them to set their own starting and ending points without restriction. This capability can be used for purchasing, selling, or both simultaneously, with the goal of selecting the route that minimizes transportation costs for each trip. This is illustrated in Figure 13, which shows the estimated transportation routes and costs for managing rubberwood biomass fuel between rubber plantations and related four industrial groups.

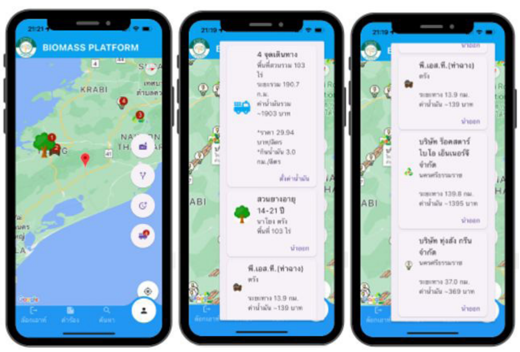
Evaluation of the prototype platform for rubberwood biomass supply chain management

In the system development phase (Construction), after the programmers completed the coding process based on the design, the next step involved testing the program to ensure its correctness according to the specified requirements. Additionally, user manuals were created, and relevant personnel were trained to understand and efficiently use the system. The most used testing method for such systems is Black Box Testing, which focuses on evaluating the input and output data without assessing the internal processing mechanisms. Before the system was launched, the research team performed Black Box Testing to evaluate the system's efficiency, functionality, and usability. Specifically, the system's performance was evaluated in three areas: 1) Efficiency, to determine how effectively the system operates; and 3) Usability, to assess user satisfaction and identify any system errors.



Source: Authors' own work

Figure 12: The data display of the four key business groups related to the rubberwood supply chain.



Source: Authors' own work

Figure 13: Estimating transportation routes and costs for managing rubberwood biomass fuel between rubber plantations and industrial groups.

The evaluation was conducted using a survey, which was designed and validated by five experts who examined the Index of Objective Congruence (IOC). Only questions with an IOC score above 0.50 were included, and the language and phrasing were reviewed to ensure the questionnaire was comprehensive. After revisions, a pre-test was conducted with a sample of 10 individuals, including rubber plantation owners, sawmill operators, rubberwood processing industry representatives, biomass factory workers, and biomass power plant personnel. The reliability coefficient (Cronbach's alpha) was 0.970, indicating that the questionnaire was sufficiently reliable for data collection.

Subsequently, a stakeholder feedback session was organized, and the technology was transferred through a workshop held on Saturday, December 16, 2023. The mobile application platform, which presents a database of stakeholders in the rubberwood biomass supply chain, was demonstrated and evaluated by 30 participants from the southern region of Thailand. The evaluation results are presented in Tables 2 and 3, and further details are as follows below.

Category	Participant	Percentage (%)
1. Gender		
- Male	20	66.67
- Female	10	33.33
2. Age Group		
- Less than 18 years	0	0
- 20–25 years	0	0
- 25–30 years	5	16.67
- 30–45 years	19	63.33
- 45–50 years	2	6.67
- 50–60 years	2	6.67
- Over 60 years	2	6.67
3. Education Level		
- No formal education	0	0
- High school education	0	0
- Primary education	0	0
- Vocational education	0	0
- Bachelor's degree	26	86.67
- Postgraduate degree	4	13.33
4. Involvement in Industry		
- Rubber plantation	2	6.67
- Middleman for rubberwood trading	2	6.67
- Rubberwood factory/sawmill	8	26.67
- Rubberwood processing plant	7	23.33
- Biomass production facility	2	6.67
- Biomass power plant	8	26.67
- Government agency/academic	1	6.67
- Other	0	0
5. Operating System Used*		
- Android	17	47.22
- iOS	19	52.78
6. Recommendation to Others		
- Would recommend	29	96.67
- Would not recommend	0	0
- Not sure	1	3.33

Note: *Participants were allowed to select more than one operating system.
Source: Authors' survey (2024)

Table 2: Demographic information of respondents (n = 30).

Factor	Average	Standard Deviation	Importance Level
1. Efficiency and Functional Requirements			
- The application has reliable security features	4.733	0.583	High
- User authentication is required every time before use	4.533	0.73	High
- The application is accurate and reliable	4.367	0.615	High
- Users can access the application anytime, anywhere	4.833	0.461	High
- Data processing is accurate and reliable	4.033	0.669	High
- The application provides detailed, comprehensive data	4.5	0.572	High
- The services meet user requirements	4.5	0.572	High
- The application is beneficial for work and analysis	4.8	0.484	High
2. Usability Test			
- The application is clear, modern, and easy to use	4.033	0.765	High
- Icons are understandable and appropriate	4.367	0.809	High
- The position, shape, and color of icons are suitable	4.167	0.699	High
- Font size and color are clear in both orientations	4.333	0.661	High
- The application is appropriate for mobile/tablet use	4.267	0.583	High
- The application responds quickly and efficiently	4.067	0.828	High
- Displayed data is detailed and complete	4.167	0.747	High
- The application is stable	4.1	0.548	High
- No errors were encountered during use	4.233	0.504	High

Source: Authors' survey (2024)

Table 3: Factors influencing the platform for rubberwood biomass supply chain management.

In evaluating the platform's performance regarding Efficiency and Functional Requirements, a survey of 30 users involved in both rubberwood biomass production and rubberwood processing indicated high overall satisfaction with the platform on both Android and iOS operating systems, with an average score of 4.538. At the factor level, the platform was rated highly for having a reliable security system for access, receiving average satisfaction scores of 4.733 and 4.533 on Android and iOS, respectively. Additionally, users expressed a high level of satisfaction with the platform's accessibility, as it can be used anytime and anywhere, achieving an average score of 4.833. The accuracy and reliability of the data and processing results were also positively evaluated, with average scores of 4.033 and 4.500. Moreover, users expressed high satisfaction with the platform's detailed and comprehensive database, which effectively met their requirements, earning an average score of 4.500. The platform was also found to be highly beneficial for facilitating users' work and analysis, with an impressive average score of 4.800.

In terms of usability, the platform's overall performance on both Android and iOS was rated very highly, with an average score of 4.504. When evaluating satisfaction at the factor level, it was found that the application was clear, easy to understand, modern, and user-friendly, earning a satisfaction score of 4.033. The icons displayed within the application were deemed easily understandable and appropriate, with an average score of 4.367. The positioning, shape, size, and color of the icons representing the data were also rated as suitable and accurate, with an average score of 4.167. The font size and color on the display were rated highly for clarity, both in horizontal and vertical orientations when adjusting the mobile device or tablet's direction, achieving an average score of 4.333. Additionally, the application was considered highly suitable for mobile or tablet use, with an average score of 4.267. Users also praised the platform's responsiveness, citing its convenience and speed, with an average score of 4.067. For data display, the information provided by the application was rated as detailed, complete, and stable, with average scores of 4.167 and 4.100, respectively. Finally, users reported no errors during the use of the application on either operating system, with an average satisfaction score of 4.233.

The development of the platform for managing the rubberwood biomass supply chain has shown promising results, especially in terms of its ability to gather and present important data for different stakeholders. The use of Geographic Information System (GIS) technology allowed for the accurate collection of data about rubber plantation areas and the age of rubber trees. This is crucial for the efficient management of biomass resources, as it helps users understand the distribution of biomass potential in the region. By accurately calculating plantation areas and tree ages, the platform supports better planning for rubberwood harvesting and biomass utilization. Moreover, the creation of databases for sawmills, rubberwood processing plants, biomass production facilities, and biomass power plants ensures that all important players in the supply chain are connected. Users can access this information through the platform, which improves communication and coordination among businesses. This is particularly useful for industries that rely on biomass resources for energy production, as it allows them to better manage their operations and make informed decisions about sourcing and transportation.

The results of the user satisfaction survey indicate that the platform is highly effective in terms of both efficiency and usability. Users found the platform to be secure, with a reliable authentication system, and were satisfied with how quickly they could access data. The ability to use the platform on both Android and iOS operating systems added to its accessibility, making it more convenient for a wide range of users. The platform's ability to display detailed and accurate data, especially concerning the biomass supply chain, was also rated highly by users. This suggests that the platform meets the needs of its users by providing them with relevant and easy-to-understand information. Additionally, the usability test showed that users found the platform to be modern, clear, and easy to navigate. The icons and user interface were well-designed, making it simple for users to find the information they needed. The application's ability to adjust to both horizontal and vertical orientations on mobile devices further improved the user experience, as it allowed for more flexible use in different settings.

Overall, the platform succeeded in addressing the main challenges faced by stakeholders in the rubberwood biomass industry. By offering a tool that integrates data from multiple sources and allows for accurate transportation route and cost estimation, the platform enhances the efficiency of biomass management. The high user satisfaction scores across various aspects of the platform —security, accuracy, and usability—highlight its effectiveness in meeting the goals of the research project.

The limitation of this research lies in its geographic scope, as the platform was developed specifically for rubberwood biomass supply chains in only 14 provinces of Southern Thailand. Consequently, the platform's findings and functionalities may not be directly applicable to other regions or nationwide without substantial adaptation. Furthermore, the data utilized such as plantation areas and tree ages were based on secondary sources, which may not accurately reflect real-time conditions or recent changes in biomass availability. Therefore, future research should focus on expanding the platform's geographic scope to cover the entire country. This would involve the collection of primary, real-time data to ensure more accurate and current information on plantation areas, biomass availability, and tree age. Moreover, the platform could be tailored to specific regions by factoring in local conditions, such as varying climate patterns, transportation infrastructure, and regional industry requirements. Such an approach would broaden the platform's utility, making it more effective for nationwide biomass management and strategic decision-making.

Conclusion

The study aimed to plan and manage biomass fuel resources in alignment with the needs of industries and biomass power plants. Initially, data collection was conducted through focus group discussions with rubber plantation owners and factory representatives to identify their requirements for a platform to manage rubberwood biomass. The discussions revealed that platform users required quantitative data, such as information on rubber plantation areas, the location of plantations, and related factories for the rubberwood biomass supply chain across 14 southern provinces. Additionally, the need for linking this information to support users in estimating biomass volumes and planning biomass collection, including managing transportation costs such as distance, time, and fuel expenses, was highlighted.

As a result, this data was used as a guideline for creating a biomass database for stakeholders in the rubberwood biomass supply chain, utilizing Geographic Information Systems (GIS) to represent plantation areas and locations. The rubber plantation database was updated using 2015 GIS data combined with secondary data from 2020. The updated plantation area and rubber tree age ranges were calculated, dividing the tree age into three groups: 1) 14-20 years, 2) 21-27 years, and 3) over 27 years. Additionally, databases were established for four main factory groups within the biomass industry: sawmills, rubberwood processing plants, biomass production facilities, and biomass power plants, covering all 14 southern provinces. The data, referenced from 2022-2023, served as the basis for developing a prototype platform capable of functioning on both Android and iOS operating systems as a mobile application.

Finally, technology transfer activities, such as workshops and focus group discussions, were conducted to verify the database and evaluate the platform's performance in terms of both efficiency and functional requirements, as well as usability on both operating systems. The evaluation results for both aspects showed a very high level of performance, with average scores of 4.538 and 4.504, respectively.

Corresponding author:
Sirirat Pungchompoo
Department of Industrial and Manufacturing Engineering, Faculty of Engineering
Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla 90110, Thailand
E-mail: sirirat.pu@psu.ac.th

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