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Abstract

Agricultural residues have emerged as promising bioenergy feedstocks for replacing fossil fuels. However, biomass residue potential is abundant and available throughout the year, and needs to be optimally utilized. A lack of optimal residue utilization can cause open burning during the postharvest period, which could result in environmental problems. Therefore, a comprehensive solution that considers the sustainability aspects and actual data is required for the design and development of these programs.

In the literature, designing the biomass residue value chain should determine the hierarchical decision-making into three levels: strategic, tactical, and operational, which depend on space and time dimensions. Furthermore, this study addresses two crucial subjects: stakeholders' willingness to participate in valorization programs is fundamental to developing a strategic plan and the economic feasibility of the rice straw supply chain at the tactical decision-making level. Production and harvesting areas are essential for identifying the potential for rice straw valorization in East Java Province, Indonesia. Simultaneously, stakeholders' (e.g., farmers, governments, academics, and entrepreneurs) opinions and expectations were utilized to present actors' relationships and obtain the performance value of programs.

Herein, farmers' willingness was obtained through a survey to identify the amount of biomass that would be supplied as feedstock. The data were analyzed using statistical data analysis and clustering methods using multiple correspondence analysis (MCA). The results are then used as a basis to identify stakeholders' roles (i.e., policymakers, the government, academics, and entrepreneurs) in providing technical and financial facilities, as well as how to extend the plan and implementation of policies and regulations issued to support valorization programs. Stakeholders' roles and structures were investigated through mapping, which was incorporated into the classical approach by considering their decision-making levels. Finally, considering the amount of rice straw availability discovered from farmers' willingness and stakeholders' participation, we propose to organize economic efficiency for optimal material flow, transportation, and storage, considering centralized and decentralized distribution networks to reduce the challenge.

Résumé

Les résidus agricoles sont devenus des matières premières bioénergétiques prometteuses pour remplacer les combustibles fossiles. Cependant, le potentiel des résidus de biomasse est abondant et disponible tout au long de l'année, et doit être utilisé de manière optimale. L'absence d'une utilisation optimale des résidus peut entraîner un brûlage à l'air libre pendant la période post-récolte, ce qui pourrait entraîner des problèmes environnementaux. Par conséquent, une solution globale qui prend en compte les aspects de durabilité et les données réelles est nécessaire pour la conception et le développement de ces programmes.

Dans la littérature, la conception de la chaîne de valeur des résidus de biomasse doit déterminer la prise de décision hiérarchique en trois niveaux: stratégique, tactique et opérationnel, qui dépendent des dimensions spatiales et temporelles. En outre, cette étude aborde deux sujets cruciaux: la volonté des parties prenantes de participer aux programmes de valorisation est fondamentale pour développer un plan stratégique et la faisabilité économique de la chaîne d'approvisionnement en paille de riz au niveau de la prise de décision tactique. Les zones de production et de récolte sont essentielles pour identifier le potentiel de valorisation de la paille de riz dans la province de Java Est, en Indonésie. Simultanément, les opinions et les attentes des parties prenantes (par exemple, les agriculteurs, les gouvernements, les universitaires et les entrepreneurs) ont été utilisées pour présenter les relations entre les acteurs et obtenir la valeur de performance des programmes.

Dans ce contexte, la désirabilitè des agriculteurs a été obtenue par le biais d'une enquête visant à identifier la quantité de biomasse qui serait fournie comme matière première. Les données ont été analysées à l'aide d'une analyse statistique des données et de méthodes de regroupement utilisant l'analyse des correspondances multiples (ACM). Les résultats sont ensuite utilisés comme base pour identifier les rôles des parties prenantes (c'est-à-dire les décideurs, le gouvernement, les universitaires et les entrepreneurs) dans la fourniture de facilités techniques et financières, ainsi que la manière d'étendre le plan et la mise en œuvre des politiques et des règlements émis pour soutenir les programmes de valorisation. Les rôles et les structures des parties prenantes ont été étudiés par le biais d'une cartographie, qui a été intégrée à l'approche classique en considérant leurs niveaux de décision. Enfin, compte tenu de la quantité de paille de riz disponible à partir du choix des agriculteurs et de la participation des parties prenantes, nous proposons d'organiser une chaine logistique durable.

Scientific production

Publishing article

1. Erry Ika Rhofita, Ridwan Rachmat, Michel Meyer, Ludovic Montastruc. **Mapping analysis of biomass residue valorization as the future green energy generation in Indonesia. Journal of Cleaner Production Volume 354,** 20 June 2022, 131667, doi: https://doi.org/10.1016/j.jclepro.2022.131667
2. Erry Ika Rhofita, Ridwan Rachmat, Michel Meyer, Ludovic Montastruc. **An Energy Potential Estimation of Rice Residue in Indonesia: A Case Study in East Java**. IOP Conference Series: Earth and Environmental Science 1024 012029. The 3rd International Conference on Agricultural Postharvest Handling and Processing. doi: 10.1088/1755-1315/1024/1/012029

Submission article

1. Erry Ika Rhofita, Rachid Ouaret, Ludovic Montastruc, Michel Meyer**. Mapping analysis of farmers' perceptions of biomass residue valorization as future green energy in Indonesia**. Environmental Development (under submission with editor)

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Chapter I. Introduction

1. Background

Fossil fuels have a vital role in human activities, which influence technological growth, development, and progress in all nations, and these have an effect on the economic, environmental, social, and security sectors. In the global energy context, fossil fuels have always had a significant share of consumption, which has continuously increased over time. It is predicted to increase by over 50% in 1995–2015 and by approximately 18% in 2015–2035 (Yıldız, 2018). It can be potentially catastrophic because fossil fuel energy has political and socioeconomic ramifications. The overload of utilization will impact the environment, climate change, depletion of global energy reserves, and public health (Oyedepo, 2012). However, in the future, fossil fuels will become obsolete in many countries due to a gradual decrease in their sources (Kılıç Depren et al., 2022). Therefore, improving biomass as clean energy sources is an option to reduce these problems and to replace fossil fuel applications (Kampman et al., 2010). For example, natural gas can be substituted by biogas produced from food waste, which is the most voluminous solid waste worldwide, via anaerobic fermentation. It is a reasonable and responsible option to intensify the economic value of residues (Maroušek et al., 2020). To support long-term energy demands, coal can be replaced by charred biowaste as a solid fuel that must meet economic energy prices and ecological criteria, such as carbon, nitrogen, and sulfur content (Mardoyan and Braun, 2015). Waste cooking or vegetable oil can be processed as biodiesel to substitute diesel oil for specific applications (i.e., public transport and hybrid or marine propulsion). Commercial biodiesel production must be financially analyzed to make it profitable at a competitive price for sustainability (Maroušek, 2015).

Biomass residue has great potential for exploitation and is an abundant resource for generating sustainable green energy (Siwal et al., 2021). The positive effects of biomass productivity on satisfying the world's energy demand can contribute significantly to environmental and socioeconomic development, particularly in rural areas (Kabir, 2021; Solarte-Toro et al., 2022). Biomass utilization can minimize environmental issues such as greenhouse emissions and climate change (Srivastava et al., 2021). Valorizing biomass for energy provides an opportunity to use better natural resources, such as reducing the competition of biomass products for food and industrial purposes, and can intensify waste management issues (Berndes et al., 2003; Cigolotti, 2012; Rasheed et al., 2021). Substituting locally generated biomass with fossil fuels increases energy and food security and provides economic and social development prospects by establishing long-term job opportunities (Jacobson and Ciolkosz, 2013).

Agricultural residue valorization is the most recent development in Indonesia, and an urgent design and plan are required to effectively and profitably implement projects to support green

energy development. Although these projects have the potential to contribute to community development in terms of sustainability, the application faces numerous barriers and challenges in a weak supply chain, including (i) an unstable feedstock supply, (ii) sustainability risks and uncertainty factors (i.e., biomass availability, weather, quality, and fluctuating costs), (iii) a lack of regulation and policy to control biomass quality and operational efficiency, and (iv) a lack of worker capability and competency. Furthermore, biomass valorization requires significant capital investment and ready-to-use operational and conversion technologies, and stakeholder awareness and willingness are key to engagement. Generally, the decision-making level in the biomass supply chain can be grouped into three categories: strategic (long-term), tactical (medium-term), and operational (short-term)(De Meyer et al., 2014; Yue et al., 2014b) (Murele et al., 2020; Pishvaee et al., 2021a).

The strategic level describes the parameters related to deciding the biomass requirement, for example, biomass variety; the type, number, location, and capacity of supply chain facilities; and material flow through the strategic network setting. Sustainability aspects were considered to guide the development of the biomass supply chain to select the locations of biomass procurement, actors in each echelon, market share, and material flow in the distribution network to minimize cost and environmental impacts (Kesharwani et al., 2018). Nagel, (2000) investigated how to develop the rural area by analyzing the economic feasibility of the significant influence of biomass potential and transportation distances for heat or power generation, as well as a selection of intermodal transport and supply chain configurations that should be implemented (de Jong et al., 2017), by identifying the specific links for biomass transportation and products delivered to markets (Paulo et al., 2015). Furthermore, Chinese and Meneghetti, (2005) and Dunnett et al., (2007) identified the impact of the biomass distribution network and material flow on electricity production by maximizing profit and minimizing operational costs. Moreover, to determine the biomass resources, technological and demand constraints were considered to minimize the total cost (Huang et al., 2010) (Ahn et al., 2015) (Cho and Kim, 2019). These were simultaneously applied to determine the locations and capacities of biorefineries, which aim to remove financial failure after all echelons are built (Alex Marvin et al., 2012). The strategic decision also determines the supply chain facilities' numbers, capacities, and locations (i.e., storage, pre-treatment, and power plants) to explore the proposed model before actual development is implemented (Balaman and Selim, 2014). The application of a geographic information system (GIS) could help secure environmental sustainability in deciding long-term planning, which is related to the most suitable candidate of resource and facility locations and conversion processes (Frombo et al., 2009) (Pishvaee et al., 2021b) (Van Holsbeeck and Srivastava, 2020).

Over time, the expansion of biomass supply is a priority to determine the optimal location and capacity of biomass resources and facilities through the projection of production and demand in the long term (Jonker et al., 2016). Specifically, social benefits (i.e., the number and location of

job creation) should be considered to determine the biomass procurement that influences economic value (Gao et al., 2019). Uncertainty factors (i.e., raw material price) require assessment to select the raw materials, products, processing technologies, location of facilities, and markets to obtain the best benefits from environmental and economic perspectives (Santibañez-Aguilar et al., 2016). Finally, the strategic design of the agri-biomass supply chain plays a crucial role in minimizing the cost of the energy produced and ensuring a continuous supply of feedstock. Rapid collection, efficient transportation, and secure storage of agri-biomass must be achieved from a systemic perspective.

On the other hand, the bottleneck of sustainable dimensions, technological, and political aspects should be analyzed to guarantee optimum and continuous activities in each echelon of the biomass supply chain. On the other hand, stakeholders' involvement in incorporating the sustainability view, including the acceptance and participation of societies, and the government's role in issuing policies, regulations, and programs (e.g., environmental protection policies, providing bioenergy production facilities, sustainable agriculture programs, tax subsidies, and incentives) should be practiced to improve the motivation of supply chain players (Jazinaninejad et al., 2022). This highlights how to drive stakeholders' awareness and willingness. Public campaigns and information-sharing activities can be applied to raise public, and business actor perceptions change. Accessible up-to-date information is a stimulant for identifying the availability and location of resources. Specifically, integrated cooperation between each stakeholder and infrastructure availability can strengthen support for project development, mainly in deciding the location, capacity, and number of facilities in the biomass supply chain.

The tactical level is the midstream of the biomass supply chain, which contains inventory planning and management and determines a long-lasting effect to improve the quality and quantity of the conversion process. At the same time, tactical and operational levels are more concerned with resource utilization efficiency to discover economic feasibility and mitigate environmental issues. The planning horizon for tactical decisions ranges from a few months to a year, and both strategic and operational problems affect it. Failure to control for these variables may result in suboptimal or even untenable supply chain decisions. Furthermore, the uncertainty and risk factors should be noted as a result of some issues, that is, (i) technological advancement, (ii) changing policies and regulations, (iii) fluctuating demand and prices, (iv) unpredictability of weather conditions, (v) fluctuations in operational costs, and (vi) natural disasters, which are obstacles to be solved to realize the integrated supply chain network design and models (Pishvaee et al., 2021c). Based on the available information linked to uncertain parameters, it is necessary to adopt an effective model for capturing such dynamics. Optimization using the superstructure approach can be applied to manage a complex model to identify and develop a systematic strategy. It is applied to discover material flow, location, and size in the synthesis of facilities to optimize the performance, input, and output in the biomass supply chain (Abdul Razik et al., 2019).

However, the development should consider several parameters, variables, and constraints to reduce the computationally intractable difficulties. Therefore, implementing scenario development in a biomass-to-bioenergy superstructure is essential for facilitating stakeholders in designing policies and regulations in the context of the economic condition of society, political and cultural aspects, technological applicability, and reducing environmental impact (Ayoub et al., 2009).

In this study, both the superstructure as a classical approach and the decision-making level were used to develop an agricultural residue valorization model based on supply chain echelons and stakeholders' willingness to participate. To the best of our knowledge, only a few studies have applied it. However, the actors' analysis and government roles have been investigated to optimize the biomass supply chain network and model (Jazinaninejad et al., 2022; Moreno-Camacho et al., 2019). Furthermore, from the standpoint of actors, farmers are the primary actors who should be actively involved in producing sustainable feedstock supplies. Simultaneously, stakeholders (i.e., governments, entrepreneurs, academics, and communities) should practice their role in providing the information and facilities identified by modeling to represent their expectations in improving project performance. Finally, the supply chain's economic feasibility is analyzed considering the distribution model network of inventory (i.e., centralized and decentralized modes) to develop efficient scenarios.

2. Research objective

The primary goal of this research is to design agricultural residues valorization, specifically rice straw, while taking production and harvesting areas into account to achieve more effective management in supply chain design. The specific objectives of this study are as follows:

1. To evaluate the potential of agricultural residues as bioenergy feedstock to determine the valorization strategy by considering the economic, environmental, and social pillars. To achieve this objective, the national scale was developed from statistical data and government reports.
2. To map and discover farmers' willingness and participation in rice straw valorization. This objective was achieved by using questionnaires and interviews to obtain data that were grouped according to the farmers' perception level. Barriers and challenges were evaluated to improve farmers' capacity to utilize agricultural residues.
3. To develop a stakeholder model that presents stakeholders' roles in supporting agricultural residue valorization. This objective was achieved by mapping and analyzing stakeholders' willingness and awareness.
4. To develop and solve an optimization model for tactical-level decisions. This model defines the material flow related to the quantity of biomass procured, stored, and used

to produce pellets each month during a one-year planning horizon to determine the best scenario in terms of economic feasibility. This objective was achieved by developing mathematical modeling by considering the classical approach of biomass supply chain (BSC) and performing a sensitivity analysis.

3. Organization of the dissertation

This manuscript is organized into seven chapters, which have detailed content in each chapter described in the schematic shown in Figure I-1.

Chapter I: Introduction. This section presents the motivation and objectives of this study.

Chapter II: Assessment the potential of agricultural residue in Indonesia as bioenergy production in Indonesia. This chapter identifies the total residue and power generation potential on a national scale, using statistical data and government reports. The findings will be used by stakeholders, particularly the government, to determine the design and plan for agricultural residue valorization to improve sustainability and support food and energy security.

Chapter III: A literature review of biomass residue supply chain: gaps and strategic direction. This chapter presents previous studies on the biomass residue supply chain in the literature, which focus on the sustainability aspects and decision-making level for determining future strategic analysis.

Chapter IV: Capturing of farmers' perceptions of agricultural residue valorization as bioenergy production in Indonesia. This chapter evaluates farmers' willingness and expectations to participate in agricultural residue valorization. The findings will be utilized to assess opportunities and barriers to improving farmers' capacities. Statistical data analysis and clustering methods using multiple correspondence analysis (MCA) were used to analyze the data. Furthermore, East Java Province in Indonesia was chosen as a case study because it produced the most rice, accounting for approximately 20% of Indonesia's total rice production.

Chapter V: Importing stakeholder participation to support agricultural residue valorization. This chapter presents the development of stakeholder scenarios for agricultural residue valorization. In more detail, integrated stakeholders' opinions and willingness to identify and manage actors and how their processes affect rice straw valorization are discussed. These findings can improve the motivation to support agricultural residue valorization through good governance by implementing the principles of accountability, transparency, efficiency, participation, and fairness.

Chapter VI: Tactical planning level of the agricultural residue supply chain: A real case in the economic optimization model. This chapter presents the suitability of supply chain development for agricultural residue through two global scenarios in centralized and decentralized distribution networks. The classical approach was integrated to determine system management at different levels. The system focuses on the tactical decision level in the medium term to address how to organize efficiency in economic aspects for optimal material flow, transportation, and storage.

Chapter VII: General conclusion and perspectives. This chapter describes the general conclusions of this study and recommendations for improving the performance of agricultural residue valorization in the future.

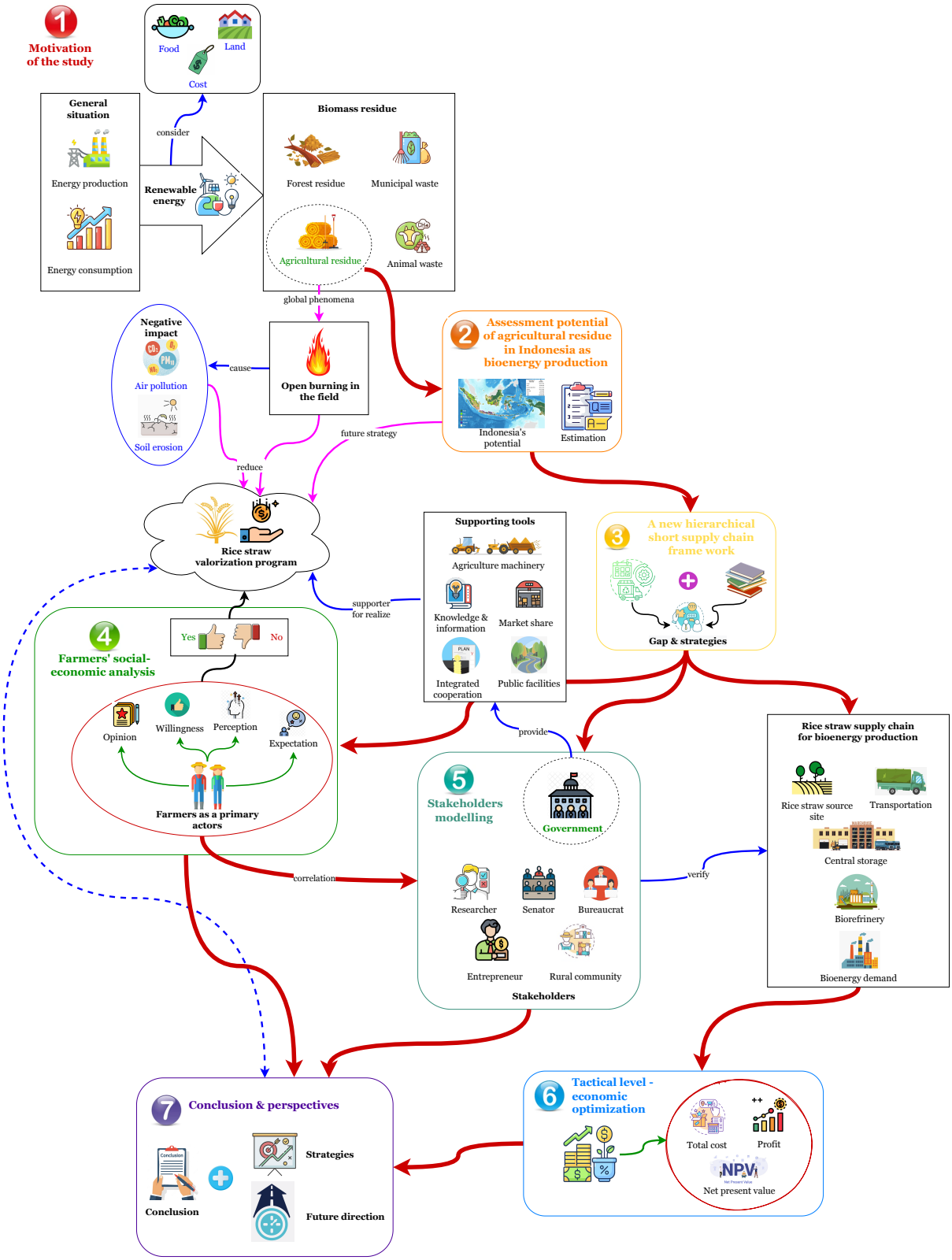


Figure I-1. Schematic description of the manuscript

Chapter II. Assessment the potential of agricultural residue in Indonesia as bioenergy production in Indonesia

1. Introduction

Biomass is biodegradable organic matter produced from plants or animals, and these derivative materials are obtained via natural or artificial transformation (Perea-Moreno et al., 2019). The direct application of biomass as clean energy would arise competition with food and several other industries, such as feed production and chemical products. Even indirectly, over the decade from 2003 to 2016, the volatility of agricultural prices (such as cereals, sugar, and vegetable oil) was affected by the crude oil price shock. High fuel prices have increased biofuel production, creating a relationship between crude oil and food price (Oláh et al., 2017). A growing biofuel product also has immense potential to cause various environmental issues, such as land-use competition, direct and indirect land-use changes, deforestation, and water supply pressure. Land availability for biomass cultivation is minimal, owing to the rapidly growing population. Therefore, marginal and degraded land optimization is required to solve the conflict between food, industry, and fuel production and to offer sustainable development according to the community's requirements (Edrisi and Abhilash, 2016). However, these issues can be resolved by utilizing biomass residue as a raw material for energy generation. Biomass residue utilization could provide multipurpose benefits for economic quality improvement through community empowerment, such as creating new jobs, promoting regional development, and regaining ecosystem quality.

Biomass resources are most closely related to territory, which is defined by its quantity and characteristics based on geographical, economic, and social factors (Wang et al., 2017). Geographically, climate and spatial models determine biomass availability; therefore, to develop a potential assessment method, the dimensions of time and location should be considered (Chinnici et al., 2015). The annual crop and forest residue variation is determined by the spatial distribution at the state and municipal levels, considering that the high availability of residue depends on the seasonal cropping cycle and the soil quality in a region (Honorato-Salazar and Sadhukhan, 2020). Indirectly, climatic conditions affect the diversity of agricultural crop production. For example, different geographic areas (i.e., 16 European Union countries and India, China, Pakistan, Nigeria, Cameroon, Uganda, and Turkey) will influence the characteristics of biomass residue, such as residue product ratio, moisture content, and heating value (Avcıoğlu et al., 2019).

The first step in utilizing biomass and its residues is to investigate the energy potential generated on different scales (i.e., local, regional, and national). Some factors should be considered, including (i) the biomass scope and boundary for biomass in a specific period; (ii) the types of

biomass potential (e.g., theoretical, technical, economic, and sustainable); and (iii) methodologies and approaches for calculating biomass potential. The methodologies used to assess biomass potential can be categorized as resource-focused, demand-driven, and integrated approaches (Batidzirai et al., 2012), as shown in Figure II-1. As mentioned in this statement, the methodology is an essential and detailed procedure that consists of the accuracy of the underlying assumptions and data correlation, which is consistent with a particular approach based on the characteristics of the location.

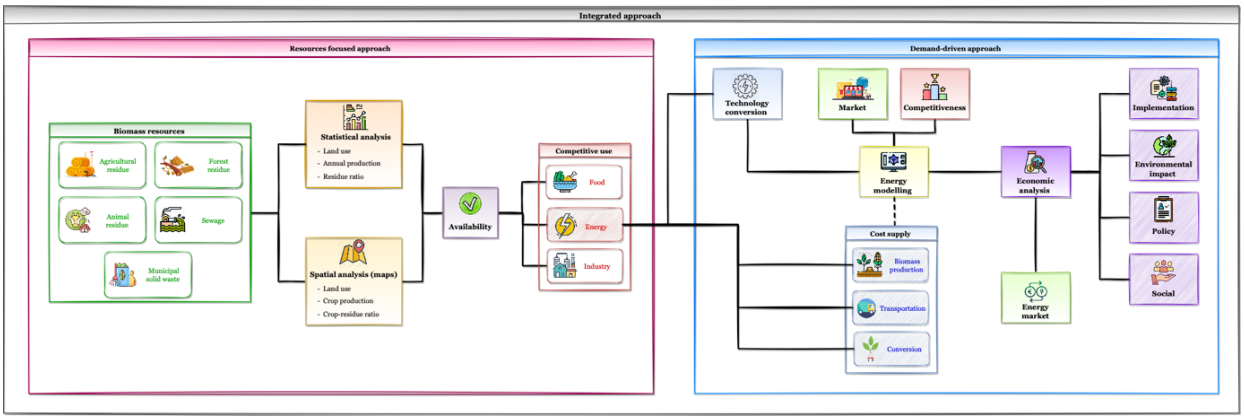


Figure II-1. Biomass assessment approach

A resource-focused approach estimates theoretical and technical potential through statistical data and spatial methods. Theoretical potential refers to the maximum quantity of biomass available for producing bioenergy, ignoring all practical limitations. For biomass residue, the theoretical potential is similar to that of total residue production. Technical potential is a fraction of the theoretical potential when considering technology restrictions, material competition, environmental criteria, and non-technical factors (Batidzirai et al., 2012). Using statistical data is a simple method for estimating the potential of agricultural and forest residues to generate energy for heat and electricity. It has been investigated by several researchers in almost all countries except Indonesia, such as Zimbabwe (Jingura and Matengaifa, 2008), Nigeria (Iye and Bilsborrow, 2013), India (Hiloidhari et al., 2014), Argentina (Roberts et al., 2015), Serbia (Nakomcic-Smaragdakis et al., 2016), Chile (Román-Figueroa et al., 2017), Ethiopia (Gabisa and Gheewala, 2018), Bolivia (Morato et al., 2019), and Turkey (Avcıoğlu et al., 2019). Another researcher applied Monte Carlo algorithm analysis to quantify the uncertainties of theoretical and technical energy potential estimations owing to limited data (Gonzalez-Salazar et al., 2014a). However, it requires the integration of probabilistic propagation, sensitivity analysis, and disaggregated sub-models to evaluate the reliability and reduce the associated uncertainty. The method was applied in Columbia, where the theoretical energy potential was 774 PJ, and the technical potential was 59 PJ in 2010. Probabilistic models have been analyzed using 1000000 Monte Carlo simulations, which exploit the energy of crop residue and animal dung estimated at 26.6 PJ and 16.9 PJ, respectively (Maqhuzu et al., 2017a). Other methods utilize three scenarios, that is progressive, optimistic, and

conservative, to evaluate the potential energy of agricultural biomass in Croatia (Bilandzija et al., 2018).

Beyond the statistical data, spatial data analysis is a fundamental method to assess the availability and distribution of biomass potential, which is a consideration of conservation issues, i.e., resources (total amount, spatial and temporal distribution), economy (transportation costs), environment, and technology (Jiang et al., 2012a). Spatial information also describes land cover, expected biomass productivity (derived from soil parameters, climatic zones, and topographical conditions), and the distribution of power plants to assess agricultural residue potential in the European Union (Monforti et al., 2013). The application of the Geographical Information Systems (GIS) database to evaluate biomass residue was studied by (Fernandes and Costa, 2010), (Gómez et al., 2010), (Lourinho and Brito, 2015), and (Pande et al., 2021). Furthermore, GIS can be used to assess the feasibility and optimization of biomass power plants (Singh et al., 2011). When sustainability parameters view modeling, the integration between statistical and spatial analysis can be considered to develop economic analysis, environmental values, and social criteria (Ketzer et al., 2017) to support sustainable agricultural production (Zhang et al. 2021). In more detail the biomass site was selected and determined by statistical analysis, and the suitability of the economic and social aspects of the biorefinery and power plant locations could be accurately identified by GIS (Venier and Yabar, 2017).

The second method, the demand-driven approach, focuses on implementing technical and theoretical potential, which is also discussed in cost-supply energy production (i.e., production, transportation, and conversion costs) and energy and economic modeling. Some studies have implemented this method to identify the supply of biorefinery feedstock in Brazil (Forster-Carneiro et al., 2013), and the economic analysis was evaluated to develop power generation using various technologies in South East Asia (Stich et al., 2017). (Zheng and Qiu, 2020) investigated the correlation between social aspects (i.e., worker availability) and economic viability for providing biorefinery sites and biomass resources by examining the sites' access to the road network and feasible transport area. However, a decade ago, an integrated approach was designed to assess policy options for climate change by calculating the correlation between socioeconomic activities and energy utilization. Specifically, it was applied to analyze the impact of biomass energy on air, biodiversity, soil, water, and employment by evaluating environmental competitiveness and land-use change modeling (M.W. Vis and D. Van Den Berg, 2010). The complete biomass assessment methodology starting in 2005 and ending in 2021 is shown in Table II-1.

Based on the explanation above, this chapter aims to identify and calculate the actual amount of agricultural residues and their energy generation in the nation based on statistics, government reports, and a comprehensive literature review to determine the scenario of efficient energy generation. The findings provide information on the potential of agricultural residues, which could be a recommendation for stakeholders to design, plan, and promote their benefits as a green

energy source in Indonesia. Producing renewable energy from agricultural waste could have positive effects on society and the environment, such as increasing energy security, enhancing socioeconomic conditions, reducing environmental issues, and decreasing reliance on fossil fuels. Therefore, in the future, the awareness and willingness of the community to participate in the valorization program can be raised.

Table II-1. Summary of the publications of biomass assessment methodology from 2005 to 2021

Reference	Country	Assessment method of biomass residue			Biomass residue sources							Energy potential estimation of biomass residue (PJ per year)	Future direction
		Biomass potential type	Approach	Methodology	Agriculture	Forest and timber processing	Horticulture	Animal manure	Sewage	Urban waste	Others		
(Sajjakulnukit et al., 2005)	Thailand	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	✓	✓	N/A	821	Develop the modern technology conversion increasing the efficiency of energy generation
(Ravindranath et al., 2005)	India	Theoretical	Resource-focused	Statistical analysis	✓	-	-	✓	✓	✓	N/A	8260	Calculated the technical energy potential of biomass waste
(Perera et al., 2005)	Sri Lanka	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	✓	✓	N/A	142	Improve the efficiency of traditional energy conversion to modern application
(Singh et al., 2007)	India	Theoretical & technical	Resource-focused	Statistical & spatial analysis	✓	-	-	-	-	-	N/A	0.235	Develop the integration of spatial analysis and mathematical modelling for energy conversion process
(Jingura and Matengaifa, 2008)	Zimbabwe	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	✓	-	-	-	N/A	130.7	Develop the integration of crop residue and industry to improve the economic benefits in collecting and selling residues
(Lopez-Rodriguez et al., 2009)	Spain	Theoretical	Resource-focused	Spatial analysis	-	✓	-	-	-	-	N/A	5.82	Develop the method to feasibility analysis the collecting area, transportation, and energy plant
(Gómez et al., 2010)	Spain	Theoretical, technical, & economical	Resource-focused	Statistical & spatial analysis	-	-	-	-	✓	-	N/A	0.110	Develop a regulation feed-in tariff the elecricity production from agro-industry residue to maintan the residue sustainability heat generation
(Fernandes and Costa, 2010)	Portugal	Theoretical	Resource-focused	Statistical & spatial analysis	✓	✓	-	-	-	-	N/A	0.106	Develop the installation of small-scale biomass plants for heating purposes to give the

													economical and environmental advantages for local investors
(Karaj et al., 2010)	Albania	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	✓	✓	-	✓	N/A	0.042	To determine the energy potential of biomass residue through regular market forces and utility energy efficiency programs, and consider food security, competing uses of biomass with other sectors and economic aspect
(Duku et al., 2011)	Ghana	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	✓	✓	N/A	0.075	Improve reseachers of the knowledge of the resource base, technology, and sustainability
(Jiang et al., 2012b)	China	Theoretical	Resource-focused	Spatial analysis	✓	-	-	-	-	-	N/A	N/A	Comprehensive utilization of crop residue resources in rural area
(Hiloidhari et al., 2012)	India	Theoretical, technical, & implementation	Integration	Spatial analysis	✓	-	-	-	-	-	N/A	1.57	Improve technology for rice straw management and transport distance
(Rahman and Paatero, 2012)	South Asian countries (Bangladesh, India, Nepal, Pakistan, and Sri Lanka)	Theoretical, economical, & implementation	Integration	Energy-economics and energy-system model methods	✓	-	✓	✓	-	-	N/A	N/A	Indepth analysis of skilled technicians for plant operation and maintenance, pure water, and facilities for residue sorting and mixing
(Forster-Carneiro et al., 2013)	Brazil	Theoretical & implementation	Demand-driven	Energy-system model methods	✓	-	✓	✓	-	-	N/A	N/A	The technical, economic, and social feasibility for implanting a biorefinery
(Iye and Bilsborrow, 2013)	Nigeria	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	657	The critical and objective analysis of the environmental, agronomic and economic impacts of residue removal of

													agricultural residue and forsetry resources
(Said et al., 2013)	Egypt	Theoretical	Resource-focused	Statistical analysis	✓	-	-	✓	-	✓	N/A	16.9	The start-up of large-large production of biomass energy need detail analysis of environment and economic
(Okello et al., 2013)	Uganda	Theoretical	Resource-focused	Statistical & spatial analysis	✓	✓	-	✓	-	-	N/A	258.29	Improve the skill personal to implement (logistic, infrastructure, and technologic)the biomass residue
(Ackom et al., 2013)	Cameroon	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	0	-	-	N/A	2.46	Improve awareness the rural community to utilise biomass residue as modern energy have lasting sustainabilitybenefits
(Shonhiwa, 2013)	Zimbabwe	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	259	N/A
(Qiu et al., 2014)	China	Theoretical	Resource-focused	Statistical, geographical, and economic analysis	✓	-	-	-	-	-	N/A	N/A	The study recommend to policy maker for formulating and implementing the policies for the location of crop residue pelleting production
(Bentsen et al., 2014)	227 countries and territories in the FAO database	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	$65x10^4$	The development incrop residue assessments should focus on stratified species or specific exponential (or logarithmic) multipliers, with stratification based on ecological or political zones
(Gonzalez-Salazar et al., 2014b)	Columbia	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	58.98	The scenario analysis to understand the influence of technology deployment on the technical potential
(Hiloidhari et al., 2014)	India	Theoretical	Resource-focused	Statistical analysis	✓	-	✓	-	-	-	N/A	4150	Improve the assessment level to assist the policy

													decisions and bioenergy planning
(Kemausuor et al., 2014)	Ghana	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	150	Evaluate the environmental, social and economic context
(Mohammed et al., 2014)	Nigeria	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	1,141.65	To create awareness and foster investment opportunities through media campaigns, research, funding and effective bio-energy policy
(Halder et al., 2014)	Bangladesh	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	344.99	Increasing the amount of recoverable biomass for electricity generation (modern technology) to reduce the traditional pattren
(Panklib et al., 2014)	Thailand	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	561.64	Dissemintaing information from government to educate the community about the alternative energy
(Ji, 2015)	China	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	N/A	To develop the bioenergy industry and biofuel strategy planning (e.g. the feasibility analysis of bioenergy production scenarios, the choice of location for bioenergy facilities)
(Chinnici et al., 2015)	Italy	Theoretical	Resource-focused	Statistical analysis	✓	-	✓	✓	✓	✓	N/A	N/A	N/A
(Ayamga et al., 2015)	Ghana	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	N/A	The sustainability assessment of socio-economic and environment consequnces to produce second generation of biofuel
(Portugal-Pereira et al., 2015)	Brazil	Theoretical, technical, economic, & sustainable	Resource-focused	Spatial analysis & LCA	✓	-	-	-	✓	-	N/A	506	Implementation of a centralised biomass power plant

(Roberts et al., 2015)	Argentina	Theoretical	Resource-focused	Statistical analysis	✓	✓	✓	-	-	-	N/A	2.60	Techno-economic analysis for the next research
(Cardoen et al., 2015)	India	Theoretical	Resource-focused	Statistical analysis	✓	-	✓	-	-	-	N/A	N/A	Create the policies for biomass valorization as identifiying technology conversion
(Guerrero et al., 2016)	Ecuador	Theoretical	Resource-focused	Spatial analysis	-	✓	-	-	-	-	Banana	N/A	Develop other source of residues for second generation bioethanol
(Shane et al., 2016)	Zambia	Theoretical & technical	Resource-focused	Statistical & spatial analysis	✓	✓	✓	✓	-	✓	Jatropha and water hyacinth	552.86	Improve access the data, make reference to and use it for policy formulation and other applications
(Prando et al., 2016)	Italy	Theoretical & technical	Resource-focused	Spatial analysis	✓	✓	✓	-	✓	-	N/A	0.13-0.27	Few modifications are required when using agricultural residue as bioenergy in domestic boiler residues
(Mateos et al., 2016)	Spain	Theoretical	Resource-focused	Spatial analysis	✓	✓	-	-	-	-	N/A	0.947	Determine the method to sustainable exploitation of the forest biomass increasing the opportunity of creat the new job and business in rural community
(Román-Figueroa et al., 2017)	Chile	Theoretical & technical	Resource-focused	Statistical & spatial analysis	✓	✓	-	-	-	-	N/A	N/A	Creating an energy production center
(Stich et al., 2017)	ASEAN (Brunei, Myanmar, Malaysia, Indonesia, Cambodia, Philippines, Singapore, Laos, Thailand and Vietnam	Theoretical, technical, & economic	Demand driven	Statistical, spatial and economic analysis	✓	✓	-	✓	-	-	N/A	N/A	The environmental impacts of electricity generation from biomass residues in ASEAN through LCA technique
(Maqhuzu et al., 2017b)	Zimbabwe	Theoretical	Resource-focused	Spatial analysis	✓	-	✓	✓	-	-	N/A	43.56	The economic viability of biofuel production is needed to ascertain the level of business success

(Al-Hamamre et al., 2017)	Jordan	Theoretical	Resource-focused	Statistical analysis	✓	-	✓	✓	-	✓	N/A	39.72	The government strategy should focus on small and large scale technologies
(Papilo et al., 2017)	Indonesia	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	77.47	Develop an alternative power generation
(Burg et al., 2018)	Switzerland	Theoretical, economic, & sustainable	Resource-focused	Statistical, spatial and energy-economics model	✓	✓	-	✓	✓	✓	N/A	209	Analysis the biomass availability in order to optimize its future use
(Gabisa and Gheewala, 2018)	Ethiopia	Theoretical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	750	The sustainable bio-energy production and utilization needs conducting a life cycle sustainability assessment along the value chain of the bioenergy
(Rahman et al., 2018)	Bangladesh	Theoretical, technical, economic, & sustainable	Demand driven	Energy-system model methods	✓	-	-	✓	-	-	N/A	222.94	A coordinated effort of the concerned authorities and stakeholders and effective implementation of the action plan
(Mboumboue and Njomo, 2018)	Cameroon	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	-	✓	-	✓	N/A	243	Optimize the collaboration of the whole society to fully utilize the biomass residue in energy sector
(Bilandzija et al., 2018)	Croatia	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	✓	-	✓	-	Arable crops residues & puned biomass	51.14	Increasing the share of renewable energy in total energy and reducing the energy import
(Morato et al., 2018)	Bolivia	Theoretical	Resource-focused	Statistical & spatial analysis	✓	-	-	-	-	-	N/A	19.20	Applicating the new policies, such as prohibiting agricultural residues in open fields and providing incentives (e.g., carbon credits) to reduce costs, can make present conditions more favourable.

(Avcıoğlu et al., 2019)	Turkey	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	✓	-	-	-	N/A	364.44	The regulatory and investment potential of biomass energy sources need to be improved in order to ensure both economical and environmental sustainability
(Algieri et al., 2019)	Italy	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	✓	✓	✓	-	N/A	4.25	More investigating the quality process and technology of biomass residue
(Golubić et al., 2020)	Crotia	Theoretical, technical, economic, sustainable, & implementation	Demand driven	Integrated analysis	✓	-	✓	✓	-	-	Viniculture	1.09	The added value stays in the local community and provides support for local and regional economic development
(Honorato-Salazar and Sadhukhan, 2020)	Mexico	Theoretical	Resource-focused	Statistical & spatial analysis	✓	✓	-	-	-	-	N/A	701.01	Giving support for strategic planning and decision-making for setting up biomass-based plants at national, state and municipal scale
(Uzair et al., 2020)	Pakistan	Theoretical & economical	Demand driven	Energy-economics model	✓	-	-	-	-	-	N/A	0.014	Government should play its role in the development of subsidized upfront tariff for attracting and facilitating the potential investors for fast tracking the development of projects related to electricity generation from biomass
(Di Fraia et al., 2020)	Italy	Theoretical & technical	Resource-focused	Statistical & spatial analysis	✓	-	✓	✓	✓	-	N/A	14.5	The economic costs and environmental analysis to estimate the available bioenergy potential from other sector, such as forestry and the best strategies of collection, transport, storage, and energy valorization

(Tolessa et al., 2020)	South Africa	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	-	✓	-	-	N/A	$11x10^{-5}$	The cost analysis anaerobic digestion technology in the smallholder farming systems
(Ordoñez-Frías et al., 2020)	Mexico	Theoretical & technical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	0.562	Pellet production could be an alternative to substitute fuel wood and promote modern bioenergy applications
(Jat et al., 2020)	India	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	N/A	0.014	N/A
(Brahushi et al., 2020)	Albania	Theoretical	Resource-focused	Statistical analysis	-	✓	-	-	✓	-	Fruit and grape processing	2.29	N/A
(Kang et al., 2020)	China	Theoretical & technical	Resource-focused	Statistical analysis	✓	✓	-	✓	✓	✓	N/A	$3.269x10^{4}$	The geographically targeted information on the exploitation of China's bioenergy resources for the mitigation of global climate change
(Rehman Zia et al., 2020)	Pakistan	Theoretical, technical, economic, & sustainable	Integration	Energy-system model methods	✓	-	-	-	-	-	N/A	82.4	The involvement of government to invest and provide incentives to local farmers
(Wang et al., 2021a)	Thailand	Theoretical	Resource-focused	Statistical analysis	✓	-	✓	-	-	-	N/A	125.6	The layout of bioenergy industry and future development of bioenergy
(Anand et al., 2021)	Bangladesh	Theoretical & technical	Resource-focused	Statistical & spatial analysis	✓	-	-	-	-	-	N/A	153	Providing the accurate data of crop residues to assess electricity generation potential
This study	Indonesia	Theoretical	Resource-focused	Statistical analysis	✓	-	-	-	-	-	-	302 PJ	Develop the strategic component to design and planning residue valorization

2. Indonesia profile

Indonesia is located in Southeast Asia and spans 1,904,569 km2 between 6° north latitude and 11° south latitude, as well as 95° and 141° east meridians. It is located in an area dominated by the tropical monsoon climate zone, insisting that Indonesia's climate is based on rainfall. The rainy season lasts from October to March, with the highest rainfall occurring in January and February, and the dry season lasts from April to September. The temperature conditions are approximately 23–33°C in the lowlands and 15–27°C in the highlands, which will significantly change due to the different altitudes. Based on the soil types and rainfall, the agroecological zones in Indonesia can be classified as dryland-dry, dryland-wet, highland, lowland, and tidal swells.

Indonesia is an agricultural country with total agriculture and forest areas of approximately 61 and 94 million hectares in 2019, respectively (Figure II-2). The forest area consists of 74.57 million hectares of dryland forest, 11.52 million hectares of swamp forest, 2.91 million hectares of mangrove forest, and 5.11 million hectares of plantation forest. It produced 57.93 million m3 of timber in 2019, an approximate increase of 4.36% from the previous year (Subdirektorat Statistik Kehutanan, 2020). At the same time, the total area of cultivated land is 7.88 million hectares for rice and cereals, 8.80 million hectares for fruit crops, 2.63 million hectares for vegetable gardens, and 18 million hectares for plantations and spice crops ("Statistics Indonesia," 2020). The primary food crop commodities are rice, corn, and cassava. Production quantities of food crops in 2019 slightly decreased by 7.76% for rice, and other yields gradually increased by 3.91% for corn and 1.51% for cassava. Those quantities were recorded at approximately 54.60 million tonnes of rice, 29.90 million tonnes of corn, and 16.52 million tonnes of cassava. Furthermore, Indonesian plantation crops such as palm oil can supply nearly 43% of the world's palm oil demand (Widiyanto et al., 2019).

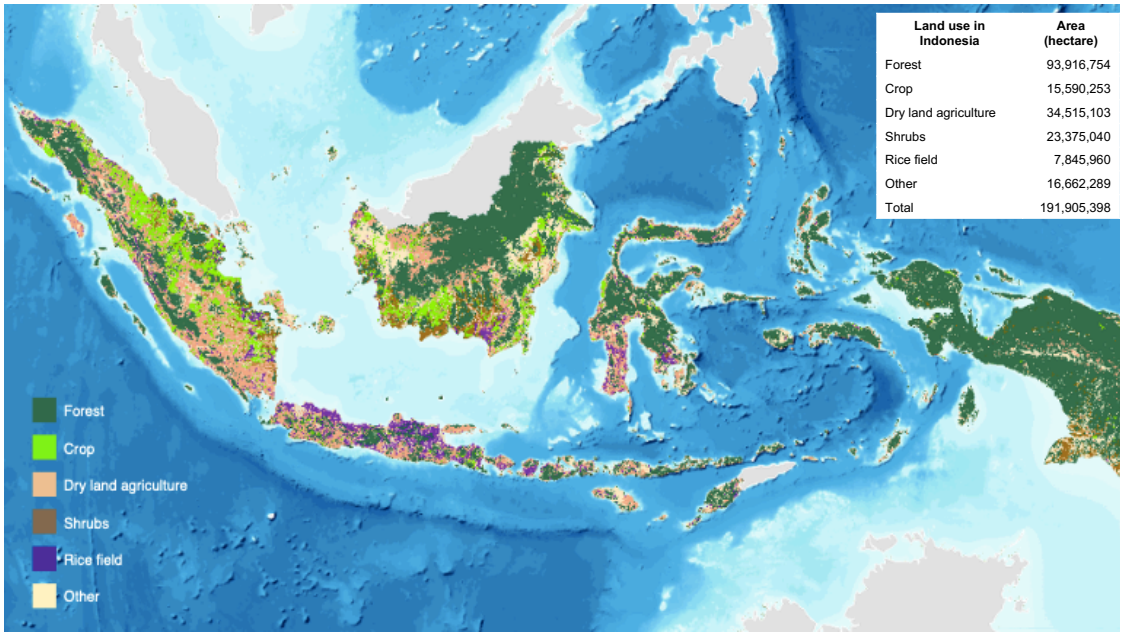


Figure II-2. Indonesia land use based on the spatial data in 2019

Indonesia's population was approximately 266.91 million people in 2019 [66]. Employment in the agricultural sector increased from 87.12% in 2015 to 88.57% in 2020. One out of every two people is employed in the "agriculture" sector (“Statistic Indonesia,” 2021). In 2019, the gross domestic product (GDP) increased by 3.64%, 1.22%, 3.80%, 5.76%, and 4.67% in the agriculture, forestry, mining, industry, construction, and service sectors, respectively. Furthermore, Indonesia's per capita GDP value was calculated as US$ 4,174.9 and realized as a 71.94% human development index in the same year (Setianto and Kurniawan, 2020). Indirectly, rapid population growth will affect energy demand owing to urbanization and industrialization. In 2019, Indonesia's primary energy supply comprised 35% oil, 37.3% coal, 18.5% natural gas, 2.5% hydropower, 1.7% geothermal, and 3% biofuel (Cornelissen et al., 2012). Over the past decade, primary energy demand has increased by 3% per year, while energy consumption has increased from $4x10^{-6}$ PJ per capita over three years (“Statistic Indonesia,” 2021).

Fossil fuels constitute a large proportion of Indonesia's energy (approximately 80%). Indonesia has sufficient resources and potential for renewable energy sources such as solar, wind, hydro, biomass, ocean, and geothermal energy. The government estimates that the global potential of renewable energy reached 1.591 PJ, which consists of geothermal energy, hydropower, biomass energy, wind energy, solar energy, and ocean and tidal energy, and is approximately 0.085 PJ, 0.338 PJ, 0.117 PJ, 0.218 PJ, 0.748 PJ, and 0.064 PJ, respectively (MEMR, 2019). At the same time, the development of biomass energy was supported by comprehensive biodiversity resources derived from agriculture, forest, animal, and agro-industrial sources, and municipal waste was spread throughout all regions. It has massive potential for clean energy access when all stakeholders can implement the design and plan.

3. Methods

Estimating Indonesian agricultural residue potential energy considers the amount of energy available from each residue resource. First, calculating the total residue during the temporal cycle in all regions depends on crop properties and energy content. Furthermore, a scenario is adopted to define the detailed range of energy that predicts the electrical energy potential.

3.1. Data sources and collection

In this chapter, the investigation focuses on agriculture residue, which is potentially exploitable as an energy source. Agricultural products were grouped into food crops (rice, corn, cassava, groundnuts, and soybeans) and plantation crops (sugarcane, coconut, palm oil, coffee, and cocoa). These are essential sectors in all Indonesian areas that can be produced annually.

The characteristics of biomass residue depend on many factors, such as local climatic conditions, crop variety, agricultural practices (cutting height during harvesting activity), and crop yields. In this study, the physical properties of biomass residue consisting of moisture content

(MC), ratio of production residue (RPR), and lower heating value of dry matter residue (LHV) were obtained from several studies. The availability factor (A) is a basic calculation of bioenergy raw materials found in the literature and a rough estimation in the field after reviewing the biomass residue for other purposes, such as animal feed, compost, and industrial uses. For every residue from each biomass plant, the average value can be calculated by taking the maximum and minimum waste considered from the references reported in Table II-2.

The plants' annual production and land area were drawn from statistical data collected over ten years (started on 2010 to 2020) which is provided by the Indonesia Central Bureau of Statistics (BPS) to achieve this research goal. Specifically, the annual report and strategic documents (e.g., i.e., the Outlook Food Crop Report and the Outlook Plantation Crop Report) present detailed information about the cultivated area, crop yields, and geographical location of the product.

The first column in Table II-2 shows the biomass category, biomass crop, and residue resulting from these fields after harvest in the second and third columns. Furthermore, residue characteristics, such as the ratio of production residue, moisture, heating value, and residue availability after being used for other purposes, are presented in different columns. According to the analysis in Table II-2, the most prominent feature was the difference in heating values among crop varieties. The moisture content of the crop influenced it, but structural components such as lignin, cellulose, and hemicellulose significantly contributed to the heating value of the biomass. The actual value of recoverable factor residue for different crops in the field has been estimated and reported in several publications, varying from 19% to 100% (Cornelissen et al., 2012). The availability residue factor from 30% to 55% was based on field observations that were investigated in Karawang (West Java), Kendal (Central Java), and Bojonegoro (East Java). As a result, using data on annual production and physical characteristics, the theoretical biomass and electrical energy potential were calculated in three steps, as shown in Figure II-3.

Table II-2. Type of agricultural residues and coefficient for the energy potential estimation performed in this study

Subgroup of Agricultural Residue	Type of Product	Type of Residue	RPR*		Moisture (%)*		LHV (MJ/kg)*		Availability Factor (%)**		Reference
			Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	
Food crop residue	Rice	Straw	0.45 – 1.76	1.11	10.00 – 15 .00	12.50	14.08 – 16.00	15.04	25.00 – 80.00	55.00	a,b,c,d
		Husk	0.20 – 0.26	0.23	9.60 – 13.30	11.45	12.90 – 19.93	16.42	25.00 – 80.00	55.00	
	Maize	Cob	0.27 – 0.86	0.57	7.70 – 8.70	8.20	12.60 – 18.40	15.50	20.00 – 60.00	40.00	c,d,e,f
		Stalk	2.00 – 2.27	2.14	15.00 – 16.80	15.90	15.50 – 18.50	17.00	20.00 – 60.00	40.00	
	Cassava	Stalk	0.06 – 0.40	0.23	15.00 – 20.00	17.50	13.10 – 16.99	15.05	20.00 – 80.00	50.00	g,h,i
	Ground nut	Shell	0.20 – 2.30	1.25	8.20 – 9.87	9.04	5.53 – 22.06	13.80	20.00 – 40.00	30.00	a,h
	Soybeans	Straw	0.75 – 3.50	2.13	12.00 – 15.00	13.50	14.90 – 19.40	17.15	40.00 – 60.00	50.00	h,i,j
Plantation crop residue	Sugarcane	Bagasse	0.28 – 0.33	0.31	15.00 – 35.00	25.00	8.57 – 20.00	14.29	20.00 – 50.00	35.00	d,f,j,k,l,m
		Top and leaves	0.05 – 0.32	0.19	50.00 – 63.00	56.50	6.82 – 20.00	13.41	20.00 – 80.00	50.00	
	Coconut	Shell	0.16 – 0.25	0.21	8.00 – 16.00	12.00	16.48 – 20.15	18.32	20.00 – 40.00	30.00	g,h,i,n,o
		Husk	0.36 – 0.48	0.42	8.00 – 13.00	10.50	14.71 – 16.23	15.47	40.00 – 60.00	50.00	
	Palm Oil	Empty fruit brunch	0.17 – 0.43	0.30	8.81 – 14.00	11.41	6.71 – 16.44	11.58	10.00 – 50.00	30.00	g,i,o
		Shell	0.05 – 0.07	0.06	10.00 – 13.00	11.50	17.00 – 18.73	17.87	10.00 – 50.00	30.00	
		Fiber	0.13 – 0.15	0.14	10.00 – 13.00	11.50	12.22 – 16.19	14.21	10.00 – 50.00	30.00	
	Coffee	Husk	0.21 – 2.10	1.16	7.00 – 15.00	11.00	3.44 – 18.35	10.90	20.00 – 60.00	40.00	i,j
	Cocoa	Pods	0.93 – 1.00	0.97	15.00 – 75.00	45.00	12.38 -15.48	13.93	20.00 – 60.00	40.00	j,n

* Based on the literature
[a](Singh et al., 2008)
[b](Iye and Bilsborrow, 2013)
[c](Okello et al., 2013)
[d](Hiloidhari et al., 2014)
[e](Chen et al., 2009)
[f] (Avcıoğlu et al., 2019)
[g](Stich et al., 2017)
[h](Sajjakulnukit et al., 2005)
[i](Wang et al., 2021b)
[j](Duku et al., 2011)
[k](Uzair et al., 2020)
[l](Gonzalez-Salazar et al., 2014a)
[m](Morato et al., 2019)
[n](Kemausuor et al., 2014)
[o](Shafie et al., 2012a)
** Based on the estimation in the field

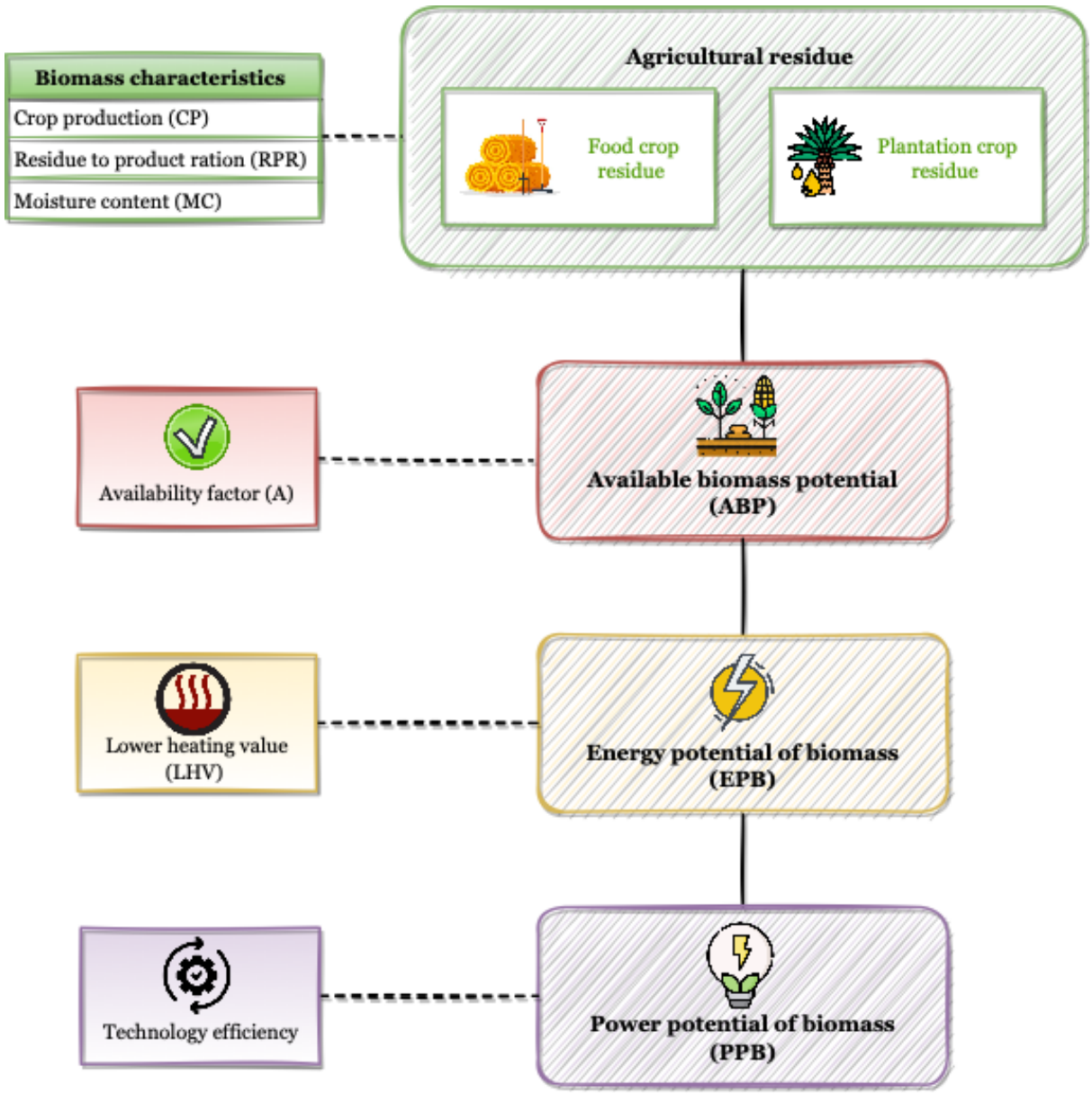


Figure II-3. Flow diagram to evaluate the energy potential of biomass residue

3.2. Key parameters to evaluate agricultural residue

Given that the steps to evaluate the biomass residue are discussed in Figure II-3, this section describes the key parameters.

1. Theoretical potential of agricultural residue

The RPR related to the total residue was generated from a tonne of harvested dry crop production. The RPR value is the basis for estimating the theoretical agricultural residue potential (TBR). For example, the RPR of rice straw is 1.75, which means that a tonne of total rice production on a dry basis could generate 1.75 tonnes of rice straw according to the physical characteristics,

cultivation method, and crop variety (Di Fraia et al., 2020). To calculate the TBR of agricultural residue, Equation II-1.

$$TBR_{AR} = \sum_{i=1}^{n} HA_{(i)} \times P_{(i)} \times RPR_{(i)} \times (1 - MC_{(i)}) \quad \text{(II-1)}$$

Where HA(i) is the annual harvested area of the crop in hectares per year, P(i) is the annual productivity of the crop in tons per hectare per year, RPR(i) is the residue-to-product ratio, and MC(i) is the moisture content of crop residue in percentage terms.

2. Availability of agricultural residue

ABP(i) refers to the availability of agricultural residue, which is calculated from the annual total residue production for bioenergy purposes after deducting it for other purposes (e.g., animal feed, fertilizer, and industrial purposes). The availability of each crop in each area differed significantly according to the harvesting method and equipment used. When rice harvesting uses agricultural machinery, the cutting height is more homogenous, making the quantity of residue easier to calculate than when manual techniques are used. As shown in Equation II-2, A(i) is the annual availability factor of agricultural residue.

$$ABP_{(i)} = \sum_{i=1}^{n} TBP_{(i)} \times A_{(i)} \quad \text{(II-2)}$$

3. Energy potential of agricultural residue

The energy potential of agricultural residue (EPB) can be evaluated using the LHV of biomass on a dry basis per year, as shown in Equation II-3.

$$EPB_{(i)} = \sum_{i=1}^{n} APB_{(i)} \times LHV_{(i)} \quad \text{(II-3)}$$

4. Power potential of agricultural residue

Agricultural residue is a raw material that can be transformed into bioenergy using specific technologies. The effectiveness of energy production depends on the crop residue (moisture content) and conversion methods. (Singh et al., 2007) grouped energy conversion into two types: thermochemical conversion (combustion), which requires materials with low moisture content, and bio-conversion, which can utilize materials with high moisture content. Thermochemical conversion is preferable for energy production because it can generate and store heat, mechanical power, and electricity by employing diverse equipment such as steam turbines, furnaces, and generators. This approach generally applies to all types of biomass residues, with a process efficiency of approximately 20–40% (Singh, 2015a). In this study, the efficiency factor can be categorized into three levels: low, medium, and high efficiency, which are 20, 30, and 40%,

respectively. The operation time (OH) was 8000 h per year. As a result, the quantity of power-potential biomass (PPB) is given by Equation (II-4).

$$PPB_{(i)} = \sum_{i=1}^{n} \frac{EPB_{(i)} \times \eta e_{(i)}}{3600 \times OH_{(i)}} \quad \text{(II-4)}$$

4. Result and discussion

The theoretical availability, energy, and power potential of Indonesian biomass residue potential from agriculture sectors were evaluated using Equations (II-1) to (II-4) according to Table II-2. The results are then presented in this section.

4.1. Potential amount of agricultural residue

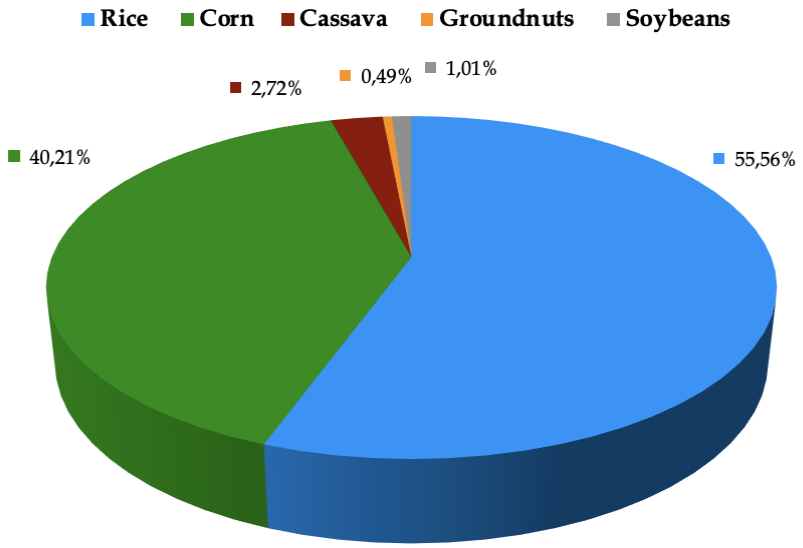
In the past decade, the three top-ranked agricultural products were rice, corn, and palm oil. GIS analysis was utilized to construct the geographical distribution of the harvested areas in each province in Indonesia, which aims to evaluate the quantity of residue for designing and planning a sustainable supply chain when valorization has been implemented. Figure II-4 presents the average harvested area in the Indonesian provinces to assess the agricultural residue potential.

The average annual production of agricultural residue has reached 374 million tons, consisting of 136 million metric tons of food crops and 189 million metric tons of plantation crops. Based on the availability factors (see Table II-2), it can be concluded that rice, corn, and palm oil are the top three agricultural products with the highest residue production, with total dry residue productions of approximately 76, 55, and 15 million metric tons, respectively. Figure II-5 shows the composition of the residue availability produced from 2010 to 2020.

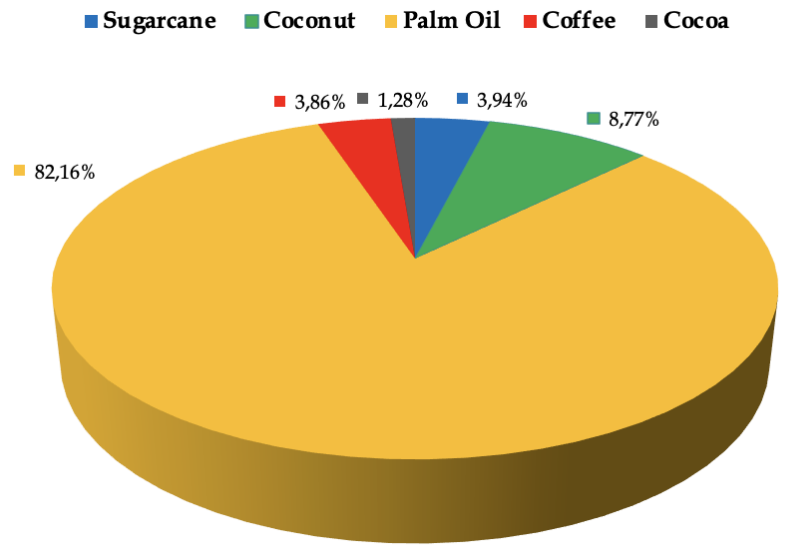
Rice and corn are food crops with residues in the form of straw and husk, as well as corn cobs and stalks, whereas palm oil is a plantation crop with residue, that is, empty fruit brunches, fiber, and shells. Figure II-4 shows that rice and palm oil can produce more than half of the total residue, while corn produces 40%. They have the potential to be transformed into bioenergy through a densification process because of their prevalence throughout Indonesia. Palm oil is grown in Sumatra, Borneo, Celebes, and Papua New Guinea but not on Java Island. It has been utilized as a biodiesel feedstock since 2018 because of the Indonesian government's mandate to mix 20% biodiesel (B20). Simultaneously, agricultural productivity should be noted because it can be used to predict the amount of residue. Therefore, it is a primary key to creating an accurate design and plan for biomass supply chains.

Figure II-4 shows that almost all regions on Java Island have a high harvest area for food crops. Rice is the most important commodity, with more than 1 million hectares harvested in three provinces on Java island, as well as provinces in South Celebes. During the past decade, Indonesia's annual rice production has been approximately 68 million tons harvested in 13 million hectares of rice fields. Owing to the vulnerability of climate change and social construction

problems, the total rice production decreased to 54 and 55 million tonnes in 2021 and 2022, respectively, which were harvested in 10.5 million hectares of rice fields during the Covid-19 period. Therefore, it is vital to manage planting adaptation strategies, such as (i) improving irrigation methods and facilities, (ii) soil structure rehabilitation, (iii) biotechnology development, (iv) managing seasonal adaptation and crop variety, and (v) improving agricultural mechanization to increase the quantity of production, considering that rice is a staple food for Indonesian societies. In 2021, Indonesia had 34 provinces with an average rice production of approximately 1.6 million tonnes. The three highest production regions are East Java, Central Java, and West Java, with total production of approximately 9.7, 9.6, and 9.1 million tonnes, respectively. As a result, East Java was chosen in this study for designing and planning the rice straw valorization concept.



(a)



(b)

Figure II-4. Composition of agricultural residue availability: (a) food crop and (b) plantation.

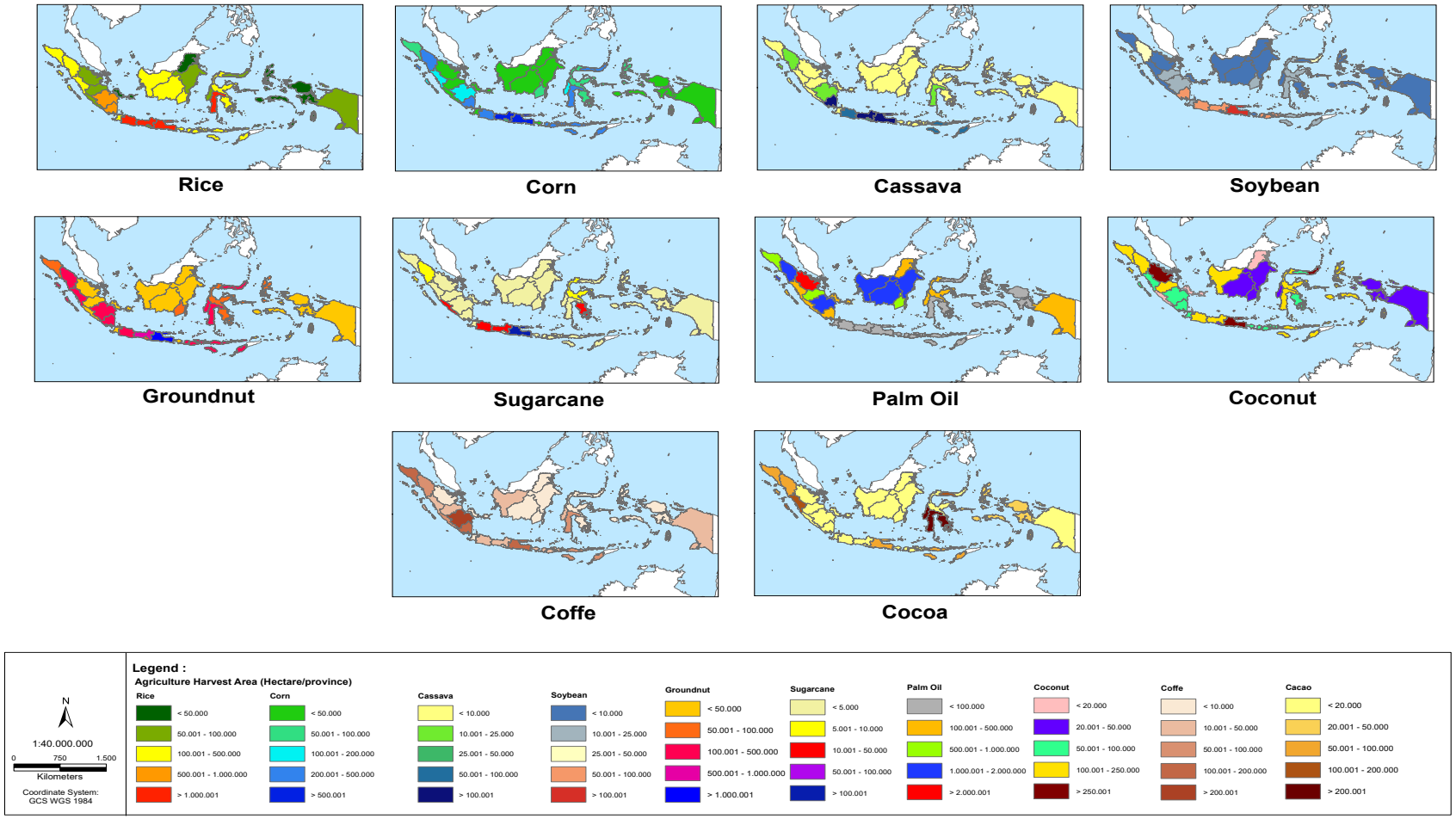
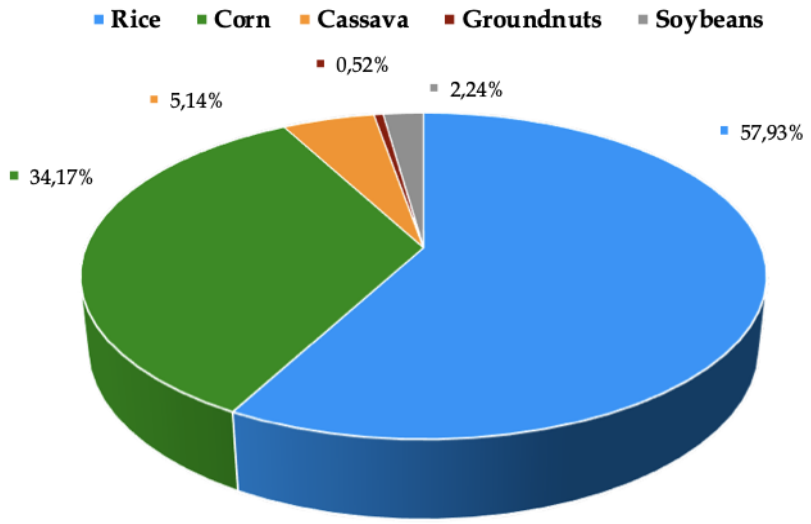


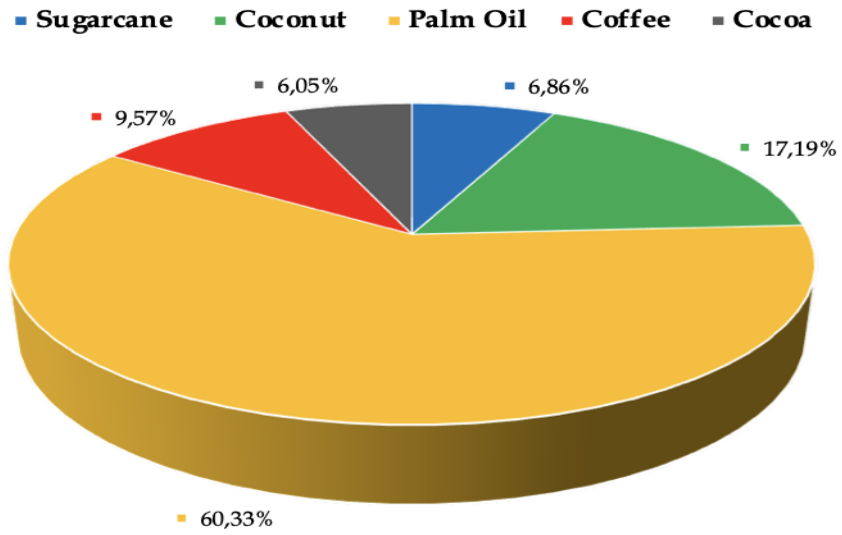
Figure II-5. Distribution of agricultural harvested area based on the Indonesian provinces

4.2. Energy and power potential of agricultural residue

The availability of agricultural residues is approximately 30–75% depending on the purpose of the application. Figure II-6 shows the composition of the energy potential of each agricultural residue. Rice residue can produce more than half of the total food crop residue, generating an energy potential of approximately 58%, equal to 136 PJ per year. Furthermore, corn residue can generate an energy potential of 34%, which is equal to approximately 73 PJ per year. Conversely, the highest residue from palm oil as a plantation crop was 82% of the total residue. It can generate an energy potential of approximately 11 PJ per year.



(a)



(b)

Figure II-6. Composition of energy potential of agricultural residue: (a) food crop and (b) plantation crop

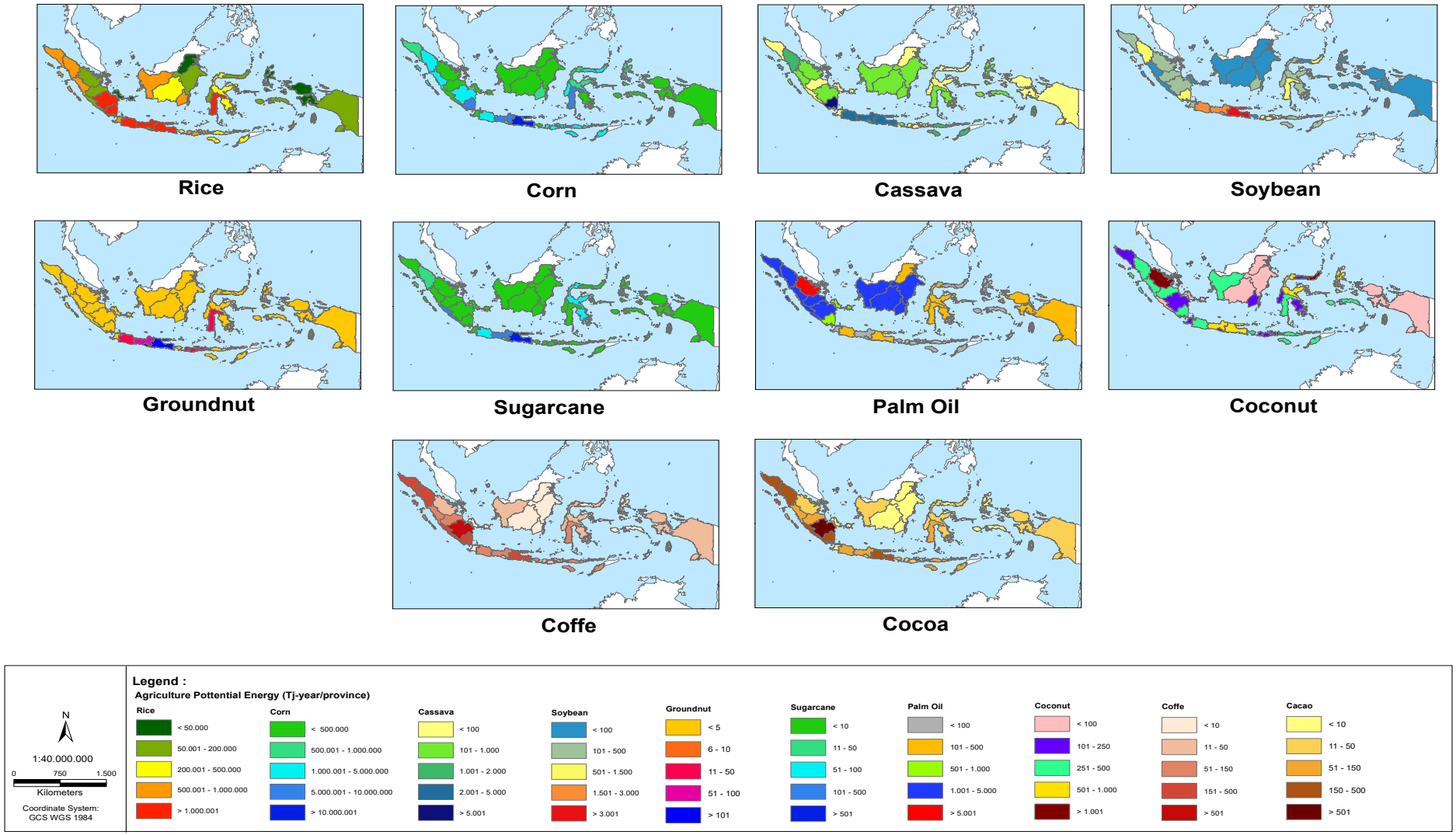


Figure II-7. Geographical distribution of energy potential from agriculture residue

Compared to other islands, Java Island has very high energy potential for its food crops and sugarcane as a plantation crop, as demonstrated by these findings. Only food crops are farmed on Java Island, whereas plantation crops are commonly cultivated elsewhere. In contrast, the island of Sumatra has very high energy potential for four plantation crops, excluding sugarcane. Palm oil is the most important plantation crop and its cultivation area in Indonesia is over 15 million hectares. The largest crop area in Sumatra is approximately 8 million hectare and has an energy potential of 22.46 PJ. While palm oil is grown in one-fourth of Borneo's land area, the island has an average energy potential of 11.65 PJ. Palm oil is cultivated only in the Sumatra, Borneo, and Papua islands, but not in the Java islands, due to insufficient water and natural resources.

In addition, three scenarios of efficiency conversion factor and operation time of 8000 hours per year were examined for agricultural waste as an energy source, as shown in Figure II-8. Using Equation (II-4), the efficiency factors of 20, 30, and 40%, which were applied to calculate the potential electrical of agricultural residue, could generate 7623.29, 11435.13, and 14389.22 MW, respectively. Straw residue, stalk residue, and husk generated the most energy under all conditions compared to the other residues. Straw, stalk, and husk residues have a relative power generation of 3,429.11, 1,918.59, and 833.75 MW when the efficiency factor is at its lowest level (20%). When biomass residue replaces coal in power plants, its annual consumption can be reduced by more than 38%. The gradual improvement in the efficiency conversion factor significantly affected the increased energy produced. Therefore, efficiency is vital for determining the design and technology of biomass-fueled power plants. Based on the technology application, the power potential of the residue was calculated using fluidized bed combustion and generating turbines (C/GT) with an efficiency conversion factor of 27% and the combined cycle of gas and steam (C/GC) with an efficiency conversion factor of 40%, which can generate a yearly power generation potential of approximately 2822.29 MW for C/GT technology and 4181.17 MW for C/GC technology. This may have accounted for approximately 28% of Indonesia’s electricity supply in 2019.

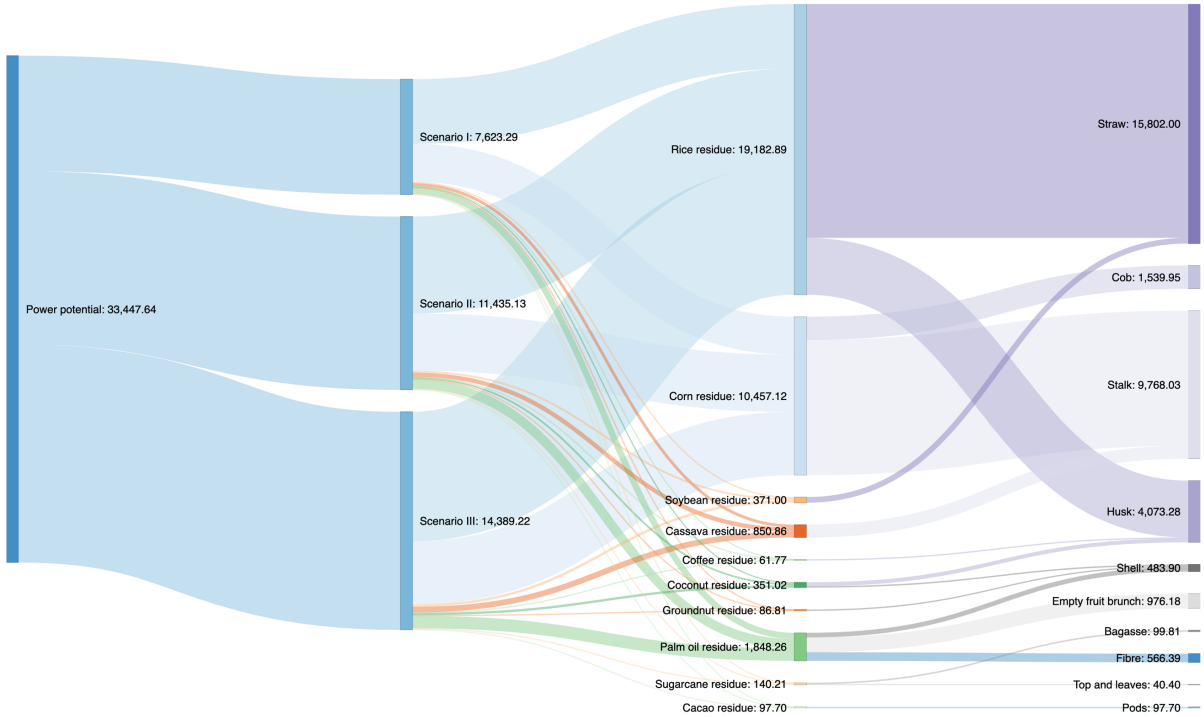


Figure II-8. Sankey diagram: annual average power potential of agricultural residue in Indonesia

5. Conclusion

The suggested method permits a straightforward evaluation of biomass potential in the agricultural sector. Indonesia has abundant resources that are supported by its climate and environmental circumstances. An extensive literature review focused on evaluating crop features using minimum and maximum values to complete statistical data on biomass production and cultivation areas. A considerable amount of residue was produced as a result of this process. According to the study, agricultural residues have an annual production of approximately 155,27 million tons of dry mass, with an energy potential of approximately 320 PJ per year, which generates 11,435 MW of power potential when the efficiency factors are 30%. Rice straw is the most abundant resource, with approximately 76 million tonnes per year, given that rice is the primary food in Indonesia and has been cultivated in all regions. Java Island is the most prolific island for producing all crops, except palm oil. It generates residue in the form of empty fruit branches and is the most abundant resource of plantation crop residue, capable of producing 49.52% of its energy potential, which is equal to 1000 MW of power potential per year.

Furthermore, to optimize the energy potential generated, it is necessary to decide on a strategy. In the long term, sustaining the feedstock supply of unproductive land might optimize its function of producing energy crops to diversify biomass types for producing bioenergy. Therefore, an integrated and sustainable analysis is required to exploit and utilize these resources. It is essential to examine the potential of biomass residue as a bioenergy source, even if this is difficult to realize in the short term. Monitoring and evaluation to recognize sustainable energy

from the guarantee of feedstock supply, the design of technology, supporting facilities, such as distribution and storage facilities, policy and regulation, and financing facilities are necessary to realize the state's sustainable development. To optimize Indonesian biomass residue, further social analysis of valorization is required to identify stakeholders' willingness and involvement as a strategic step to other decision-making and economic and environmental analyses of the biomass residue potential in all echelons of the supply chain, such as collection, storage, transportation, and energy conversion. In detail, based on the residue distribution conducted in the previous section, the East Java province is appropriate as a case study to realize valorization programs.

Chapter III. Assessment of biomass residue supply chain: a literature review

1. Introduction

Many researchers have reviewed the biomass supply chain (BSC) to estimate and evaluate biomass utilization for energy production in design, planning, managing, converting, and raising decision-makers awareness to support it. For example, Sharma et al. (2013) comprehensively reviewed the design and modeling of energy needs, energy targets, biomass feedstocks, and conversion technology. Furthermore, determining efficient supply chain design and operation can be analyzed by modeling different variables and scenarios (Nunes et al., 2020a). However, environmental sustainability must be highlighted to design a sustainable BSC (Kumar and Singh, 2019). It is both an opportunity and a challenge to assess the environmental aspects of biofuel production's design and supply chain (Zaimes et al., 2015). It parallels the following question of how the design position and methodology solve the problem and overcome the obstacles by integrating the sustainability context. For example, in all supply chain echelons, biomass residue still needs to be fully utilized; moreover, in logistics and transportation, which yet entirely depend on bioenergy, around one-third of the total energy consumption almost entirely depends on fossil fuels (Yadav and Yadav, 2016). It is difficult to substitute or change the dependency without reducing the efficiency of logistics performance in order to improve sustainability contexts, but it is a challenge to provide an agile supply chain with a good strategy of logistics. At the same time, bioenergy conversion and production technology also have specific challenges and barriers to significantly reducing costs and maintaining low emissions (Sims et al., 2010). However, when precise design and methodology of BSC were applied, these could improve social quality by creating new jobs and additional income in rural areas (Miret et al., 2016). Furthermore, public awareness should be considered deciding the decision-making; hence, the decision-makers can incorporate it into the sustainability pillar. Therefore, it needs a detailed review and study of the sustainability pillars of the BSC to contribute to solving the obstacles.

In the view of the decision-making level, the design of BSC should be able to reflect the resulting process of the three dimensions of the supply chain (i.e., actors, management, and sustainability), which have a hierarchical correlation to influencers, design decisions, and structure (Melnyk et al., 2014). Zandi Atashbar et al., (2018) described that the BSC could involve various actors, e.g., farmers, bioenergy producers, distributors, customers, and stakeholders, whose performance depends on the network design, planning, and operational activities. Furthermore, the time dimension is a fundamental part of determining the decision-making levels to decompose the complexity in optimization, which is grouped into strategic, tactical, and operational (Pishvaee et al., 2021a). The strategic decisions focus on long-term goals (i.e., more than one to several years),

which are related to the variety of biomass, the type, number, location, and capacity of supply chain facilities, and the material flow (Pishvaee et al., 2021b). In contrast, the tactical plan relates to the inventory planning of biomass resources and bioenergy products in the medium term, ranging from a few months to one year (Murele et al., 2020). Operational planning is created in the short term (e.g., weekly, daily, or hourly) to schedule the operation (Atashbar et al., 2016). The strategic decision level is a complex system with a high level of uncertainty and multiple actors who affect the final decision (Melnyk et al., 2014), while the tactical level is more important to maintain the optimal inventory policy (Nguyen, 2019). In more detail, many researchers have reviewed and applied the integration of sustainability context into each decision level in BSC, as shown in Table III-1 of the systematic literature review, to answer what characteristics studies applied to integrating sustainability dimensions and decision-making levels in BSC.

Table III-1 shows that most of the literature (71%) integrates the sustainable aspect and decision-making level in BSC applications for producing biomass products such as bioenergy (heat, electricity, and biofuel). Almost all reviews have presented an overview of the optimization method and model for managing biomass-to-bioenergy production from upstream to downstream. For instance, Sharma et al. (2013), De Meyer et al. (2014), Cambero and Sowlati (2014), Nematollahi and Tajbakhsh (2020), and Zahraee et al. (2020) applied mathematical model optimization. Furthermore, the implementation of the operations research (OR) model has been highlighted by An et al. (2011) for modeling the biofuel supply chain like petroleum-based fuel production. Similarly, Barbosa-Póvoa et al. (2018) presented sustainability practices using OR methodology. In the BSC assessment, uncertainty factors should be considered to prevent unexpected situations from affecting the failure process or loss of performance and profit. It has been studied by Awudu and Zhang (2012), Balaman and Selim (2015), Abbasi et al. (2021), and Mottaghi et al. (2022). At the same time, Table III-1 has scope for stakeholder involvement and government roles in the BSC system. Stakeholder involvement at the strategic decision level assists the BSC plan (Santos et al., 2019). Incorporating the social dimension, such as participation and acceptance by communities and stakeholder engagement, has a substantial opportunity to frame the maturity of BSC implementation (Cerca et al., 2022). Jazinaninejad et al., (2022) addressed the government's role in policy, regulation, and programs as part of sustainability, which can be practiced by issuing government policies and regulations (e.g., tax subsidies, incentives, land-use policies, and bioenergy production facilities). The synergies between the BSC development and sustainability issues are shown in Figure III-1.

Table III-1. The systematic literature reviews

References	Scope	Number of papers	Reviewed periods	Decision-making level			Sustainability dimensions			Characteristics
				Strategic	Tactical	Operational	Economic	Environment	Social	
(An et al., 2011)	Biofuel and petroleum	30	1962 - 2010	✓	✓	✓	-	-	-	Model optimization, decision-making level,
(Awudu and Zhang, 2012)	Biofuel	N/A	N/A	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level, uncertainties
(B. Sharma et al., 2013)	Biomass product	32	1997 - 2011	✓	✓	✓	-	-	-	Design and modeling, decision-making level, technology conversion
(De Meyer et al., 2014)	Biomass product	59	1997 - 2012	✓	✓	✓	✓	✓	✓	Optimization methodology, decision-making level
(Cambero and Sowlati, 2014a)	Forest product	54	1995 - 2014	✓	✓	-	✓	✓	✓	Sustainability dimension, model optimization, decision-making level
(Balaman and Selim, 2015)	Biomass product	120	2000 - 2011	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level, uncertainties
(Ghaderi et al., 2016)	Biomass product	146	1997 - 2016	✓	-	-	✓	✓	✓	Sustainability dimension, model optimization, uncertainties
(Ba et al., 2016)	Biomass product	124	1989 - 2014	✓	✓	✓	-	-	-	Decision-making levels, modeling approaches
(Espinoza Pérez et al., 2017)	Biomass product	72	2006 - 2015	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level
(Barbosa-Póvoa et al., 2018)	Biomass product	220	1990 - 2016	✓	✓	✓	✓	✓	✓	Sustainability dimension, operation research, decision-making level, opportunities and challenges
(Sun et al., 2018)	Biomass product	185	1989 - 2017	✓	✓	✓	-	-	-	Decision-making levels, modeling approaches, and employed solution methods

(Moreno-Camacho et al., 2019)	Biomass product	113	2015 - 2018	-	-	-	✓	✓	✓	Sustainability dimension, model optimization, actor analysis
(Santos et al., 2019)	Wood forest product	188	1995 - 2017	✓	✓	-	✓	✓	✓	Sustainability dimension, model optimization, stakeholders' involvement, decision-making level
(Nematollahi and Tajbakhsh, 2020)	Agriculture product	247	1987 - 2019	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level, actor analysis, agriculture planning
(Zahraee et al., 2020)	Biomass product	300	1980 - 2020	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level
(Abbasi et al., 2021)	Microalgae	151	1980 - 2020	✓	✓	✓	-	-	-	Decision-making level, uncertainties
(Dashtpeyma and Ghodsi, 2021)	Forest product	450	1987 – 2020	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level
(Joshi, 2022)	N/A	87	2010 - 2021	✓	-	-	✓	✓	✓	Sustainability dimension, model optimization, uncertainties
(Mottaghi et al., 2022)	Biomass product	178	2009 - 2021	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level, uncertainties
(Stellingwerf et al., 2022)	Biomass product	84	2011 - 2020	✓	✓	✓	✓	✓	✓	Sustainability dimension, decision-making level
(Jazinaninejad et al., 2022)	Biomass product	450	1987–2020	✓	✓	✓	✓	✓	✓	Sustainability dimension, model optimization, decision-making level, government role
This study	Biomass product	116	2013-2022	✓	✓	-	✓	✓	✓	Incorporate between sustainability dimensions and technology, and political aspect in strategic and tactical decision-making level

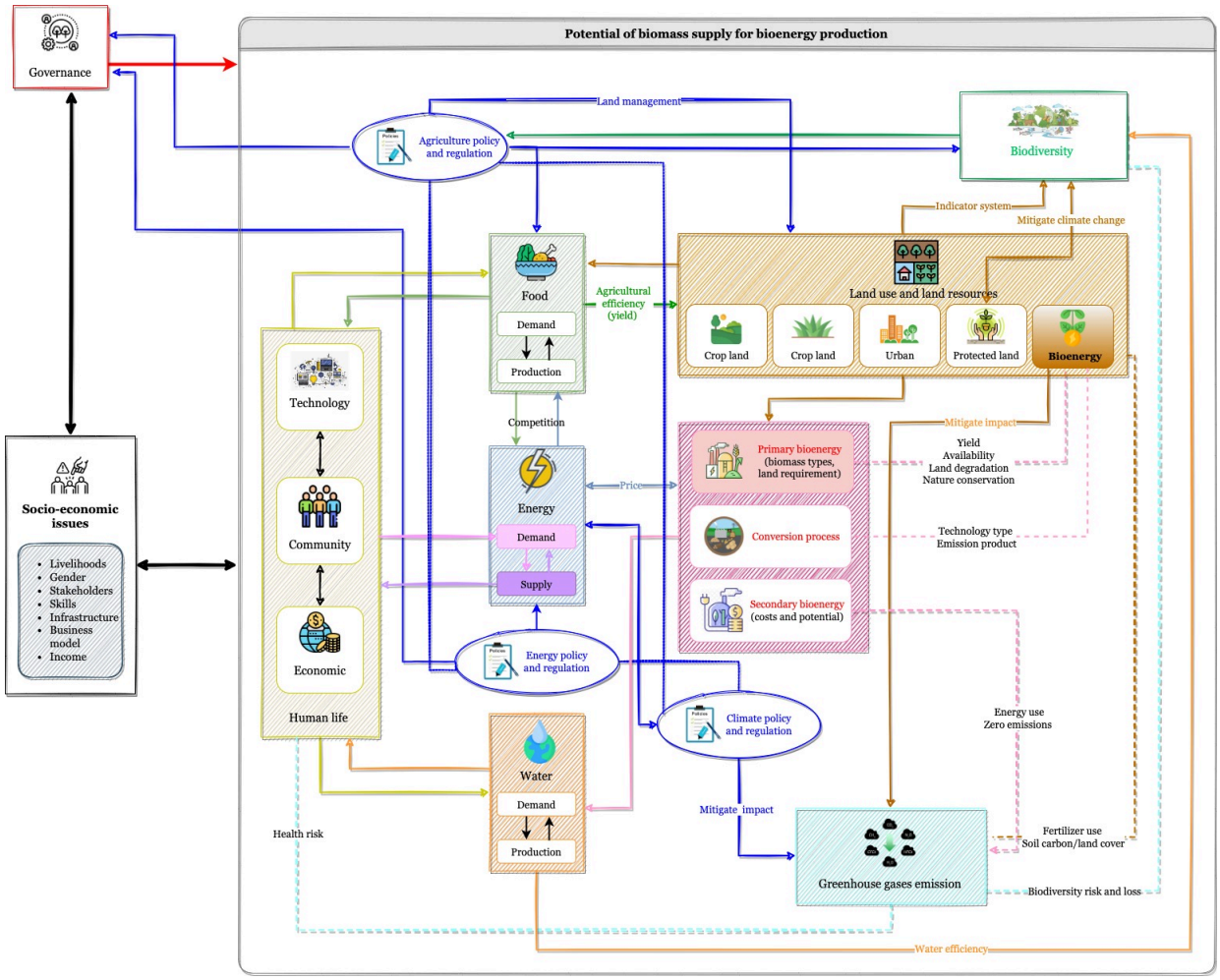


Figure III-1. The synergies between BSC development and sustainability issues

Figure III-1 presents the context of social-economic issues related to the two scopes, i.e., human life and governance. Globally, human life causes uncontrollable and excessive energy consumption (Jakob et al., 2012), which encourages the development of bioenergy from biomass to replace fossil fuels and mitigate negative environmental impacts (Zhang, 2016). At the same time, governance was required to speed up the deployment of biomass-based products and systems in the adaptive framework, which is continuously applied to monitor and evaluate situations; it should be built upon sustainability dimensions and integrate the relevant policies and regulations. The relevant actors' and stakeholders' engagement along the BSC is a successful part of implementing sustainability governance. Pashaei Kamali et al. (2018) stated that an effective BSC governing strategy is interconnected with the sustainability dimension and should be identified by putting forward the most critical social issues with reliable data and practical methods. The fundamental question of how to design and manage biomass resources to meet bioenergy production demand should be answered. In long-term design and planning, the perspectives of policy in determining the selected resources and facilities can have a different impact on stakeholders; thereby, the imbalance can influence the relationship among actors and their perceptions, which then affect the performance of BSC. Furthermore, at the tactical decision-

making level, minimizing the overall operational cost of BSC and considering the inventory site adjacent to the processing area tend to be interesting to investigate to identify the impact of the business plan within sustainable constraints. Despite the fact that the implementation of the residue supply chain has many barriers and challenges, this chapter investigates the systematic context of the BSC, focusing on the gaps between strategic and tactical decision-making levels and the significance of sustainability dimensions to assist in improving stakeholders' roles. The descriptive analysis will be conducted through scientific database contexts over the last decade, 2013–2022, which allows us to critically synthesize the latest studies on the BSC's strategic and tactical decision-making levels and recommend future research by considering economic and social aspects.

2. Methodology

In this chapter, the systematic review approach employs two levels of analysis: material selection and descriptive analysis.

2.1. Material selection

Material selection was defined as a single journal article, means a unit of research in English that is published as a research article type, not a review article type. It is described in detail as follows:

- Development of the keywords

  In this study, the keywords were classified into three general topics: biomass, supply chain optimization, and two levels of decision-making in BSC (e.g., strategic and tactical). The following study keywords were combined with Boolean logic operators: parentheses and quotation marks.

  (i) "Biomass" AND "strategic" AND ('optimization' OR 'supply chain' OR 'biomass supply chain') for strategic decision-making level.

  (ii) "Biomass" AND "tactical" AND ('optimization' OR 'supply chain' OR 'biomass supply chain') for tactical decision-making level.

- Conducting the research search

  The electronic database Web of Science (WoS) was used to explore the keywords mentioned above in the "title, abstract, and keyword" parameters published from January 1, 2013, to December 31, 2022. This search resulted in a collection of 581 and 80 papers at the strategic and tactical decision-making levels, respectively, on WoS.

2.2. Descriptive analysis

The descriptive analysis presents a network map of keywords obtained through full counting. It was evaluated using VOS Viewer software to identify the relatedness between two items that linked the topics with keywords.

3. Results and discussions

This section presents the preliminary results and conclusions of the literature review.

3.1. Descriptive analysis

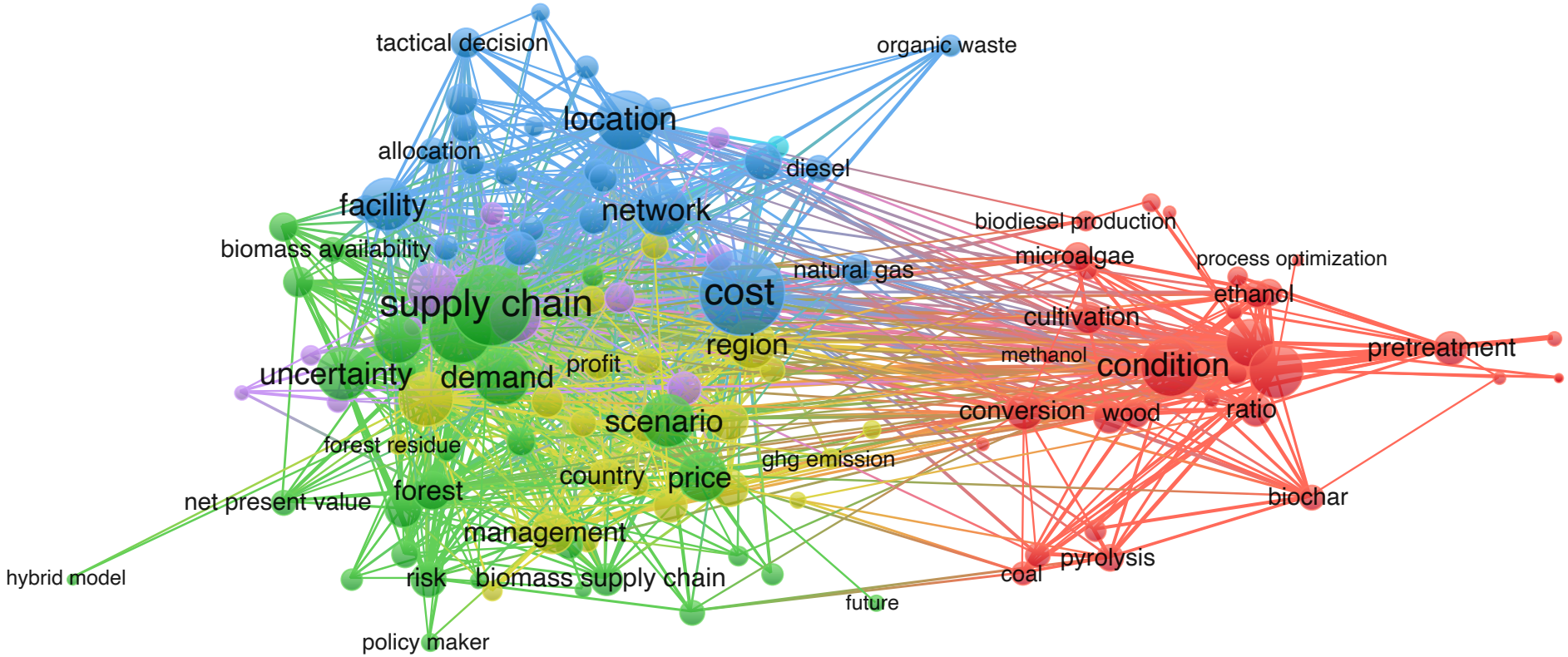
It begins with a descriptive analysis and a profound overview of the evaluation of each decision-making level. First, the resulting overlay visualization from the VOS viewer software displays the network visualization from 661 papers found in databases over a decade development of research topics over time, as shown in Figure III-2, while Figure III -3 depicts the development of research topics over time.

Figure III -2 (a) shows the keyword network visualization from the strategic decision-making level, comprising 121 items related to the topic. Fantastic dots were generated and represented by lines to show their relatedness when a large number of items were generated. For example, the supply chain item is linked to 113 other items (e.g., network, facility, cost, and risk). However, itemized strategic decisions are highlighted in this analysis because they are significantly related to tactical decision items, such as location, facility, demand, network, yield, policy, and cost. Furthermore, Figure III-2 (b) presents a visualization at the tactical decision-making level, comprising 23 items related to the topic. To increase profits, tactical decision items are strongly linked to storage and biorefinery locations. In this case, the question of how to efficiently upgrade biorefinery capacity without reducing profits depends on the strategic decision. Moreover, from this perspective, mixed integer linear programming (MILP) has been investigated and applied to solve the optimization problem in BSC to generate bioenergy. As a result, these items were fundamental in determining major decisions in the following analysis.

Figure III -3 (a) shows the resulting overlay visualization at the strategic decision-making level over time. The yellow colors display the possible latest research development focused on the strategic economic efficiency of the pre-treatment aspect to produce bio-oil and biochar from organic waste. Furthermore, Figure III-3 (b) presents the predicted results of the research development at the tactical decision-making level, more focused on the review and study case of a bioenergy supply chain to replace fossil fuels. However, research on BSC optimization at a tactical level has focused on inventory management on the economic side. It is also linked to strategic decision-making and uncertainty factors.

Moreover, to better understand the study keywords, an analysis of the frequently used keywords with a total of 40 keywords in each decision-making level of the BSC is presented in Figure III-4. In the next section, a detailed analysis is conducted considering the sustainability

dimensions (i.e., economic, environmental, and social). Finally, 116 selected articles consisting of 68 and 48 articles at strategic and tactical decision-making levels, respectively, were comprehensively described to identify the gap.


tactical decision
organic waste
location
allocation
diesel
facility
network
biodiesel production
biomass availability
microalgae
process optimization
natural gas
cost
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cultivation
region
pretreatment
methanol
condition
profit
uncertainty
demand
conversion
wood
ratio
scenario
forest residue
ghg emission
country
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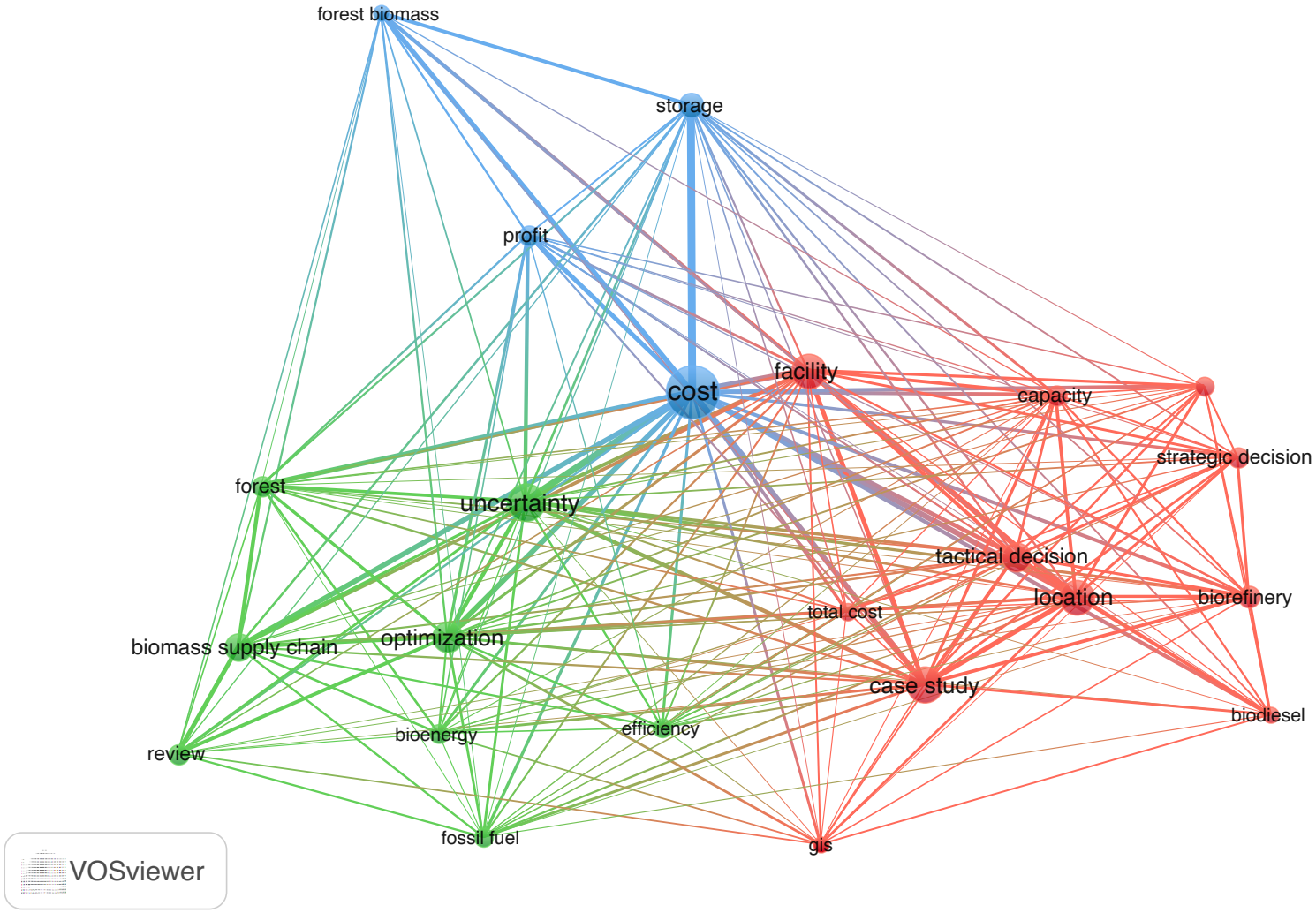
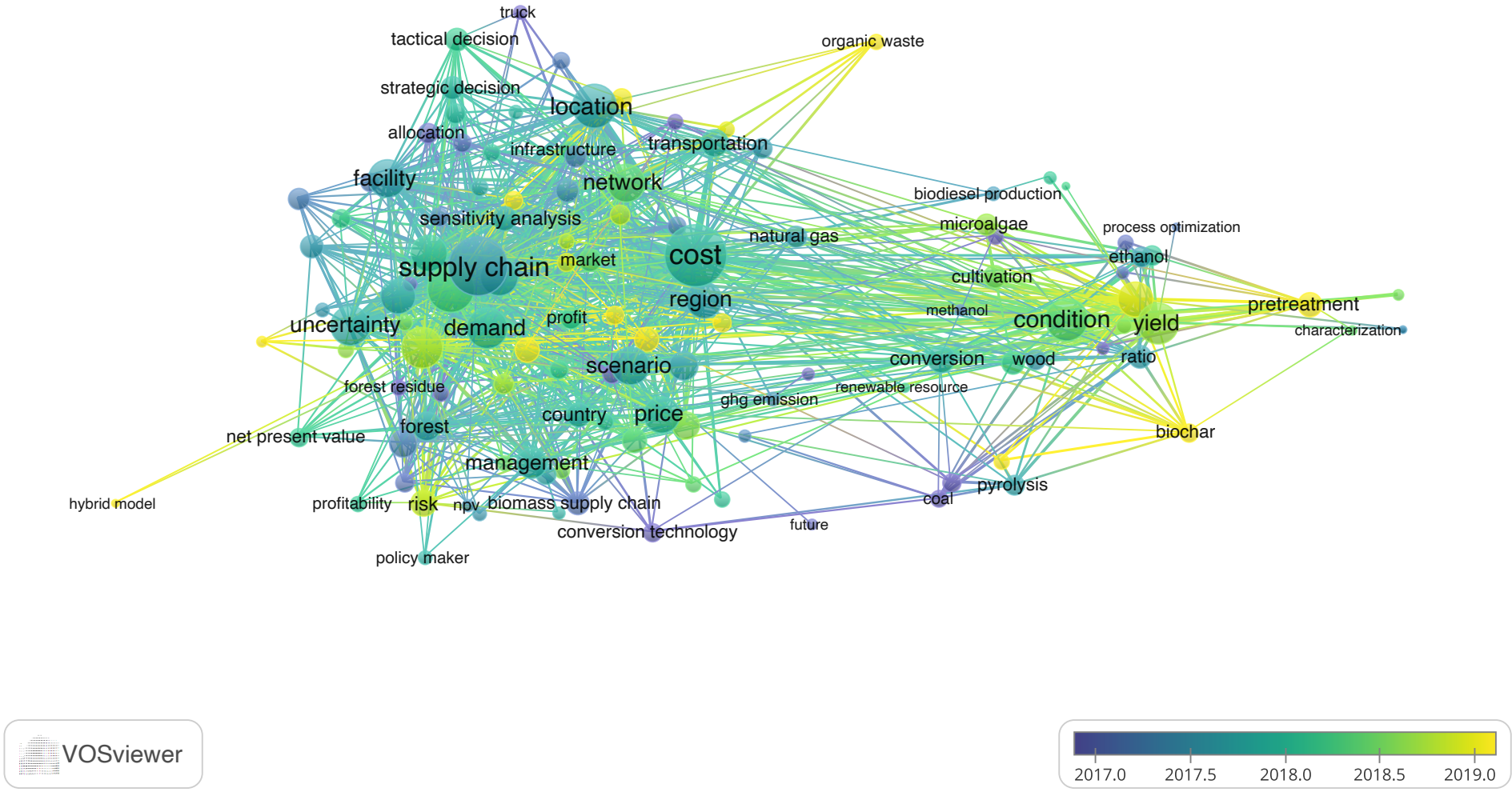
coal
future
policy maker
VOSviewer

(a)



(b)

Figure III-2. Keyword network visualization of the sample: (a) strategic decision-making level and (b) tactical decision-making level


truck
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organic waste
strategic decision
location
allocation
infrastructure
transportation
facility
network
biodiesel production
sensitivity analysis
microalgae
process optimization
natural gas
supply chain
market
cost
ethanol
cultivation
region
pretreatment
methanol
uncertainty
demand
profit
condition
yield
characterization
conversion
wood
ratio
scenario
forest residue
renewable resource
ghg emission
country
price
net present value
forest
biochar
management
pyrolysis
hybrid model
profitability
risk
npv
biomass supply chain
coal
future
conversion technology
policy maker
VOSviewer
2017.0
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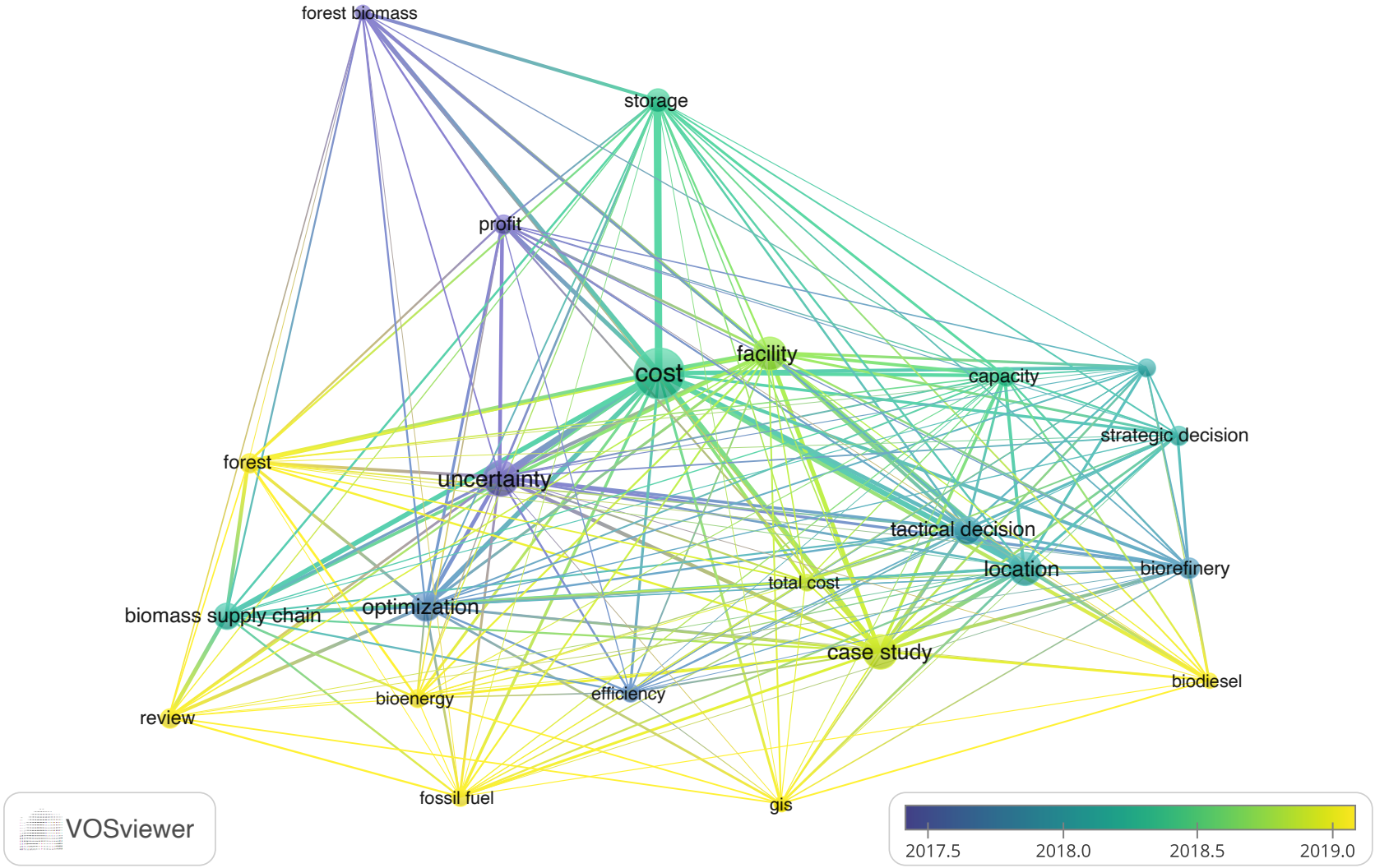
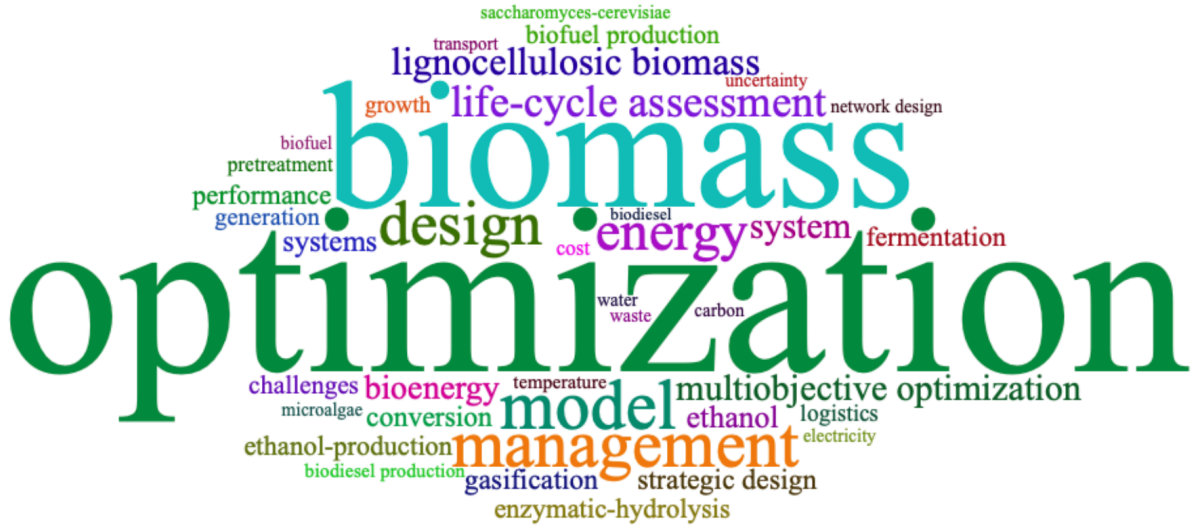
2018.0
2018.5
2019.0

(a)

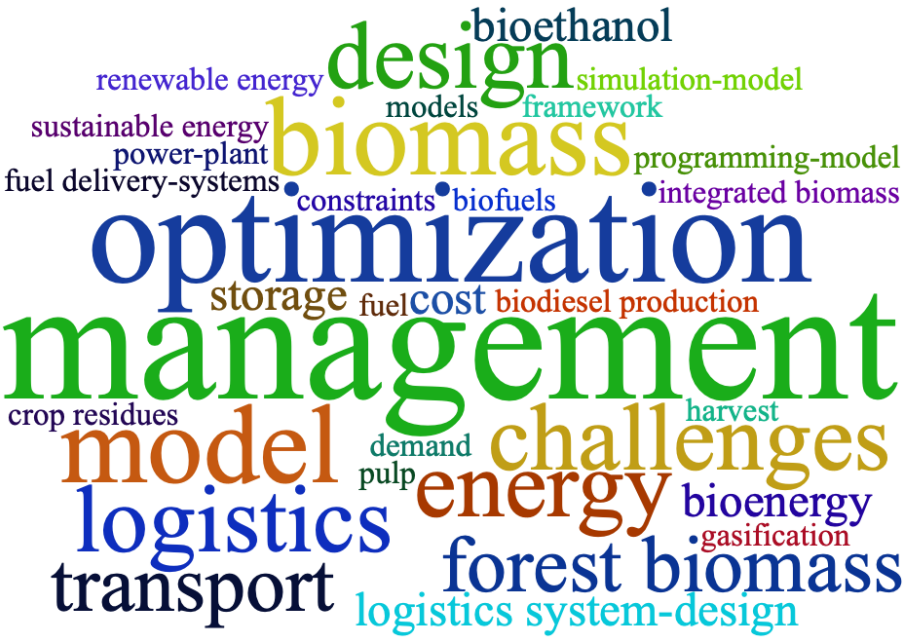


(b)

Figure III-3. Development research topic based on the keyword: (a) strategic decision-making level and (b) tactical decision-making level



(a)



(b)

Figure III-4. Frequently keywords based on the analysis: (a) strategic decision-making level and (b) tactical decision-making level

3.2. *Overview strategic decision-making level*

The result of the strategic decision-making level considering sustainability pillars reveals that the majority of the research is focused on the economic aspect (97%). 46 and 22% of papers discuss environmental and social aspects, respectively, and 13% focus on all three aspects. Figures III -5 depict the distribution of the evaluation studies in terms of sustainability. Simultaneously, 60% (41 papers) also considered the tactical decision-making level to be an integrated system with a strategic decision-making level. Transportation planning and inventory management must be considered in long-term design and planning, particularly in distribution networks. A distribution

network aims to effectively deliver materials (consisting of feedstock, supporting materials, or products) in terms of time and cost. Therefore, it is necessary to systematically optimize and design the distribution network by determining the optimum location, number, and capacity of terminals, considering the available candidate locations and transportation links (Pishvaee et al., 2021a). Moreover, the strategic plan should consider the material flow in transportation, production, and storage levels (Pishvaee et al., 2021b). As a result, as shown in Table III -2, a detailed literature summary at the strategic decision-making level.

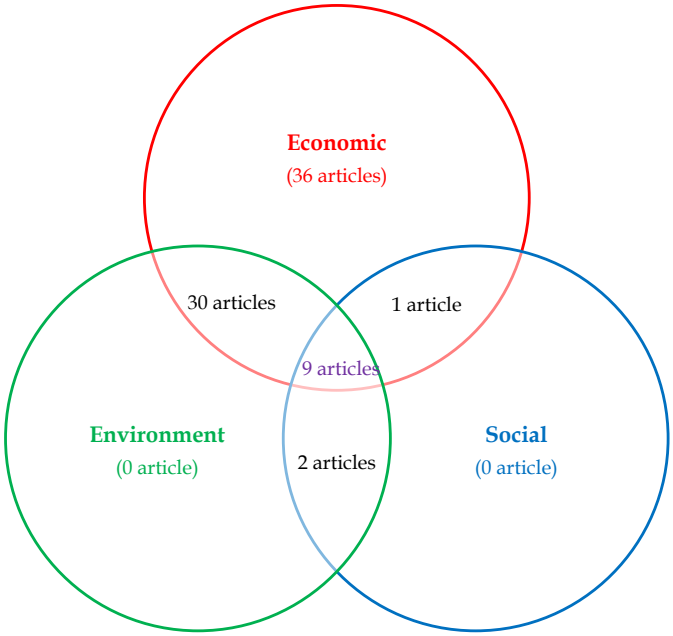


Figure III-5. Distribution of evaluation studies according to the sustainability aspects at strategic decision-making level

The strategic decision level is correlated with long-term planning, which is concerned with stakeholders' interests in developing bioenergy production by supporting the BSC design and network. It refers to the investment in designing the BSC network regarding biomass sourcing and allocation, facility type, location, and size (Awudu and Zhang, 2012; De Meyer et al., 2014). An agreement of feedstock supply contracts between suppliers and consumers is a consideration for investors to develop and balance financial and environmental factors. However, this risk should be considered when making correct decisions (Iakovou et al., 2010). In line with this statement, (Barbosa-Póvoa et al., 2018) address the main aspects of strategic decision-making in five categories: supplier selection, network design, resilience, risk, and product development. Furthermore, (Cerca et al., 2022) reviewed the bottleneck at the strategic level of the BSC in eight groups: research and development, policy, logistic planning, economic, social, ecological, biomass quality, and biomass availability. A detailed literature summary at the strategic decision-making level found in *Appendix A*.

The techno-economic, socio-environmental, technological, and political factors of the system are correlated, and they should be considered when designing the BSC, particularly at the strategic

decision-making level. It is important to remember that biomass is a plentiful bioresource with low bulk density, low calorific value, high moisture content, seasonal and geographical availability, and handling and storage requirements, all of which pose challenges for improving the quality of biomass-based products. Indirectly, it is associated with the material flow and costs (You et al., 2012). Therefore, the comprehensive planning of the logistics network should include some significant elements, that is, (i) frequency and harvesting time, (ii) biomass procurement sites, (iii) transportation modes, (iv) storage methods, (v) supporting infrastructure (e.g., roads, railways, ports, and public warehouses), and (vi) supporting non-infrastructure facilities (e.g., policy and regulation) to optimize the long-term operational efficiency of the BSC. Aligned with this, integrating GIS in BSC design has been implemented by some researchers to determine the location of resources, facilities, and logistics planning (Chakraborty et al., 2022; Frombo et al., 2009; Jayarathna et al., 2020; Sahoo et al., 2016; Sultana and Kumar, 2012; Thomas et al., 2013; Zheng et al., 2021). Moreover, Ahl et al. (2020) described that smart technology applications have the potential to improve efficiency and transparency in BSC design by utilizing automated technology for harvesting, collecting, and handling. However, despite the BSC application heavily depending on spatial and temporal conditions (Torjai et al., 2015), the challenges of feedstock procurement could account for maintaining demand. Spatially, the number and size of lands are correlated with biomass production, which varies by region, type, and farm management practices (Lin et al., 2014a). It directly determines biomass yield, whereas biomass availability is calculated as a surplus of resources after reducing the final application (i.e., food, feed, fertilizer, and biofuel). The transportation distance from the biomass site to the processing facility was based on their spatial distribution. At the strategic decision-making level, these spatial characteristics are strongly associated with a facility's location and capacity selection (Kim et al., 2011). Temporarily, set restrictions are implemented on the size, time, and method of harvesting, storing, and transporting biomass, thereby reducing biomass deterioration (Lin et al., 2014a).

At the same time, fluctuating prices have been considered in the context of biomass procurement to maintain the economic value and supply sustainability to biorefineries. When the farmers' decision to sell biomass follows the market price, the contract period as a supplier could be continued; otherwise, when the market price is too high, the decision makers are less interested in purchasing and will reduce biofuel demand. Nguyen and Chen (2018) indicated that a long-term contract could guarantee the biomass price. However, price competition does not encourage farmers' willingness to provide feedstock. Some factors, such as weather, stakeholders' involvement in issuing policies (e.g., incentives and subsidies), providing supporting facilities, technology availability, the environmental impact produced by the BSC process, and farmers' socioeconomic status, can be a stimulus. Therefore, risk-mitigation strategies should be considered and planned by creating a schema for the optimization of land use and improving farmers' income by supporting agricultural policy.

Increasing the promotion of biofuels to reduce greenhouse gas emissions and raise food and feed demand leads to land-use conflicts and decreases the natural ecosystem. Uncontrollable agricultural or forest land use changes can cause natural disasters (e.g., floods and erosion) and social issues in the long term. Hence, the assessment of resource use in relation to land availability is required as a reference point for stakeholders when considering sustainability implications (Bringezu et al., 2012). Englund et al. (2020) proposed that mapping soil quality as a consequence of land-use change could support the policy development for a new strategic establishment of a suitable agricultural landscape. Furthermore, the bio-economy concept of biomass residue utilization as biofuel feedstock is a short-term method for mitigating land-use change and environmental problems. However, the improper management of biomass waste causes environmental and health issues (Awasthi et al., 2020)(Awasthi et al., 2020). One solution is a decentralized biorefinery concept that considers local cultural conditions to optimize the BSC (Awasthi et al., 2019); it also requires proper waste control and regulation to achieve zero feedstock cost.

At the same time, farm management implications vary based on the method and subject, which are restricted to the cultural context, such as the amount of energy consumption, labor conditions, and total revenue and income along the BSC. As a result, it is critical to emphasize the interaction of social and environmental aspects from the upstream to the downstream level of the BSC, given that a new biomass-based supply chain would significantly impact the ecosystem and livelihood of agricultural workers. Therefore, agricultural workers should not only be viewed as suppliers but also as a crucial component of the planning and design decision-making process in optimizing the BSC (Cerca et al., 2022). Specifically, farmers' understanding, motivation, and acceptability are essential for showing their participation in the decision-making process. It defines the continuity of supply to fulfill biorefinery demand. Indeed, implementing residue utilization can potentially promote local economic development in rural areas; however, it should be strengthened by issuing policies regarding their obligation to contribute to environmental protection and living circumstances that are appropriate to their culture and values.

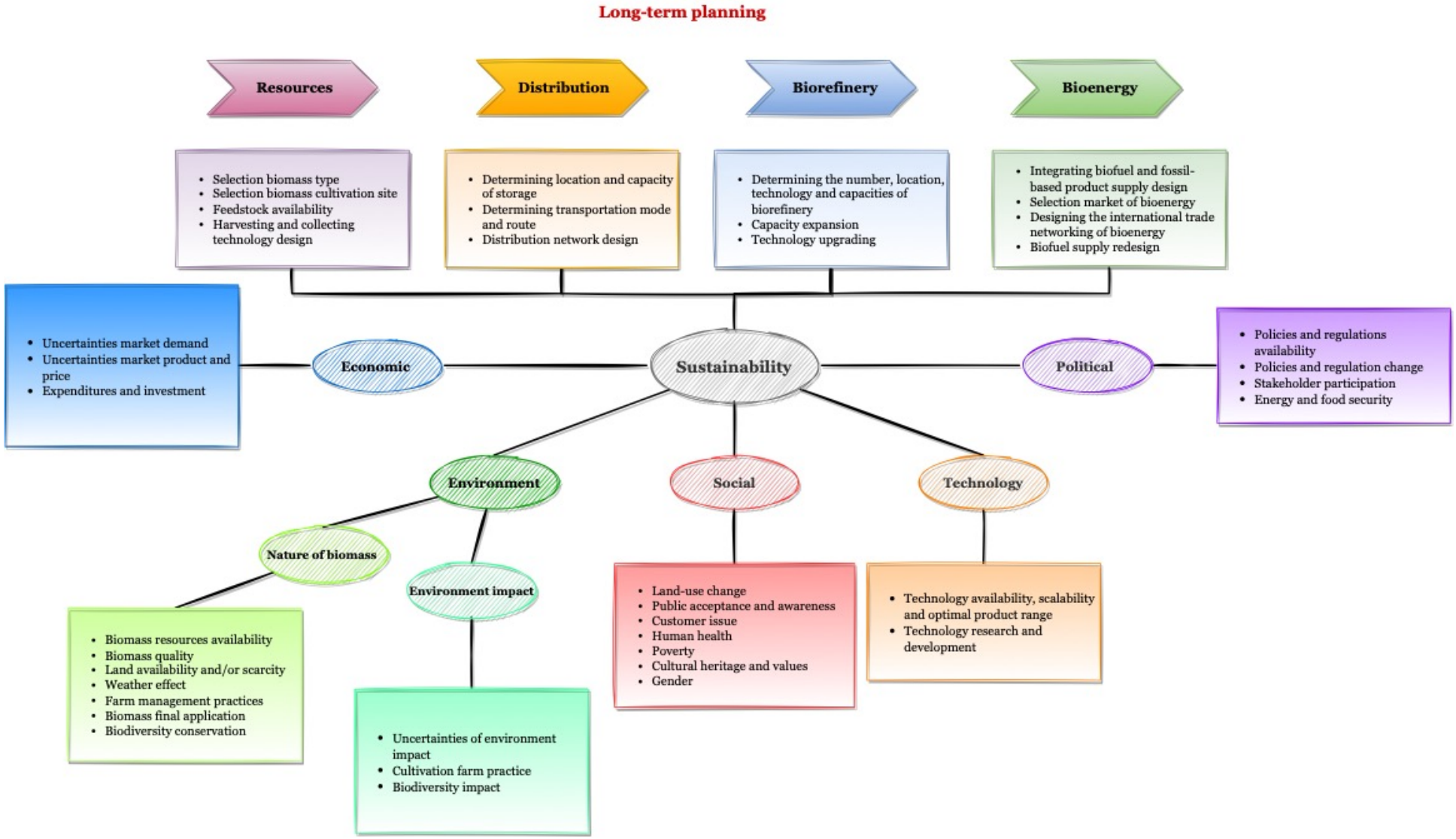


Figure III-6. Overview the strategic decision-making level

The planning and design of the BSC depend on context, product, and scale. The final product is significantly associated with various technological pathways for converting biomass to biofuel, which vary in terms of operational and capital costs, conversion method, process efficiency, energy consumption, and type and specification of biomass feedstock (Pishvaee et al., 2021a). On the other hand, waste produced from biomass conversion should be reviewed as part of the sustainability assessment. Techno-economic assessment (TEA), life cycle assessment (LCA), and social life cycle assessment (S-LCA) are systematic analyses that evaluate the sustainability impact associated with all stages of the process, and they require a multidimensional approach. However, the S-LCA approach has not yet been applied to evaluate the social impact associated with worker lifestyle, working environment, working health, and the impact on society (Chazara et al., 2017). However, it should be explored in the future (Barbosa-Póvoa et al., 2018). Regarding social impact, new job creation positively impacts BSC, although conflict and rejection may arise due to the stakeholders' differing goals. Therefore, long-term planning should provide integrated collaboration to prevent and mitigate conflicts by identifying stakeholders' willingness and awareness. It was investigated using some methodology; for example, group concept mapping (GCM) identified German stakeholders' perceptions of biomass-based value chains (Berg et al., 2018). Interviews and surveys have been implemented to show farmers' willingness to participate in BSC applications, i.e., in China (Qu et al., 2016; Wang and Watanabe, 2016); United States of America (P. Burli et al., 2021; Caldas et al., 2014; Oltra, 2011); and India (Hassan et al., 2015; Zyadin et al., 2015). Wheeler et al., (2018) studied how the implementation of the questionnaire can direct assessment to show acceptance and rejection of sustainability problems in the design and planning of a sugar/ethanol supply chain. Furthermore, a statistical approach was used to identify the correlation between various perspectives of social aspects obtained from the survey and questionnaires to provide new data information for decision-making (D'Eusanio et al., 2019). Stakeholder analysis is a methodology for formulating policy and program development and the resulting participation strategies (Grimble and Wellard, 1997).

The long-term strategy provides not only a new job but also the development of education, skills, a healthy working environment, gender diversity, and younger generation participation as fundamental to designing the BSC concept. As mentioned above, BSC development has significant economic, environmental, social, technological, and political benefits and challenges; therefore, the design and planning at the strategic decision-making level should not be done by individuals or closed groups (Vukasinovic et al., 2019). Stakeholder involvement is not only their role but also vital to configuring the performance and sustainability of the activities. Multidisciplinary research and transformative knowledge linked to sustainable development goals should be developed to strengthen the connection among sustainability dimensions, technology, and political aspects, such as economic-political, environmental-technology, and social technology, to eliminate the bottleneck in BSC application.

3.3. Overview tactical decision-making level

The result of the tactical decision-making level considering sustainability pillars reveals that most research focuses on the economic aspect (75%). Only one paper has discussed the environmental aspect, focusing on carbon tax and carbon trading in the palm oil supply chain to produce electricity and heat (Memari et al., 2018). When papers describe all aspects of sustainability, job creation is highlighted as an effect of the BSC activities. Nearly 11 % of the studies investigated this issue. Simultaneously, greenhouse gas emissions remain an interesting subject for investigation; therefore, the environmental cost should be evaluated to reduce the environmental impact cost. Moreover, two studies have investigated daily inventory management and transportation schedules, which are included at the operational decision-making level (Ebadian et al., 2014; Malladi et al., 2018). As mentioned in the previous subsection, 33 studies incorporated a strategic decision-making level. Most studies discuss the linkage between the location and capacity of facilities with transportation planning and inventory management to minimize operational costs and environmental impacts. A detailed literature summary of tactical decision-making is presented in *Appendix B*.

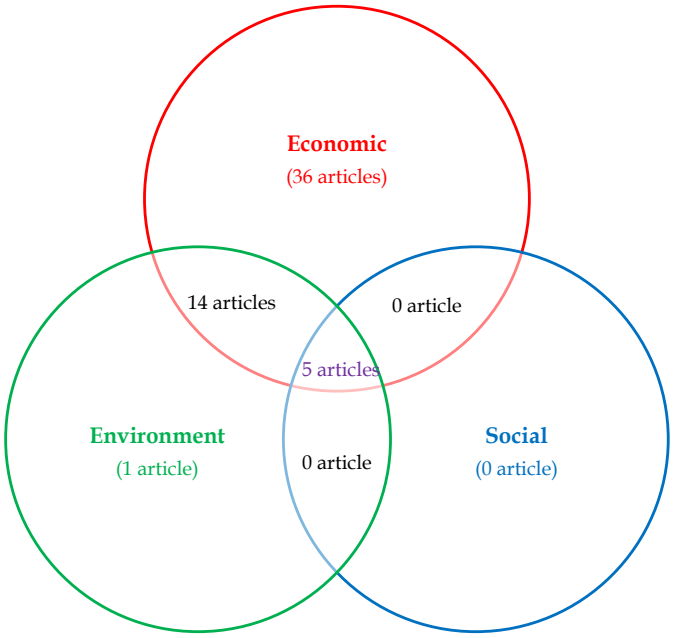


Figure III-7. Distribution of evaluation studies according to the sustainability aspects at tactical decision-making level

Tactical planning can bridge the bottleneck between long-term planning (strategic level) and short-term planning (operational level) to sustain biomass supply in daily activities (Pishvaee et al., 2021c). The tactical decision-making level is medium-period planning in the range of time between six months and one year, which refers to a strategic-level plan and design (Zahraee et al., 2020). Some studies have presented an outline process in BSC tactical planning that includes procurement, logistics (transport configuration and fleet management), inventory, and product

sales planning when the time is zero (at the start of design and planning) (Awudu and Zhang, 2012) (De Meyer et al., 2014; Melis et al., 2018). At the same time, (Cambero and Sowlati, 2014a) described logistical aspects, including the optimization of biomass flow between the supply source and demand point and allocating equipment, technology, and transport for harvesting, storage, production, and shipping. (Acuna et al., 2019) illustrated that road planning, route definition, and annual bioenergy demand should be considered in tactical decision-making. As a result, the overview of tactical decision-making level as shown in Figure III-3.

Biomass quantity and quality are determined by the harvesting and collection processes, which should be timely and cost-effective. This decision is linked to operational planning in a short time to determine the quantity of biomass procurement and the schedule for harvesting and collecting biomass from each source (Malladi and Sowlati, 2018). Calculating the geographical distance traveled from the biomass procurement site to the storage or processing location should be minimized to ensure an isolated location and quantity of available biomass. Therefore, when biomass is not easy to harvest and collect, decision-makers can select the appropriate and optimal biomass from another source. However, the period between harvesting and collecting is a limited window; therefore, biomass properties should always be maintained. As a result, when they are not effectively planned, the reliability of the biomass supply is at risk and the quality decreases.

The selection of harvesting technology significantly impacts the efficient exploitation of biomass and its associated sustainability pillars. The application of advanced technology will indirectly and significantly affect productivity; however, the environmental aspect should review the amount of energy consumed in the process. Land availability, soil properties, and climatic conditions should also be considered when determining the harvesting schedule and biomass collection plan (Mafakheri and Nasiri, 2014). At the same time, the affirmation of work safety has strongly encouraged harvesting mechanization that is assisted by innovative technology compared to semi-mechanized operation to contribute to worker professionalism as a social impact and mitigate site impact during feedstock selection (McEwan et al., 2020).

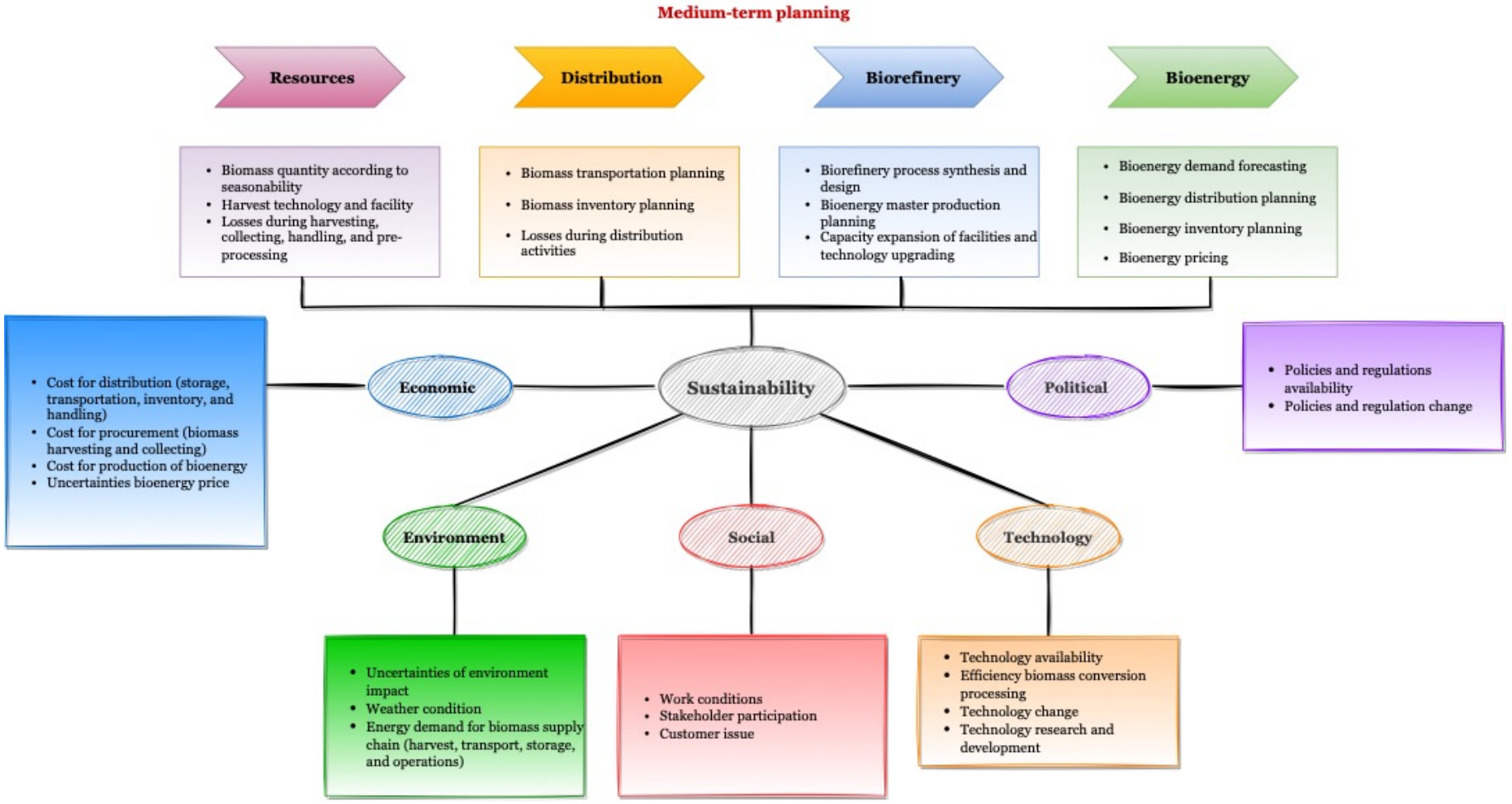


Figure III-8. Overview the tactical decision-making level

Furthermore, the inventory system determines the amount of biomass stored each season or month. The inventory system selection should consider the biomass characteristics, such as seasonal availability, scattered geographical distribution, and uncertain biomass yield, primarily caused by unpredictable weather conditions. However, storing a massive volume of biomass in a warehouse or field is impossible because it hinders preparation for the upcoming planting season (Ebadian et al., 2017) and causes high losses and quality degradation of stored biomass. Therefore, inventory management should estimate the tradeoff between the cost of storage and the cost of material loss based on the biomass degradation rates produced by various storage strategies (An et al., 2011). The quantity and quality of the feedstock stored and distributed should be appropriate to the resources, human labor, and technology utilized in an adequate amount of time and at a reasonable cost. Simultaneously, inventory monitoring is a critical tactical decision that has been investigated to show the logistics cost and emissions (Akhtari et al., 2019) (Rout et al., 2021) by modeling the predictive control of stock levels (Álvarez-Rodríguez et al., 2017). (Zhang et al., 2012) addressed energy consumption and GHG emissions in logistics planning and management. In addition, transportation planning determines the amount of feedstock transported from supply areas to a biorefinery in a given period along a particular route; a problem integrated into inventory planning. A Web-based Decision Support System can optimize the biomass traveling route to provide updated information and network; therefore, logistic costs and GHG emissions can be minimized (Ayoub et al., 2007). Optimization models can manage the link between biorefinery design and inventory management by describing optimal conversion pathways and flow material decisions while considering the long-term availability of feedstock, potential technology application, and final product. While other decisions, such as resource forecasting, bioenergy pricing, and demand forecasting, are reasons for compliance with the BSC in the medium term, the primary consideration in each BSC process embeds the sustainability pillars. In addition, incorporating government regulations (i.e., environmental and economic) as a consideration in inventory and transportation routing will contribute to developing an integrated system of inventory management that assists in illustrating the prediction of future bioenergy demand and biomass supply (Becerra et al., 2022).

In the biorefinery segment, production planning in the middle term focuses on the quantity of material produced or consumed by ensuring the efficiency of timely and economical biomass allocation, workers, and technology. These are related to the design, synthesis, expansion capacity, and upgrading of technology conversion for long-term decision-making. A thorough examination by research and development is required to identify the optimal processing pathways, taking into account feedstock availability, potential process and technology, and final product without compromising the sustainability pillars as fundamental. On the other hand, the final link in the biomass supply chain is the demand side of biofuel as a product, which should be evident in the demand forecasting, distribution planning, inventory, and price. These are influenced by the

policies and regulations that the government issues as uncertain variables. Changing policies and regulations can occur when the technology changes, there is significant feedstock fluctuation caused by natural factors, and there are customer issues (e.g., decreased participation in the use of biofuels), which indirectly affect biofuel demand, price, and market situation. However, it is important to note that most technology conversions still need to be developed, and only a few have been commercialized. Likewise, biofuel prices are highly associated with fossil fuel prices, which are essential for decision making.

4. The research gaps

Assessment studies are a requirement to evaluate the relatedness between main decision in BSC echelons and sustainability aspects. It useful in the decision-making process although the most studies discuss the integrated strategic and tactical level but it is helpful to identify the optimum materials flow and inventory management. The involvement of the stakeholders should receive attention to decide precise time and cost decisions. In more detail, to developing the BSC system the definition of the specific activities should be managed within the system boundaries to set the problem statement. For example, in the view of feedstock resources, biomass was harvested by noticing time and space dimensions. It is transported to a storage center or processing facility. Furthermore, the bioenergy produced is delivered directly to the user or storage facilities. The mathematical model is worthy of implementing decision-making for its process, which is correlated to the BSC design and optimizes the number, location, process, and network of materials and facilities. In detail, the powerful analysis method and tool that should represent how to design the problem and solve it are applicable, simple, and reliable.

In the classical BSC approach, the superstructure represents a summary of the mathematical model and the methodology used to calculate the model. The association between information, components, and the facility of input, processing, and output is illustrated by considering the sustainability aspects. According to (Ayoub et al., 2009) and (Andiappan, 2017), an optimized superstructure is a pathway for determining the optimal pathway to determine potential technology conversion. The superstructure is also used to show material flow, location, and size in the synthesis of facilities to optimize the performance, input, and output (Abdul Razik et al., 2019). It has wide applications, such as chemical processing (Saif et al., 2009), eco-industrial parks (Andiappan et al., 2016), and biorefineries (Haghpanah et al., 2022; Ng et al., 2015). In BSC applications, the superstructure is used to represent the BSC network by considering biomass resources, facility location and technology, transportation design, government policy, and power plant location and capacity for configuration into one optimization system (Abdul Razik et al., 2019; Ling et al., 2019). It shows the configuration of integrating sources and the final product, starting from the biomass procurement site, distribution location, and production location, as a

unified system (Bowling et al., 2011). Furthermore, superstructure applications of BSC have been studied in recent years. For instance, (Miret et al., 2016) and (How et al., 2018) integrated all sustainability aspects into the superstructure. (Ooi et al., 2022) used the superstructure before developing the mathematical model and the stakeholders' behavior for facilitating the palm oil residue supply chain through three conversion layers (pelletization, pyrolysis, and upgrading) and two storage layers. Incorporating a superstructure and a mixed-integer linear programming (MILP) model to optimize BSC to produce biofuel for electricity and heat has been studied by some researchers, i.e., Bowling et al. (2011), Laínez-Aguirre et al. (2015), Ling et al. (2019), and Maharana et al. (2022), while (Mutenure et al., 2018) added the geographic information system (GIS) to show the detailed procurement and distribution locations. Meanwhile, multi-food printing has been considered to optimize the supply chain through superstructure applications (Wan et al., 2016). As a result, by observing a centralized or decentralized network, the performance of the process and product toward the integration system to convert biomass to bioenergy by superstructure utilization can be optimized (Ling et al., 2019); thus, the benefits of the socio-economic and economic environment can be clearly seen (Maharana et al., 2022) (Haghpanah et al., 2022).

In this study, the superstructure is utilized to design the value-creation concept by considering the sustainability aspect in each decision-making process. Incorporating the classical and proposed approaches of the BSC will be designed depending on the context and objective of the study, which will be discussed in the following chapter.

5. Conclusion and perspective

This chapter provides a literature review on the assessment of BSC considering economic, environmental, and social aspects, which is raised to answer the question of how to design and plan a sustainable BSC to implement valorization programs. The fundamental key to strategic decision making is to maintain stakeholder participation. Simultaneously, tactical decision-making involves guaranteeing feedstock availability and inventory. Both decisions strongly correlate with cost-cutting goals, while retaining sustainability aspects.

At the strategic decision-making level, the social aspect is highlighted to identify stakeholders' motivation as supply chain players to achieve bioenergy resilience in the future. Therefore, assessing stakeholders' opinions is a fundamental step toward improving their willingness and involvement in bioenergy development. For instance, farmers' willingness to supply feedstock is an important key that will be analyzed in Chapter IV. The role of other stakeholders, such as policymakers, the government, academics, and industry, in providing facilities and guaranteeing the BSC system through the issuing of policies and regulations is a vital part of the investigation. This will create an image of the stakeholders' willingness and their expectations to determine the strategy for future bioenergy projects, which will be discussed in Chapter V. Furthermore,

minimizing operational costs in transportation and inventory is a tactical goal in determining the economic feasibility of the BSC, which is investigated in Chapter 6. These expectations critically explore the importance of integrated cooperation and stakeholders' roles in BSC activities in order to develop and strengthen the connection, communication, and understanding of their potential, particularly natural resources. Developing systems thinking regarding sustainability will ensure successful deployment of the BSC process.

Chapter IV. Capturing farmers' willingness of agricultural residue valorization as bioenergy production in Indonesia

1. Background

As mentioned in Chapter II, rice plant can produce rice grain as a primary product and rice straw as a potential feedstock for bioenergy generation. In 2021, Indonesia's rice production reached 54 million tons, an increase of approximately 46 thousand tonnes (0.08%) compared to 2019 (Khasanah et al., 2021). According to the assessment result, the gross amount of rice straw production in Indonesia reached 51 million tonnes, when rice productivity and harvesting area were approximately 4.11 ha per tonne and 10.4 million hectares in 2021. On the other side, the Indonesian National Energy Plan by Presidential Regulation No. 22 of the year 2017 stated that in 2025, rice residue could generate 1.9 GW of electricity from 8.4 million tonnes of biomass residue, and rice straw could generate 7 GW of electricity annually when optimally utilized and converted (Rhofita et al., 2022). Therefore, agricultural residue will likely play a prominent role in the rural energy allocation of the national energy supply for power generation in the near future. Moreover, it has many benefits obtained from the expansion of this activity, such as promoting new businesses and job opportunities, strengthening rural economies through partnerships between government, industry, and rural communities at the local and regional levels, and combating environmental problems caused by open-air burning and unsustainable farming practices.

However, increasing the quantity and quality of rice straw utilization requires technical support to minimize the challenges in its application. First, the fundamental challenge was that both the consumption and production data for residue needed to be completed, which can result in an overestimation of the amount of available residue during the postharvest period or, otherwise, a limited quantity. Official data on how much rice straw is used in almost all developing countries are not available, and it is not clear what it is used for. Rice straw grows in different places at different times of the year, making it hard to collect and handle. It should be noted that when uncompressed rice straw was collected directly from the field, the bulk density was approximately 13–18 kg per m^3. In contrast, chopped straw with a length of 2–10 mm has a bulk density of approximately 50–120 kg per m^3, and a rice straw bale with a length of 70 cm and a diameter of 50 cm has a bulk density of approximately 60–90 kg per m^3 (Van Hung et al., 2020). Therefore, accurate data on rice straw potential should be obtained for the BSC's design and plan to be economically feasible without abandoning environmental and social dimensions.

Aside from technical issues with residue collection and handling, the key barrier is farmers' willingness to participate in the sustainability of supplying the residue. As mentioned in Chapter III, the social aspect has been an exciting part to be investigated at the strategic decision-making

level, particularly with farmers as primary stakeholders. In 2021, almost 85% of the working-age population over 15 years of age will be workers in the informal agricultural sector (Statistics Indonesia, 2021). Their understanding and participation levels are indispensable to their growing enthusiasm to engage in agricultural residue valorization programs. What is their motivation to participate? What are their expectations for the future when farmers manage agricultural residues?

Motivations are the main foundation for realizing the existence of a bioenergy project by integrating sustainability aspects (economic, environmental, and social) into its development and how the emerging benefits from the project are realized. (Hicks and Ison, 2018) explored the motivations driving the community to participate in bioenergy projects, which can be encapsulated in sustainability features, as shown in Figure IV-1. Economic benefits play a substantial role in motivating farmers to participate in energy crop cultivation, even though they also consider minimizing adverse impacts on the landscape when selecting crop planting and harvesting characteristics (Paulrud and Laitila, 2010). Furthermore, policy motivations and stakeholders' roles significantly reflect the availability of socio-technical resources, which aim to succeed in the modernization and innovation of biofuel production (Silveira and Johnson, 2016). It provides valuable information on strategic planning for implementing bioenergy projects (Augustenborg et al., 2012). Specifically, a manifestation of motivation is how to embark on a mission by enfolding, balancing, or making decisions that are influenced by contextual factors, such as technology and policy (Hicks and Ison, 2018). However, the barriers and potential should be noted to identify the level of actors' involvement in supplying energy crops, such as sociocultural characteristics, governance models, formal rules, and allocation methods (Ostwald et al., 2013). The critical point is how to eliminate these barriers and strengthen bioenergy promotion by improving awareness, understanding, and adoption of methods and technologies as a benchmark for its final goals. Therefore, active communication between stakeholders is a fundamental way to adopt and implement a bioenergy project, and it is necessary to have better knowledge and understanding to determine the best options for its development (Bailey et al., 2008; Buchholz et al., 2007; Halder, 2014; Mccormick and Kaberger, 2007; Upreti and van der Horst, 2004).

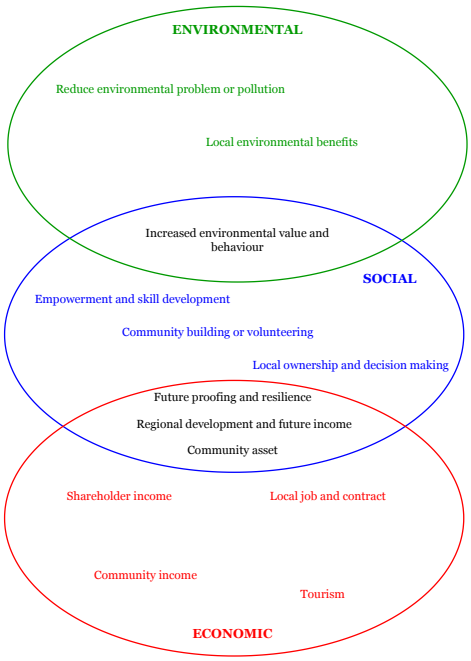


Figure IV-1. Motivation driving community

The farmers' socio-psychology factor construct, whose specific role affects farmers' intentions, behaviors, and perceptions to utilize the residue, is an instrument used to evaluate farmers' awareness and participation in managing crop residue postharvest (Jiang et al., 2018; Raza et al., 2019). Recognizing insufficient farmers' perceptions of utilizing crop residue is necessary to assess the continuity of their willingness to reuse agriculture by determining their socio-demographics, such as age, gender, education, farm size, and other factors (He et al., 2016a). Furthermore, environmental factors can be grouped into economic and non-economic factors, such as land tenure security, the government's role in providing the policy, and adequate economic development to retain biomass residue management as a critical approach to determine the farmers' role in crop residue management (Batidzirai et al., 2016; Xu et al., 2020). Although many researchers have conducted these empirical studies, the question of the critical drivers for farmers to participate in biomass residue as bioenergy requires additional investigation (Gai et al., 2021), for example, to reduce the environmental problems that are happening or the economic factors in the future (Augustenborg et al., 2012; Lopes et al., 2020). The sustainability of bioenergy development is influenced predominantly by government subsidies, policies, and facilities (Zeng et al., 2020). Farmers' participation problems can be mitigated by showing stakeholders' roles in determining the success factors for improvement. In the context of the biomass residue supply chain, the formal dimensions (e.g., transportation infrastructure, business model integration, and biomass quality control) and informal dimensions (e.g., respect for values and traditions, relationship and trust, and local vitalization) are used to balance stakeholders' perceptions and long-term implications in bioenergy policy (Ahl et al., 2018). High-quality and up-to-date information and communication are required to transfer knowledge (Villamil et al., 2012).

Simultaneously, a market structure and clear biomass sales and demand are critical for the viability of programs (Valverde et al., 2021), which should be supported by formulated policies and actions on the sustainability of resources (Kulindwa and Ahlgren, 2021). Therefore, farmers' understanding of willingness and awareness should be identified and analyzed to avoid conflict during valorization. As stated above, this chapter aims to assess farmers' willingness in rice straw valorization to support bioenergy development in East Java, Indonesia. The main research objectives of this study were as follows:

- To assess the utilization of rice straw
- Presenting farmers' characteristics
- To identify the internal and external factors (contextual environment) correlated with farmers' perceptions and expectations of rice straw management programs.

To achieve these objectives, we adopted a methodology based on a survey of 300 farmers, using a questionnaire. The collected data were analyzed using standard multidimensional statistical analysis tools including multiple correspondence analysis (MCA) and clustering.

The contributions of this study lie in three main points: (i) evaluating the variable that is correlated with farmers' perceptions and expectations of participating in rice straw valorization in Indonesia, (ii) supporting sustainable bioenergy production, and (iii) assessing the opportunities and barriers to improving farmers' capacities. These results can be used to identify an appropriate method for improving the social acceptability of biomass energy programs. Moreover, the effectiveness of the decision-making process can be sustainably established when the farmers' perceptions and expectations are better understood.

2. Relevant theory

Stakeholder behavior can be viewed in the context of the theoretical foundation of willingness to participate in biomass residue valorization. (Unay-Gailhard and Bojnec, 2016) observed two main questions related to participation: what are their reasons for participating, and how to stimulate their participation in more desired activities? Their reason to participate or change their behavior was correlated to their values, attitudes, and intentions, for which knowledge and the environment are supporting factors. In practice, both reason and behavior change help identify the level of stakeholder participation. This is correlated to the sociopsychological approach; Wegener and Kelly (2008) described sustainable biofuel development as the implication of the level of understanding, thinking, and behavior required to accept the benefits and weaknesses of biofuel development. Furthermore, identifying their understanding of adoption requires advanced analysis to discover the level of public beliefs and the social change that occurs to show individuals' attitudes; thereby, it is helpful in guiding their behavior, but is also significantly determined by their knowledge level.

To study farmers' willingness to participate in rice straw valorization, different theoretical frameworks have been fundamentally implemented for detailed exploration. First, social cognitive theory (SCT) emphasizes the critical role of physical structure and motivation as leading theories for promoting electrical savings in Denmark (Thøgersen and Grønhøj, 2010). The application of this theory suggests two approaches to changing behavior: (i) changing the social structure and behavior, which can be implemented through empowerment to reduce barriers and improve individual quality, and (ii) promoting social norms and communicating expectations of programs' benefits as a technique for achieving the goals. Generally, Bandura's SCT is a complex theory that is complicated to operationalize. However, individuals' characteristics as internal factors (i.e., demographic aspects), environmental factors as external factors, and behavior are interesting for solving the problem in terms of understanding and willingness (Bandura, 2001). The key elements contributing to and achieving the outcome are their capabilities and self-efficacy beliefs derived from their past behavioral experience and environmental forces (Schunk and Pajares, 2010). Bandura (1986) assumed that behavioral goals or intentions mediate the influence of psychological factors on behavior. It is related to an individual's behavioral objectives, which are primarily determined by his or her outcome expectations and self-efficacy, but perceptions of the behavior of others and the socio-structural environment may account for additional variance. However, one or more of the included psychological antecedents may account for the additional variance in behavior. Whether or not a behavior is actually performed depends primarily on the person's behavioral objectives and possible facilitators and impediments. In proportion to the success of the individual's goal pursuit, which depends partly on socio-structural factors, the behavior will result in anticipated outcomes. In conclusion, this description of a social cognitive model of behavior is indicated in Figure VI-2.

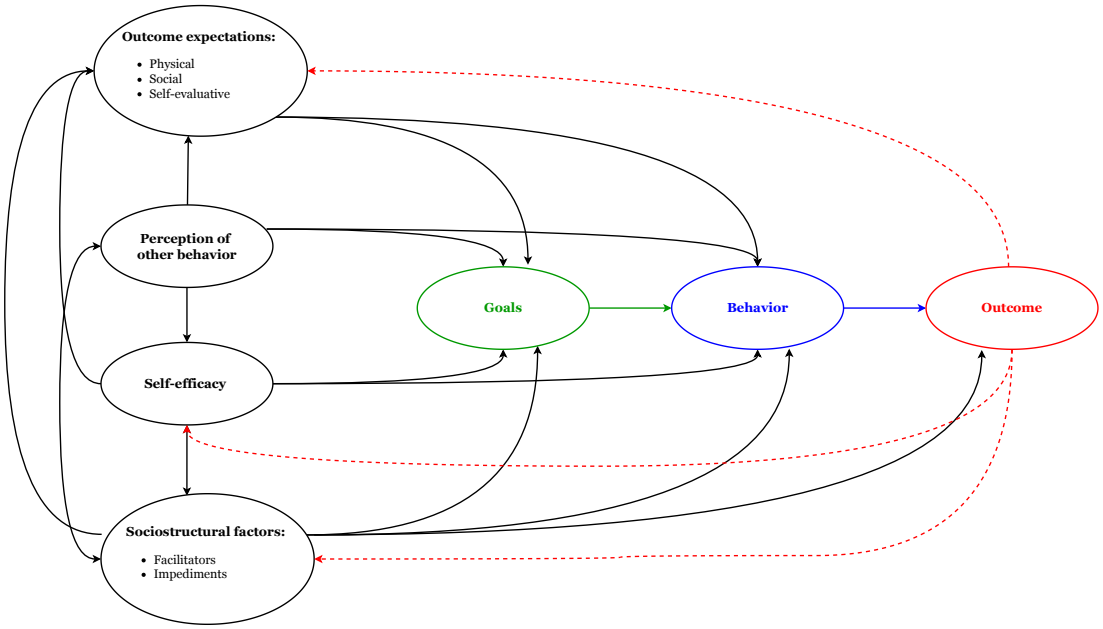


Figure IV-2. A social cognitive model of behavior

Second, the theoretical framework should be examined to explain how stakeholders adopt innovation according to their roles in rice residue valorization. The diffusion and innovation adoption theory by Rogers is a primary theory to identify the level of encouragement and how the actor adopts the innovation, defined as "an idea, practice, or object perceived as new" (Rogers, 2003). It is related to the knowledge and persuasion stages of behavior change, showing the importance of social factors in decision-making. The application of this theory has been investigated to show farmers' contributions to adoption decisions in the biofuel supply chain based on the innovation curve by considering individual factors, socio-temporal dynamics, institutional settings, and their interactions (P. H. Burli et al., 2021). To accelerate adoption, new policies can facilitate diffusion by providing new harvesting and transportation technologies and establishing incentives to support raw material production. Critical elements, such as communication and reducing uncertainty and associated risks, are required to encourage diffusion and innovation in bioenergy development (Jensen et al., 2011).

The social network approach is another theory that can be applied to analyze stakeholders' engagement in bioenergy development, such as in the Philippines and Vietnam (Minas et al., 2020), China (Zhu et al., 2020), Slovenia (Grilli et al., 2015), and Japan (Ahl et al., 2018). These studies attempt to describe stakeholders' interactions and exchange new resources and information to examine the potential for innovation in biofuel development. The roles of social actors should be analyzed to identify their willingness to participate, and it is helpful to answer the questions of (i) who influences the decision, (ii) how interactions among actors occur, and (iii) how they develop the best network connection to support the collaborative partnership. Stakeholders' social networks have substantial value as social capital to facilitate the exchange of resources and information considering social needs, which can provide spaces for negotiation of innovation (Ofolsha et al., 2022) and influence their participation due to the persuasiveness argument provided by decision-makers and actors (Juntti and Potter, 2002). Simultaneously, experience and knowledge level are vital points to sharing their experience; thereby, sociocultural heritage and institutional arrangements should be notified to investigate the impact of adoption through integrating individual characteristics (i.e., age, education, and economic conditions) and knowledge flows (Ramirez, 2013) (Nyambo and Ligate, 2013). Social interactions between actors within social networks have strong links to accessing and sharing innovation (Ridges & Hickey, 2016).

Finally, the theory of planned behavior (TPB), developed from the theory of reasoned action (TRA), identifies the psychological factors that influence actors' intentions and behaviors, affirming that knowledge, resources, and opportunities are objective restrictions in determining a decision. Three constructs determine the actors' intention (willingness to involve a specific behavior) and its importance in determining behavior: (i) attitude (positive or negative evaluations of performing a specific behavior), (ii) subjective norm (social pressures on performing a specific

behavior), and (iii) perceived behavioral control (perceptions of their own capabilities to perform a specific behavior based on their experience and resources) (Ajzen, 1991). This theory has been applied to analyze stakeholder perceptions and participation in biofuel development from biomass residue (Mattison and Norris, 2007) (Chin et al., 2016) (Jiang et al., 2018) (Yaghoubi et al., 2019)(Alemayehu et al., 2020; Yaghoubi et al., 2019). The roles of decision makers and biofuel producers are vital to persuading farmers to become involved in the biomass supply chain by promoting the benefits of production (harvest practice and income), perceived environmental benefit, and perceived ecological impact (Chin et al., 2016). Furthermore, understanding farmers' motivation to supply raw materials has a causal-effect relationship with farming characteristics (i.e., dependency on product collectors, landownership status, plantation size, and plantation experience) (Chin et al., 2019). The role of decision-makers in the design of biofuel crop promotion and regional infrastructure development significantly improved farmers' intentions and perceptions (Mattison and Norris, 2007), which influenced the prediction of their willingness (Yaghoubi et al., 2019). While the intention is to introduce and diffuse bioenergy innovation by revealing the differences between decision-making processes, advanced research and policies are strategies to boost the adaptation rate of bioenergy innovation and development (Alemayehu et al., 2020).

3. Research methodology

3.1. Study area

East Java Province is the leading rice producer in Indonesia, covering approximately 1.76 million hectares of rice field area in 2021 (Wahidayat et al., 2021). Based on the statistical data, three districts in East Java province have the highest rice production, productivity, and largest rice field area compared to the other 35 regions, that is, Bojonegoro, Magetan, and Lamongan (Figure IV-1). The precise reasons are: (i) high agricultural activities due to one-fifth of the population being farmers and more than 25% of the regional income coming from the agriculture sector; (ii) high biomass residue potential due to above-average production and productivity of rice; and (iii) awareness of government support to develop agricultural activities, such as policies and regulations that describe sustainable food protection, cropping patterns in irrigated areas, farmer protection and empowerment, and agricultural facilities and funding, as shown in Table IV-3.

Table IV-1. Regulations and policies related to agriculture activities

Location	Title of regulations	Purpose
Bojonegoro	Bojonegoro Reagent's Regulation No 43 the year 2020 on the second amendment of Bojonegoro Reagent's Regulation No 48 the year 2018 on the independent farmer programs	The guidance of farmer facilities to develop agricultural business by funding grants, farming education and training, agricultural product purchasing cooperation, crop failure insurance, and farmer family scholarship.
Lamongan	Lamongan Government Rules No 12 the year 2015 on sustainable food land protection	The framework of sustainable land protection through agricultural revitalization programs and ecosystem balance aims to provide sustainable food and environment.
	Lamongan Government Rules No 13 the year 2015 on protection and empowerment of farmers	The mechanism of protection and empowerment of farmers by planning, monitoring, and evaluating agricultural businesses to develop sustainable agriculture.
	Lamongan Reagent's Regulation No 7 the year 2019 on guidelines of Lamongan agricultural intensification program in 2020	Guidance on the preparation and implementation of agricultural intensification programs in accordance with potential and necessities.
Magetan	Magetan Government Rules No 3 the year 2017 on protection and empowerment of farmers	The mechanism of protection and empowerment programs for farmers to improve the quality and quantity of sustainable agricultural businesses.
	Magetan Reagent's Regulation No 2 the year 2020 on guidelines of planting patterns and system implementation in 2019/2020 on irrigation areas	Guidelines of available water supply for agricultural activities to minimize water shortage problems during the cultivation period.
	Magetan Government Rules No 8 the year 2021 on the sustainable food land protection	Framework to achieve food security and minimize the function and reduction of arable land.

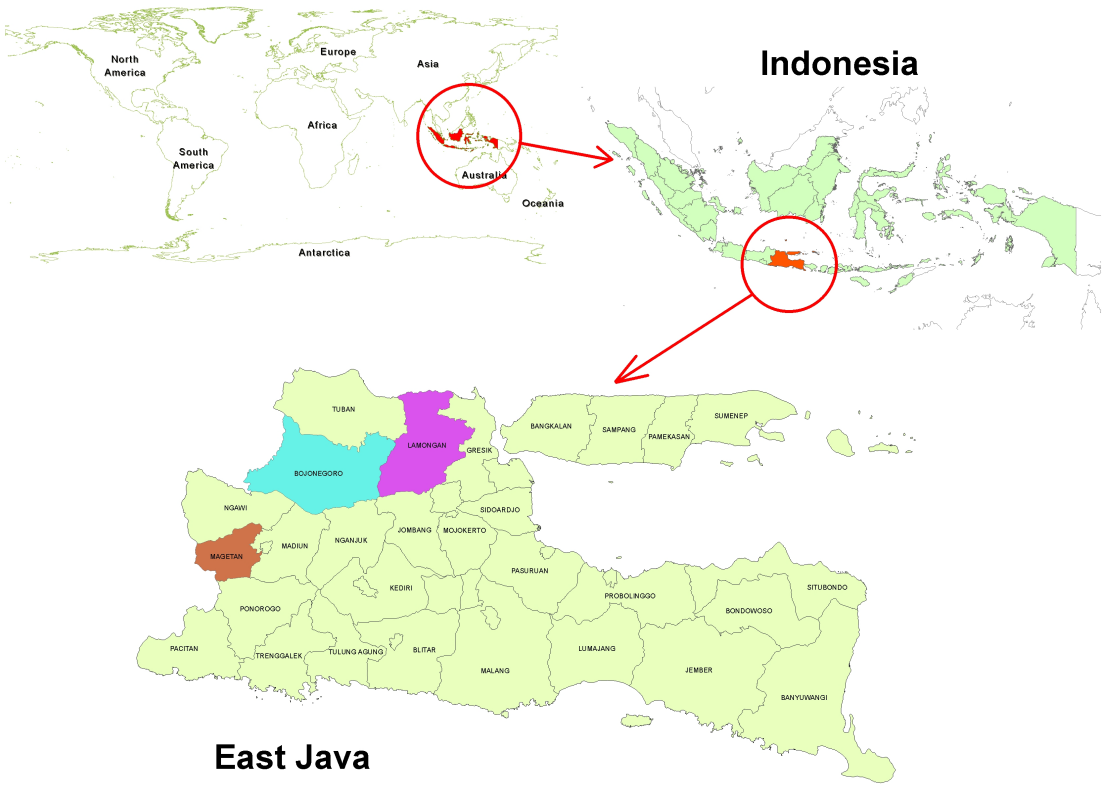


Figure IV-3. Study areas

3.2. Survey design

According to the government's official data, the population was 1545 farmers from the three regions. To further explore farmers' participation in and expectations of rice straw valorization programs, purposive sampling was used by considering three criteria: (i) the farmers are business actors, not farm laborers or seasonal cultivators; (ii) they are registered in the farmer's group; and (iii) the main crop is rice, cultivated at least twice per year. As a result, it was decided that 300 farmers will conduct face-to-face interviews through a door-to-door survey from November 2020 to March 2021. This method was chosen for the best interview due to the time of the COVID pandemic to discover specific answers, and applying another survey method (i.e., forum group discussion, or FGD) was impossible.

A structural questionnaire was used to collect data and information based on previous group discussions and interviews with the farmers in April 2019. Before the formal survey, a trial survey and group discussion were sent to 20 farmers in Kendal, Central Java, in September 2020 to identify any possible misinterpretations and ambiguities in the questions and respondents' responses. Furthermore, the questionnaire was reviewed and modified based on responses to the pilot survey. The questionnaire consisted of two parts. The first describes internal factors related to farmers' social and economic conditions. The data were obtained through another questionnaire on rice cultivation for a year, as shown in Figure IV-4, and the detailed questionnaire in Appendix C, Part 1. The second part has five sections to identify farmers' willingness to provide information regarding (i) the farmers' profile with the open question (i.e., gender, age, education, and working time as farmers); (ii) the farmers' opinion related to their external factors that influence the method of rice cultivation and that come from their environment, for example, their rice residue utilization and supporting facilities from the government; (iii) farmers' motivation to discover their reason to participate in rice straw valorization considering sustainability aspects; (iv) farmers' perception of rice straw valorization; and (v) farmers' expectations when they are managing the rice residue. In the second to fifth sections, five Likert scales were applied to identify farmers' answers; however, in the first question in the second section, the percentage scale was used to define their quantity of rice straw utilization. A detailed questionnaire to map farmers' willingness is shown in Appendix C, Part 2.

Previous studies have investigated multiple factors that affect farmers' perceptions of converting biomass into bioenergy (Launio et al., 2014; Li et al., 2020; Zyadin et al., 2021). Therefore, this study will provide insight to help determine the active variables used to identify farmers' perceptions and expectations of participating in the rice straw valorization project. The complex variables are listed in Table IV-2.

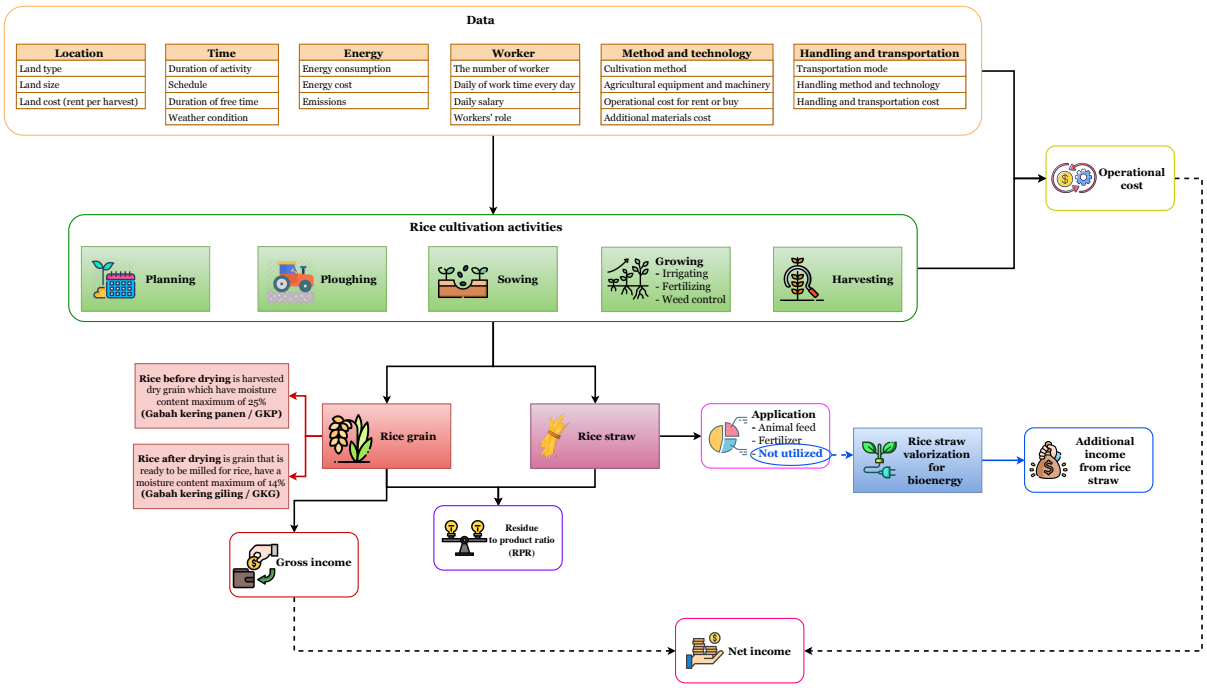


Figure IV-4. Schema of farmers' social and economic conditions

Table IV-2. Definition of variables from five factors and the corresponding coding

Code	Factor and variables	Type	Definition	Response code
Internal factors			*Farmers' characteristics that related to the economic aspect of the rice cultivation during a year*	
Field_area	Field area	Continuous	An area of land used for rice or other food crop cultivation purposes	0.13 – 0.74: Small (S) 0.74 – 1.47: Medium (M) 1.47 – 3.38: Large (L) 3.38 – 7.85: Extra-large (XL)
Rice_before_drying (BD)	Production before drying	Continuous	The rice grains contain a moisture content of between 18% and 25% (18%%<MC<25%), and the maximum impurity content is approximately 10%. It was obtained shortly after the rice was threshed	<9.97 tonnes: BD_low 9.97 – 27.30 tonnes: BD_medium > 27.30 tonnes: BD_high
Rice_after_drying (AD)	Production after drying	Continuous	The number of rice grains containing a maximum moisture content of approximately 14%, and the maximum impurity content is approximately 3%. It was obtained from the calculated result of the rice grain after drying activity to reduce moisture content and purity	< 8.24 tonnes: AD_low 8.82 – 22.8 tonnes: AD_medium > 22.8 tonnes: AD_high
Rice_straw_production (RS)	Rice straw production	Continuous	The quantity of rice straw obtained from harvested activity. It is calculated from production during each planting period in a year	< 18.50 tonnes: RS_low 18.50 – 68.20 tonnes: RS_medium > 69.20 tonnes: RS_high
OP_cost (OP)	Operational cost	Continuous	The expenses related to rice cultivation per year, starting from planting preparation, sowing, plowing, fertilizing, eradicating pest and plant diseases, harvesting, threshing, and drying activities	US$136 – US$971: OP_extremely low US$971 – US$1,936: OP_low US$1,936 – US$3,371: OP_medium US$3,371 – US$6,800: OP_high US$46,800 – US$12,843: OP_extremely high
Gross_income (GI)	Gross income	Continuous	The revenue of all rice grains or rice sales and profits before deducting the operational cost of rice cultivation and taxation	US$478 – US$4,129: GI_extremely low US$4,129 – US$7,143: GI_low US$7,143 – US$12,000: GI_medium US$12,000 – US$19,929: GI_high US$19,929 – US$43,500: GI_extremely high
Total_income (TI)	Total income	Continuous	The revenue is computed from the residual of all operational costs and gains for the period, with fewer expenses and losses	US$314 – US$2,536: TI_extremely low US$2,536 – US$4,771: TI_low US$4,771 – US$8,500: TI_medium US$8,500 – US$14,643: TI_high US$14,643 – US$30,929: TI_extremely high
External factors			*The factors that originate from the environment, and objects can change the farmer's perception of rice straw utilization management*	

Amount_utilization	Current rice straw utilization	Categorical	The percentage of rice straw utilization as a raw material for other activities, such as feeding and bedding, and planting purposes (e.g., mushroom cultivation and soil erosion reduction)	0.0 – 30.5%: Amount_Utilization_Low 30.50 – 61.60%: Amount_Utilization_Moderate 61.80 – 81.80%: Amount_Utilization_High 81.80 – 100%: Amount_Utilization_Extremely high
Utilization_feed	Rice straw utilization as animal feeding and bedding	Categorical	The frequency of farmers' utilization of rice straws for animal feed is a part of the purpose of their weight maintenance	1: Never 2: Rarely 3: Sometimes 4: Often 5: Always
Utilization_planting_ purposes	Rice straw utilization as planting purposes	Categorical	The frequency of farmers' utilization of rice straws for planting purposes, such as mushroom media planting, fertilizer, and mulch	
Information_available Weather_available Facilities_available	Supporting facilities availability	Categorical	The availability of facilities from the government to farmers to support the development of rice straw management activities. The supporting facilities, i.e., the information on cultivation methods, weather information, and facilities (e.g., agricultural equipment and machinery, public warehouse, irrigation network, and distribution and market share)	1: Strongly not available 2: Not available 3: Possibly 4: Available 5: Strongly available
Government_information Government_facilities	The governments' role in rice straw management	Categorical	The physical and nonphysical support that the government has provided for rice straw management activities, for instance, the information of up-to-date cultivation methods and weather information through periodic agricultural counseling and training, and facilities to help improve the farming quantity and quality	1: Not at all role 2: Slightly role 3: Somewhat role 4: Very role 5: Extremely role
Motivation factors			*Encouraging farmers themselves or their environment to implement rice straw management activities*	
Environment	Environment	Categorical	The farmers have encouragement to manage and utilize rice straw to reduce open burning and environmental problems such as air pollution, soil erosion, and water contaminants	1: Very poor 2: Below average 3: Average 4: High 5: Very high
Economic	Economic	Categorical	The farmers have encouragement to manage and utilize rice straw to earn more income from rice farming activities	
Social	Social	Categorical	The farmers have encouragement to manage and utilize rice straw to participate in job creation and improve social welfare	
Perception of rice straw valorization			*An activity and a process for farmers to determine the activities' responses, goals, and impacts*	
RS_reduce_OB	Rice straw utilization and	Categorical	Farmers' perception that rice straw utilization and management in the postharvest period can reduce open	1: Strongly disagree 2: Disagree

	management reduce open burning		burning that causes environmental problems and human health disruption	3: Neutral 4: Agree 5: Strongly agree
RS_reduce_erosion	Rice straw utilization and management reduce soil erosion	Categorical	Farmers' perception that rice straw utilization and management can reduce erosion and improve soil water storage by maintaining a level of soil carbon stocks and nitrogen content over time.	
RS_income	Rice straw utilization and management is additional income	Categorical	Farmers' perception that rice straw utilization and management is one method for additional income by increasing the usability of rice residue for valuable material.	
The expectation when managing rice straw factor			*The desire to become a reality that rice straw management activities will maintain environmental sustainability and improve farmers' socio-economic standard of living. The farmers expect that the government will provide some support in the forms of:* *a. Training and education.* *b. Supporting facilities.* *c. Funding assistance.* *d. Distribution network and market share.* *e. Integrated cooperation between stakeholders.*	
Education_training	Farmers' expectation of education and training	Categorical	Farmers hope that the government will provide education and training to improve their competency in supporting rice straw utilization and management.	1: Strongly disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly agree
Facilities	Farmers' expectation of supporting facilities	Categorical	Farmers hope that the government will provide supporting facilities for more accessible rice straw utilization and management.	
Funding	Farmers' expectation of funding assistance	Categorical	Farmers hope that the government will provide funding assistance to facilitate rice straw utilization and management to be better.	
Market_share	Farmers' expectation of market share	Categorical	Farmers hope that the government will provide a distribution network and market share to sell their rice straw.	
Cooperation	Farmers' expectation of cooperation	Categorical	Farmers hope that the government will cooperate with stakeholders to realize the rice straw valorization program.	

3.3. Multidimensional statistical analysis methods

Descriptive statistics present the answer distribution by providing general trends and information in the data set from all variables, including farmers' socio-professional status and demographic profiles. Furthermore, discretization was applied to the detailed internal factors to transform continuous variables into category variables before conducting a multivariate analysis. Two types of multivariate analysis data tools were used to identify the answers given by the farmers: MCA (Benzécri and Bellier, 1973), and hierarchical clustering analysis, using R software (R Core Team, 2021). MCA aims to provide insights into the dependence of multiple categorical variables. MCA explores the interrelationships among the variables and individuals (farmers), allowing for the description of categorical variables in a multidimensional space.

MCA identified different farmers with similar profiles in their answers to questions. A cluster analysis was performed to classify farmers according to their internal and external features, perceptions, and expectations of participating in rice straw valorization. The second tool is hierarchical clustering analysis based on general linking data, using the Ward criteria aggregation method to calculate the correlation among variables in each factor and other factors. The similarity variable was regrouped through a minimal Euclidean distance for ease of measurement, relevance, and reliability. Combining multivariate analyses is relevant to visualize the correlated (or similar) variable and identify the close farmers' characteristics; hence, it can identify the least good and best correlation to make a recommendation.

In this study, multidimensional analysis and dimensional reduction are part of unsupervised machine learning methods. Dimension reduction is primarily concerned with taking high-dimensional data, which typically means that the number of variables is greater than four and making a more straightforward version (2-dimension) by conserving the original data properties as much as possible. The purpose of performing dimensionality reduction is to obtain a visual overview of our survey data and enable rapid exploratory data analysis. The profile of elements m with a specific property is constructed by their sum, which is 1, which is the position of a dimensionality space $m - 1$. This can be identified as a lower-dimensionality subspace that is close to all profile points. In correspondence analysis, the criterion is a weighted sum of squared distances, or inertia, and the lines and planes of the best fit are discovered by minimizing the inertia that is lost by projecting points onto a lower-dimensional space. Suppose that I profile points exist in a multidimensional space and S denotes a potential low-dimensional subspace. $di(S)$ can be used to calculate the X^2-distance between the *i-th* profile point with mass mi and S. The profile proximity to the subspace is $mi[di(S)]^2$, that is, the squared distance weighted by the mass. The geometric developments and the original name "analyze des correspondances" have their roots in the work of Benzécri and coworkers (1973) (Benzécri and Bellier, 1973).

Finally, to facilitate the comprehension of the research approach, Figure IV-5 shows a diagram of the methodology.

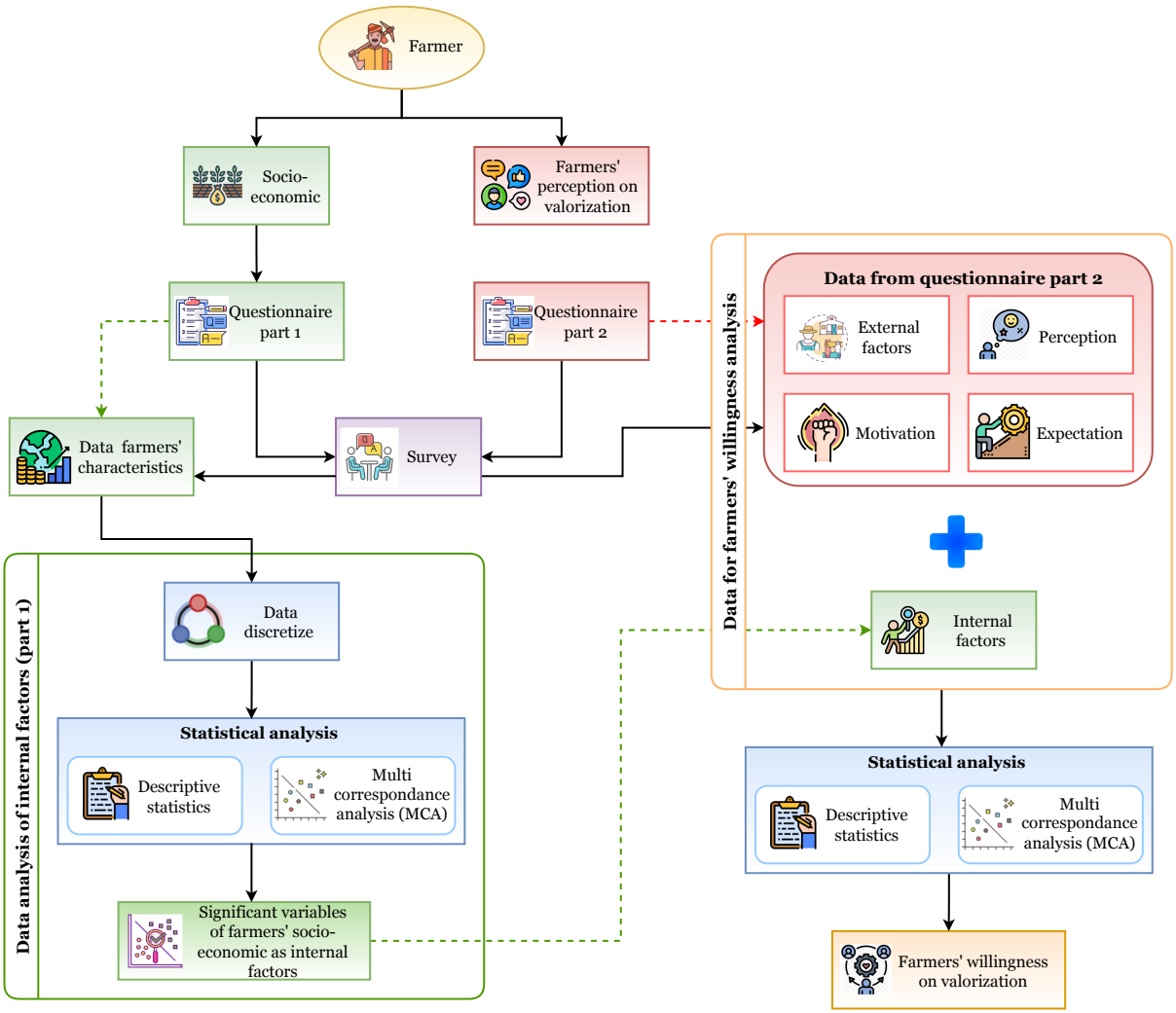


Figure IV-5. Diagram of the farmers' willingness methodology

4. Results and discussions

4.1. Characteristics and profile of farmers

Gender can affect farming productivity and rice straw management. A total of 300 farmers were interviewed, including 256 males (85.33%) and 44 females (14.67%). Furthermore, age is an essential factor in determining the competence of rice straw management. In this study, the age taken is continuous data; hence, a discretized analysis is required to convert it into categorical data. A quartile value was used to cluster the age variables into four groups to present data with a normal distribution and homogeneity. The average farmer's age was nearly 52 years, while the highest proportion of respondents were elderly (31.67%), aged between 58.90 and 73 years, followed by older (24.33%), middle-aged (24.0%), and young (20.0%). In Indonesia, productive ages between 32 and 64 years are considered excellent in terms of physical and intellectual competence.

Educational level significantly influences the adoption and innovation of rice straw management technologies. The high level of education among farmers gives them great potential to access the latest information and technologies. In this study, nearly 32.33% had completed high school, 31.67% had completed primary school, 27.33% had completed middle school, and 8.67% had completed a bachelor's degree. Furthermore, in the agriculture sector, the demographic problem has been less profitable because of an increase in the number of older farmers (over 50 years old), while the younger workforce is decreasing. This adds to the classical problem of the low average level of farmers' education compared with other sectors. According to the agricultural census, in the last two decades, approximately 64% of Indonesian farmers graduated from elementary school; consequently, this has caused low productivity in agricultural areas (Susilowati, 2016). This phenomenon also shows that young rural workers choose something other than farming as their primary profession because of decreasing farming areas, uneconomical cultivation activities, and their perception that farming cannot provide the necessities of life.

Farmers' work hours are influenced by their experience, which is essential in accepting residue management methods. Based on observations, most farmers have worked in the field for more than ten years, approximately 74%), while 15% of respondents are new farmers who changed their social status because they have free time after retirement. Previous studies have described that gender, education, farming experience, and access to agricultural services are essential in determining their perceptions of farming methodology and technology (He et al., 2016b; Mahama et al., 2021). Therefore, stakeholders' roles are required to bridge the gaps in knowledge and education among farmers through regular agricultural extension and training. The detailed farmers' characteristics and profiles are shown in Table IV-3.

Table IV-3. Personal characteristics of 300 farmers respondents

Farmers' profile	Options	Number	Percentage
Gender	Male	256	85.33%
	Female	74	14.67%
Age	35.00 – 44.40 years	60	20.00%
	44.40 – 51.40 years	72	24.00%
	51.40 – 58.90 years	73	24.33%
	58.90 – 73.00 years	95	31.67%
Education	Primary school	95	31.67%
	Middle school	82	27.33%
	High school	97	32.33%
	Bachelor degree and above	26	8.67%
Working time as farmers	Less 10 years	79	26.33%
	10 – 15 years	39	13.00%
	16 – 20 years	18	6.00%
	21 – 25 years	31	10.33%
	Over 25 years	133	44.33%

3.2. Determine variables in the internal factors

Internal factors aim to represent farmers' socioeconomic status, which MCA analyzes to show the relationship pattern of categorical dependent variables and capture individual similarities. In the questionnaire on rice cultivation, the internal factor consisted of a supplementary variable (region) and 16 active variables that were grouped into four categories: (i) individual characteristics (i.e., age, gender, education, and length of time working as a farmer); (ii) private facilities to support their agricultural activities (i.e., rice field area, transportation mode, distance from their house to the field area, and warehouse ownership); (iii) rice cultivation period during a year (i.e., amount of rice planting period, time planting rice, and farmers' free time); and (iv) rice production (i.e., rice grain production before and after drying, rice straw production, operational cost, gross income, and net income). Almost 73% of the variables in the four groups are continuous; hence, discretization is required to convert the continuous variable to a categorical variable using the interval method (equal interval width). Furthermore, the internal factor analysis results indicated that approximately 60% of the variables (nine variables) were close to the center of the coordinates (Figure IV-6). These are insignificant because the coefficient of determination (R^2) is less than 0.7, which is close to the center and was not used in the subsequent analysis. Therefore, this study selected seven variables to represent the internal factors with an R^2 value over 0.7 (a significant variable) in the first factorial axes, as shown in Figure IV-7, and the exact R^2 values are listed in Table IV-4. Nevertheless, some variables that describe farmers' characteristics (i.e., gender, age, education, and working time as a farmer) were analyzed using descriptive statistics in the previous section.

Table IV-4. The coefficient of determination value (R^2) of variable in internal factor

Internal factor variables	Dimension 1	Dimension 2
Production before drying	0.860	0.717
Rice straw production	0.858	0.612
Production after drying	0.857	0.711
Gross income	0.847	0.703
OP cost	0.839	0.638
Total income	0.782	0.637
Rice field	0.721	0.563
Time planting	0.370	0.107
Free time	0.364	0.072
Vehicle type	0.358	0.083
Planting pattern	0.234	0.016
Warehouse	0.066	0.057

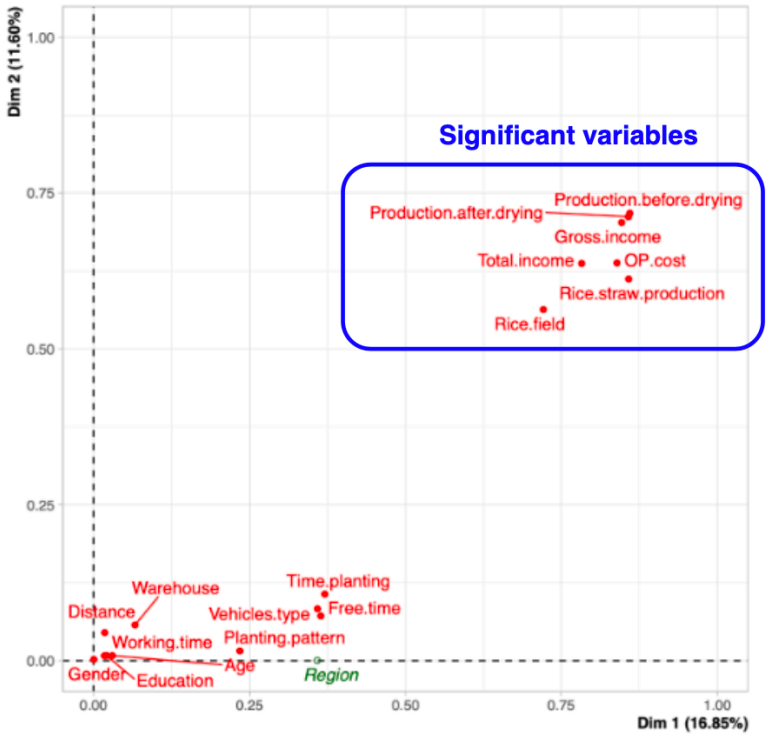


Figure IV-6. The representation of variables in internal factor

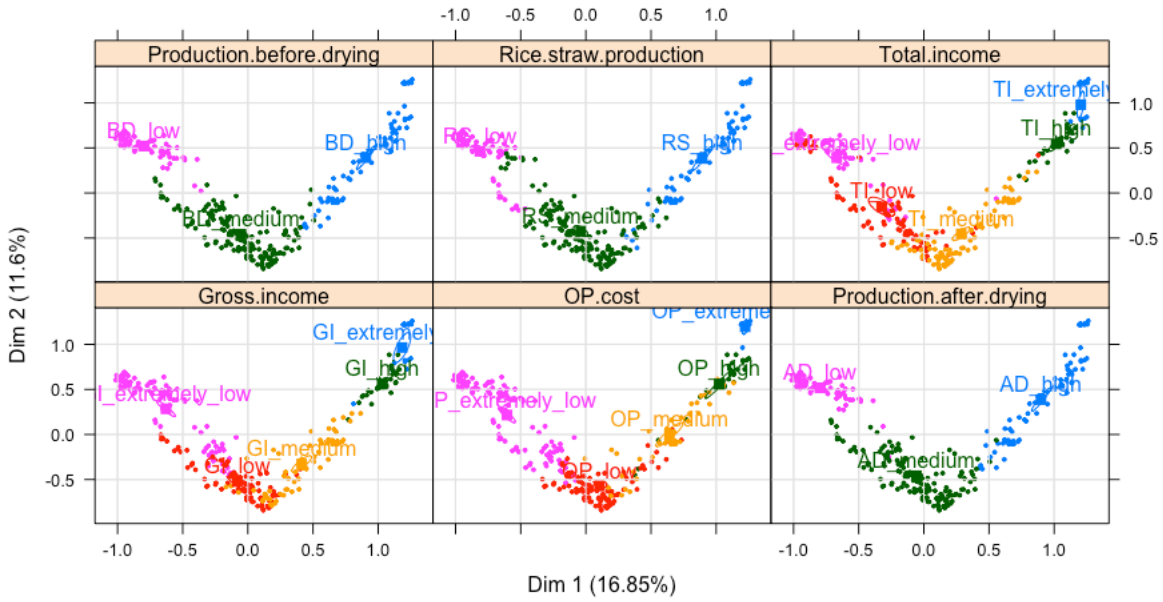


Figure IV-7. Projection of individual data (row) of the most significant results of MCA

Considering the first three percentages of variation is an essential value that describes an acceptably large percentage for MCA analysis because the percentage of inertia explained by the axes is "small" by its construction. These can clarify that the seven variables after reduction have a higher cumulative variance value of approximately 28.87% of the variation. The first dimension strongly correlates with farmers having an above-average economic condition with a positive value, whereas a negative value is opposed. Most farmers have a large rice field area (1.47–3.88 ha) that can produce rice grain before and after drying in a high category, equal to more than 22 tonnes per year.

The second component has significant (negative or positive) associations with the average economic conditions. Most farmers have a medium-sized rice field area, between 0.74 and 1.5 ha, with an annual farming production at a medium level per year, between 9.97 and 27.30 tonnes of rice grain before drying, 8.82 and 22.8 tonnes of rice grain after drying, and 18.50 and 68.20 tonnes of rice straw. As a result, farmers earn a medium-income annually, equal to approximately US$4,700 to US$8,500. Finally, the third component is associated with a particular variable, such as the rice field area in an extra-large category and high and extremely high categories of total income. These phenomena are influenced by the region and the amount of time spent planting per year. When MCA projections are viewed by region, farmers from Magetan have a positive value. In contrast, farmers from Lamongan have a small rice field area and earn a low level of rice production and income. The contribution of the active category to the internal factor variable is presented in the appendix, while the general socioeconomic of farmers is shown in Figur IV-8.

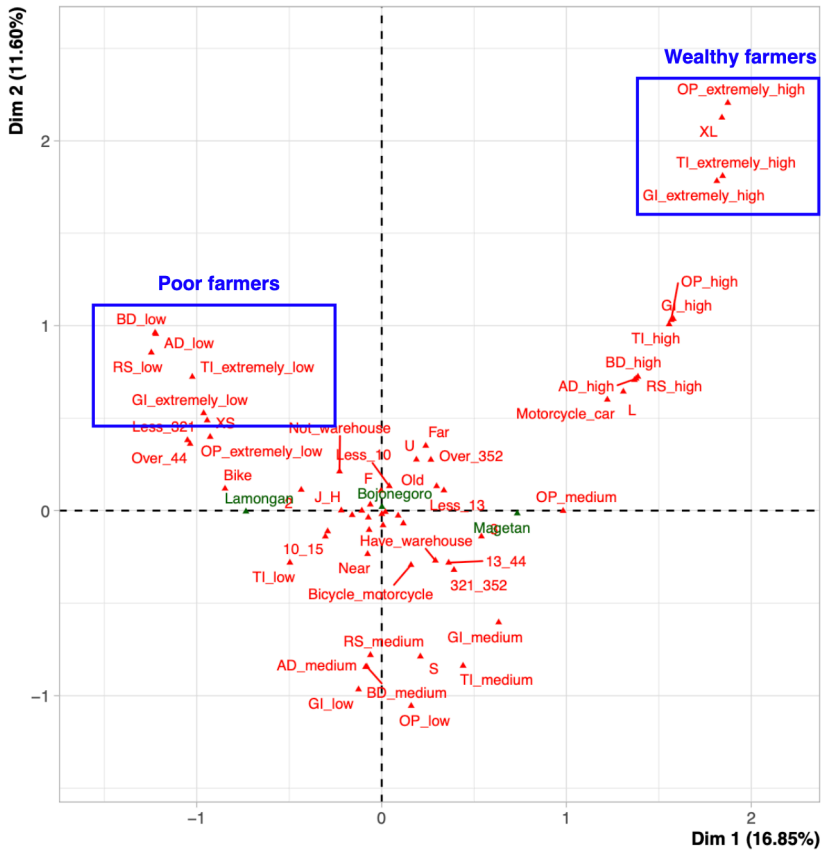


Figure IV-8. The representation of farmers' socioeconomic status

Most of the MCA results corresponded to the Guttman effect, matching a parabolic shape on the 1-2 planes. This configuration indicates a well-known phenomenon in MCA: a strong link between the various survey questions. Configuration occurs when there are multiple links between answers. The same example will be explained later; that is, the graph of individuals will highlight some variables. The strength of the first eigenvalues also indicates that it is approximately 0.86, contributing 12.50% of the variant. The histogram of eigenvalues and the inertia level led to retaining the first of the three axes of analysis for interpretation, contributing nearly 64.52% of the total variant. Indeed, the phenomenon appears when there is an ordered structure in both individual and variable sets. Consequently, the central axis opposes the extremes, whereas the second axis opposes the average individual to the two extremes.

Regarding the MCA results (Figure IV-9), it is shown that most farmers who have over 1.5 ha of rice field area located in the positive values on the right consist of the highest value of rice field area (extra-large group). In contrast, on the left position (the negative value), these are followed by farmers who have a rice field area of less than 0.7 ha (small group). In the center position, the farmers have a rice field area between 0.7 and 1.5 ha. Hence, the farmers on the positive side (on the right side of the MCA projection) are wealthy; they also have rice grain and rice straw production in a high cluster, which is more than 27 and 69 tonnes, respectively. Its significant

correlation with net and total earned income affects operational costs in the high and extremely high categories (Figure IV-10).

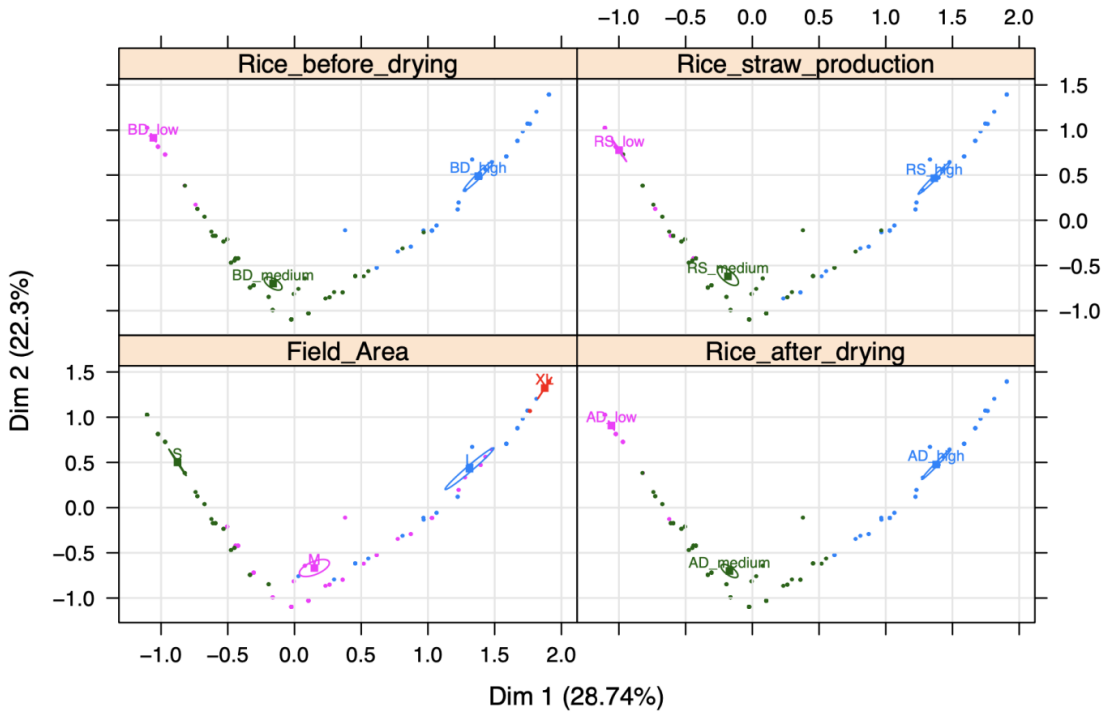


Figure IV-9. Projection of individual data (rows) on the first factorial plane for rice production and drying

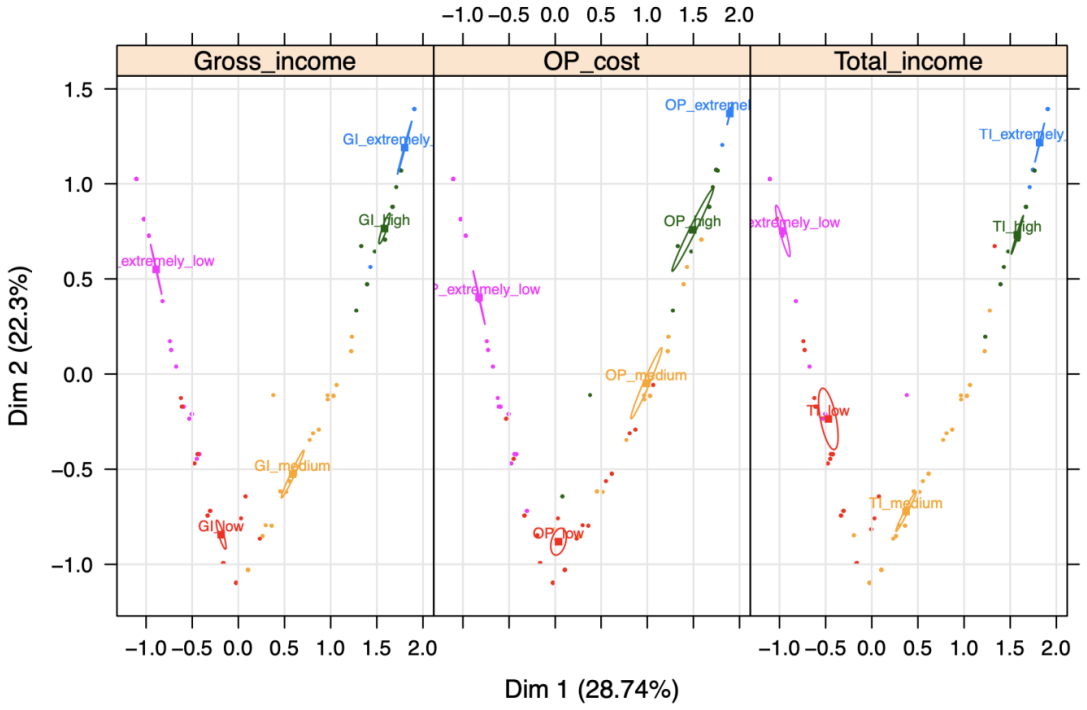


Figure IV-10. Projection of individual data (rows) on the first factorial plane for total income, gross income and OP cost

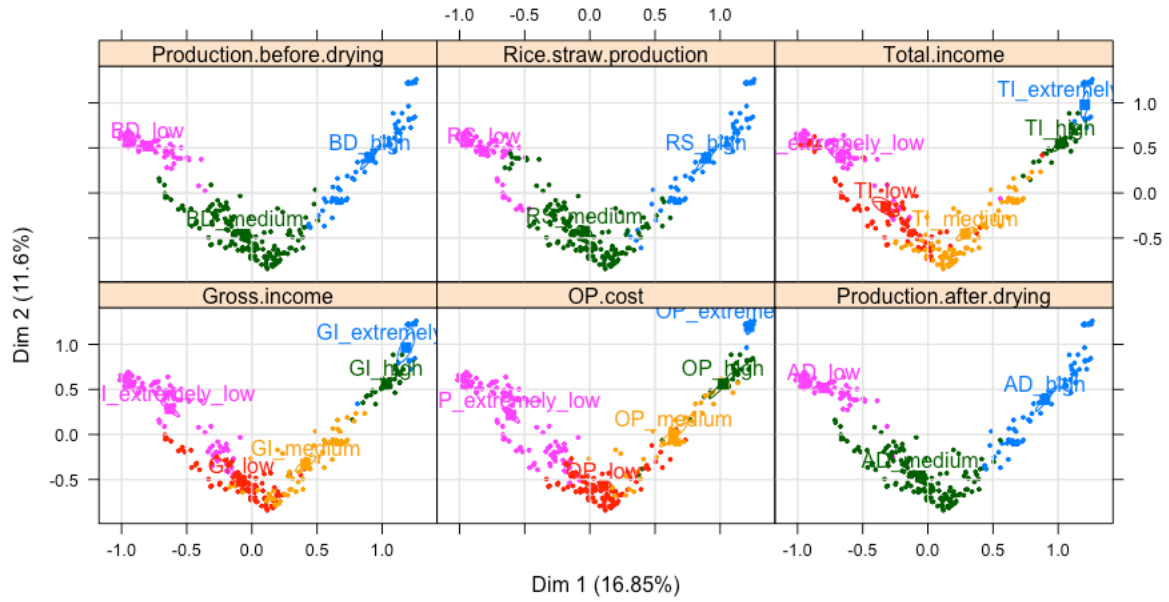


Figure IV-11. Projection of individual data (row) of the most significant results of MCA

The MCA results for the first three percentages of variation are an essential value that describes an acceptably large percentage for MCA analysis because the percentage of inertia explained by the axes is "small" by its construction. These results clarify that the seven variables after reduction had a higher cumulative variance value of approximately 28.87% of the variation (Figure IV-11). The first dimension of positive value is strongly correlated with wealthy farmers in average economic conditions, such as farmers with more than 3.4 hectares of rice fields and an annual income of more than US$14 thousand. Otherwise, a negative value indicates poor farmers, while farmers with average economic conditions are close to the center of the second component (Figure IV-8).

4.3. MCA results of all variables

In this study, 26 variables describe the relationship between groups of internal factors (related to rice production), external factors (i.e., current rice straw utilization and government support), motivation, perception, and future expectations when managing rice straw to realize the goal of valorization. *Appendix D* presents a detailed plot of each variable of the 300 farmers' characteristics recorded in the factor map. At the same time, the supplementary variable is a region that is used to detail farmers' characteristics depending on spatial variation and compare them. The variables were interpreted based on their relative distances and positions on the central axis. The points located at either end of a given axis represent opposing variables. The variables that are close to each other represent a homogenous interpretation of similar characteristics.

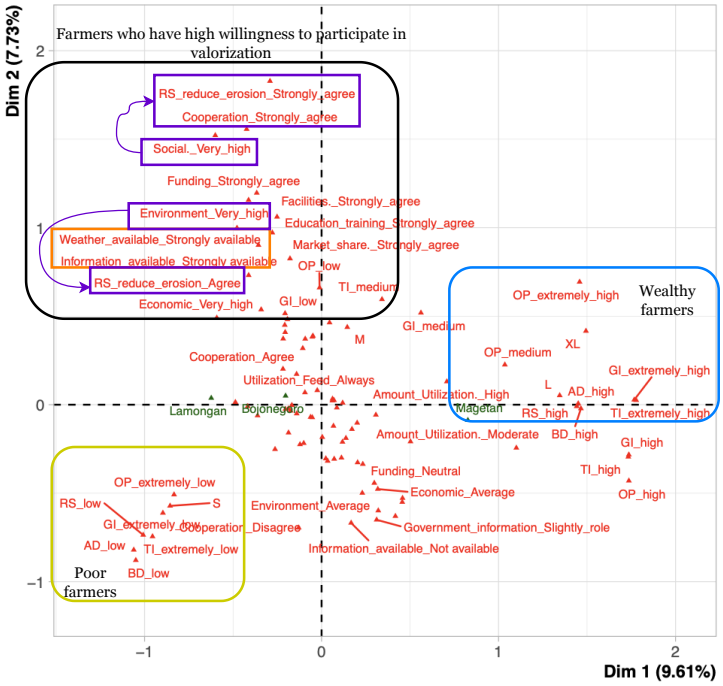


Figure IV-12. Two first dimensions of MCA explaining the distribution of categorical variables

The x-axis of the biplot in Figure IV-12 (Dim 1, approximately 9.61% of the total variance) shows that the positive values on the right side consist of the highest value of the internal factors that follow a decreasing and discriminating causality gradient on the left side (negative value). As described in the previous section, farmers with a positive value for the first component (right side) are more prosperous (in the blue box) than those with a negative value (in the yellow box). When viewed by region, Magetan opposes the Lamongan region, which means that there are differences between farmers from one region and another. Bojonegoro is not a discriminating variable since it is in the center of the graph. The spatial variable determines how socioeconomic aspects discriminate against farmers in terms of internal variables. Although the timing of rice cultivation, such as the annual planting pattern, planting period, and free time of farmers, has a slight influence on rice production, operational costs, and revenue, the rice field area has a more significant influence on the amount of input and output. In the Magetan, most farmers with rice field areas of over 1.5 ha earn a high level of rice production and income of approximately more than 22 tons, which is equivalent to between US$8500 to US$14500 per year. In contrast, the Lamongan opposite is less than 0.7 ha and produces rice grain at a low level of approximately less than 8 tonnes; they earn an annual income of less than US$1000. This x-axis could be interpreted as the opposition between high- and low-value farmers' economic conditions. As a result, the farther the variables are from their origin, the lower the economic conditions for individuals.

The y-axis of the biplot (Dim 2, approximately 7.73% of the total variance) is mainly interpreted as the opposition axis between the positive and negative values of the farmers' opinions, motivation, perception, and expectations of rice straw utilization and management. A positive

value indicates that farmers with a high level of motivation are on the verge of positioning the strongly agreed-upon perception and expectation factors for realizing rice straw value. Among the variables, there were significant correlations, while disagreements about perceptions and expectations were damaging. Information and weather availability indicate that the government intends to support agricultural intensification related to increasing crop productivity (orange boxes). This correlates with the farmers' belief that the government plays a significant role in providing supporting facilities. Farmers' perspectives were linked to their environmental motivation and belief that rice straw management can reduce soil erosion (purple box).

4.4. HAC results

In the HAC results, cutting the tree into various levels and sorting the related data into various partitions are based on determining the number of clusters. In this study, the dendrogram was divided into three clusters, as presented in Figure IV-13, and it shows the results of farmers' characteristics in two dimensions to facilitate and represent the description from the multidimensional clusters. The lower the dendrogram height value cut-off, the more significant the number of clusters obtained, resulting in lower farmers' willingness and participation in rice straw valorization. In contrast, the higher the dendrogram height value that was cut off, the fewer the significant clusters obtained(Riviére and Marlair, 2010).

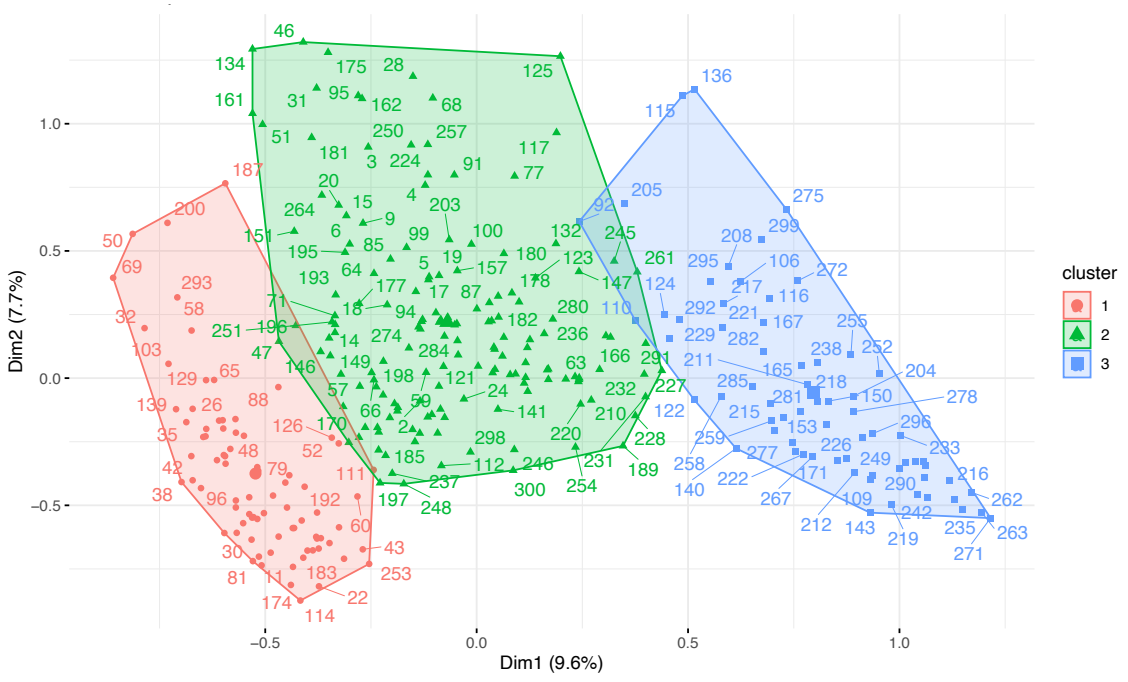


Figure IV-13. Farmer characteristics clustering in factor map

Table IV-5 presents the characteristics of the farmers in each cluster. From the three clusters, the typology of farmers can be concluded to indicate that the farmers who are grouped in the first cluster have below-average socioeconomic conditions compared to the second cluster. From the perspective of residue valorization, in the third cluster, wealthy farmers can produce more than

69 tonnes of rice straw annually; they can supply approximately 55 tonnes of bioenergy feedstock after reducing it as animal feed by 20%. Farmers earn an additional income of approximately US$394 when a ton of rice straw is valued at US$7.14. Therefore, stakeholders should develop integrated cooperation to improve farmers' awareness of managing the rice straw. Nearly 75% of the farmers were willing to participate in rice straw utilization and management. However, to realize the valorization program, the government needs to support physical and non-physical facilities according to farmers' expectations. At the same time, barriers and challenges should be limited by strategies at each decision level to maintain a sustainable supply chain when rice straw commercialization is planned, developed, and implemented.

Table IV-5. Description of clusters

Clusters	Number of farmers	Farmers' internal variable	Farmers' external factors	Farmers' motivation	Farmers' perception	Farmers' expectation
Cluster 1	80	• Small size of rice field area (less than 0.7 ha) • Low level of rice production and income	• Rice straw utilization in low level • Supporting facilities is slightly available • Government does not have role to support the rice straw valorization	• Very high level of economic motivation • High level of environment motivation • Below average level of social motivation	Farmers have neutral perception of rice straw valorization program	Farmers have neutral expectation of rice straw valorization program
Cluster 2	154	• Medium size of rice field area (between 0.7 – 1.5 ha) • Medium level of rice production and income	• Rice straw utilization in extremely low level • Supporting facilities is possible available • Government does not have role to support the rice straw valorization	• High level of economic motivation • Average level of environment motivation • Average level of social motivation	Farmers have extremely high perception of rice straw valorization program	Farmers have extremely high expectation of rice straw valorization program
Cluster 3	66	• Large size of rice field area (over 1.5 ha) • High level of rice production and income	• Rice straw utilization in high level • Supporting facilities is available • Government have slightly role to support the rice straw valorization	• High level of economic motivation • High level of environment motivation • Average level of social motivation	Farmers have high perception of rice straw valorization program	Farmers have high expectation of rice straw valorization program

4.5. Discussion

All the variables in the internal factors have similar values and significantly influence each other, and the rice field area is directly correlated with production, operational cost, and income. For example, farmers who have a rice field area of over 3.38 hectares (in the extra-large category) will pay an operational cost of between US$6,800 and US$12,843. They earn over US$20,000 in net income and nearly US$14,000 in total income annually. Otherwise, farmers with a rice field area of fewer than 0.7 hectares (in the small category) will produce rice grain and straw weighing less than 8 and 18.5 tonnes, respectively. It incurs an extremely low operational cost to obtain net and total incomes of less than US$4,000 and US$2,500 annually. The annual rice planting pattern can influence rice production but depends on the irrigation system, weather, rice variety, and harvesting method. Some studies have shown that climate and weather significantly influence crop methods and yield; however, farmers' decision-making and technology can reduce the modulating influence of these phenomena. Therefore, knowledge and management of cultivation are essential to minimize the uncertainty of future climate impacts, and strategies have been developed to facilitate increased productivity (Iizumi and Ramankutty, 2015) (Khairulbahri, 2021) (Loko et al., 2022).

External factors are applied to the investigation of three groups related to (i) the current utilization of rice straw, (ii) the availability of supporting facilities, and (iii) the government's role in supporting rice straw valorization. Almost 57% of the farmers used rice straw post-harvesting, with less than 30% in the low category, followed by the high and moderate categories. In terms of quantity and quality, the time of planting is directly correlated with weather and has a significant influence on rice straw production. Annually, most farmers conduct rice cultivation twice, but some regions with sufficient water resources for irrigation can cultivate rice three times. These cases will influence the percentage of rice straw utilization in each planting period. For example, the first planting starts from January to April during the wet season; hence, the low percentage of rice straw utilization at a low level is approximately 28%. Furthermore, in the second period, during the dry season starting from May to August, the utilization of rice straw at the moderate level reached 52%, whereas in the transition season starting in September and December, the utilization of rice straw at the extreme level was nearly 17%, due to the stocks of rice straw for animal feed still being available. Second, most farmers always utilize rice straw for animal feeding and bedding; approximately 47% of farmers, and 42% of farmers rarely utilize rice straw for planting purposes, such as mushroom planting media, fertilizer, and mulch. According to the interview results, only some farmers used rice straw in the post-harvesting period as bioenergy or biomaterials because it is not economically feasible and requires a particular approach to management and processes, such as transportation and distribution, method, and technology. Therefore, it can be concluded that rice straw generated from harvesting is generally used in

animal feed, cattle house flooring, straw handicrafts, covering materials for fields, or returned to the soil by plowing, composting, or even combustion (Matsumura et al., 2005).

Regarding external factors, the percentage of rice straw utilization has a similar value to the internal factor because farmers believe that rice straw production and income determine the amount of rice straw utilization. However, both animal feed and planting depend on weather, knowledge, and economic conditions. Furthermore, the group on rice straw utilization and farmers' opinions on support system availability (i.e., information, weather, and public facilities) had a correlation value of nearly 1.0, and the government's role influenced both. Energy prices and policies play a crucial role in developing crop residue valorization as bioenergy, and residue supply and technology should not limit it. This study's underlined government roles provided information and support facilities to optimize rice straw collection and handling. The periodic agricultural extension from the agricultural office in each region provided updated information and weather data. Simultaneously, facilities are obtained through collaboration with integrated stakeholders and decision-making in all sectors by revising the work plan and budget for developing crop residue valorization. Therefore, it can also be seen that internal and external factors are significantly correlated among the motivation groups. Farmers' habits, knowledge, competency, and access to information sources significantly affected the adoption of cleaner production in managing crop residue. This is similar to the statement of information and policy objectives that the government's contribution has effectively increased farmers' willingness to implement forest-based bioenergy (Qu et al., 2016).

Motivation plays a vital role in the decision-making process at the farm level; it stimulates farmers' actions and directs their behavior towards their decision-making, in this case, perception and performance. Over 40% of farmers are highly motivated to manage and utilize rice straw for economic and environmental purposes. Their character and environmental support influence farmers' motivation. Almost none of the farmers in this case had low motivation. According to the interviews, they believed that utilizing rice straw could reduce the cost of buying animal feed. As a result, they can save operational expenses and diversify their income. According to profound interview results, the farmers also believed that appropriate rice straw management could reduce environmental problems such as air pollution, soil degradation, and water contamination due to open burning. At the same time, the majority of farmers had a social motivation to utilize and manage rice straw at an average level (41.33%), followed by below average (29.67%), high (19.33%), and very high levels (9.67%). Farmers can receive more profits from rice straw collection and processing. In this case, farmers do not understand the benefits of biomass residue application for social welfare; therefore, there is an urgent need to develop new methods and technology for rice straw valorization.

Farmers' willingness to obtain environmental benefits from their actions must be improved by appreciating their enthusiasm for carbon emission abatement programs. Economic factors control

the vital key to farmers' motivation. One study suggested that economic motivation has become an important way of influencing the community to manage biomass residue because of the significant financial benefit expected from improving the supply chain, and indirectly, it can benefit the environment (Blennow et al., 2014) (Jiang et al., 2018). In bioenergy production, most farmers are motivated to utilize biomass residues to generate energy materials for environmental benefits, not just for economic reasons (Augustenborg et al., 2012). Climate change and diminishing fossil fuel reserves are the primary drivers for achieving residue valorization without creating conflicts between the food and petrochemical industries. Otherwise, the open burning of crop residues in the field would be a simple reason to justify the farming method to save cost and time. Therefore, providing information to farmers through counseling, training, and education to practice sustainable agriculture through crop residue use, which aims to reduce soil erosion, air pollution, and water contamination, has become a significant motivation for adopting bioenergy programs. The social benefits of the valorization program will boost the circular application of bioeconomics in rural areas. This can create a large number of jobs in the biomass supply chain. The benefits of the rice straw valorization program should be conveyed to farmers to assist in decision-making and the adoption of these methods.

Regarding farmers' perceptions, more farmers strongly agreed that rice straw utilization and management could reduce open burning. This is approximately 40%, although 7% of the farmers disagreed with the statement. It was similar to the results that rice straw utilization and management could improve additional income; more than 40% of farmers agreed with the statement. Regarding perception related to both variables, it could be represented that none of the farmers strongly disagreed because it is correlated to their motivation that the rice straw application can improve their environment and economic quality. In contrast, 37.0% and 22% of farmers agreed and strongly disagreed, respectively, that rice straw utilization and management could reduce soil erosion. As a possible explanation, most farmers had a negative perception that the rice straw was returning to the soil, which could improve soil quality. Nevertheless, nearly 13% of the farmers positively perceived that soil erosion could be reduced by using rice straw as fertilizer and mulch. Therefore, their willingness to mitigate the negative impact of crop burning must be improved through integrated communication among stakeholders through regular agricultural extension and other programs related to rice straw valorization. When farmers have a positive perception and high motivation, it can be confirmed that they are willing to implement the valorization program using and managing rice straw. Moreover, farmers' characteristics, such as socioeconomic and demographic characteristics (e.g., education, knowledge, and income), can determine their perceptions (Nigussie et al., 2021; Wang and Watanabe, 2016). Therefore, the agricultural extension can be a valuable resource for raising awareness and encouraging farmers to use up-to-date information, which will impact their perceptions in the future. The perception of rice straw management significantly influenced expectations of the government's role in realizing

the program. The two cannot be inseparable and are correlated with each other, which determines the programs' trust and acceptance.

Finally, when the farmers were asked whether their expectation of realizing the sustainability program of rice straw valorization was adequate for supporting their activities that the government must provide, over 30% of farmers agreed that they needed the government to provide education and training periodically, supporting facilities (i.e., agricultural equipment and machinery and public warehouses), funding assistance, a distribution network and market share, and integrated cooperation among stakeholders (i.e., government, industry, academics, and communities). However, some farmers need to understand how the design and implementation obtained funding assistance, market share, and cooperation from the government. Therefore, more than 40% of farmers have neutral expectations of funding and cooperation. However, only 24% expect a neutral market share because rice straw collection and management require more operational resources and time than burning. Surprisingly, no farmer expressed strong negative expectations if rice straw had no benefit for sustainable development. In the future, extending and delivering awareness and competency should be conducted regularly through agricultural extension programs.

4. Opportunities and barriers of rice straw valorization for bioenergy production: a recommendation synthesis

Farmers' opinions, perceptions, and expectations are fundamental for improving the quality of residue management in rural areas. The rice straw valorization program requires an integrated approach to address current management problems, such as open burning, which farmers prefer to collect and process as valuable materials. Currently, numerous gaps hinder the realization of these programs, which need to be addressed by identifying the opportunities and barriers to growing farmers' motivation to engage in the biomass supply chain. Therefore, strategies should be developed to realize the program goals, as shown in Figure IV-14.

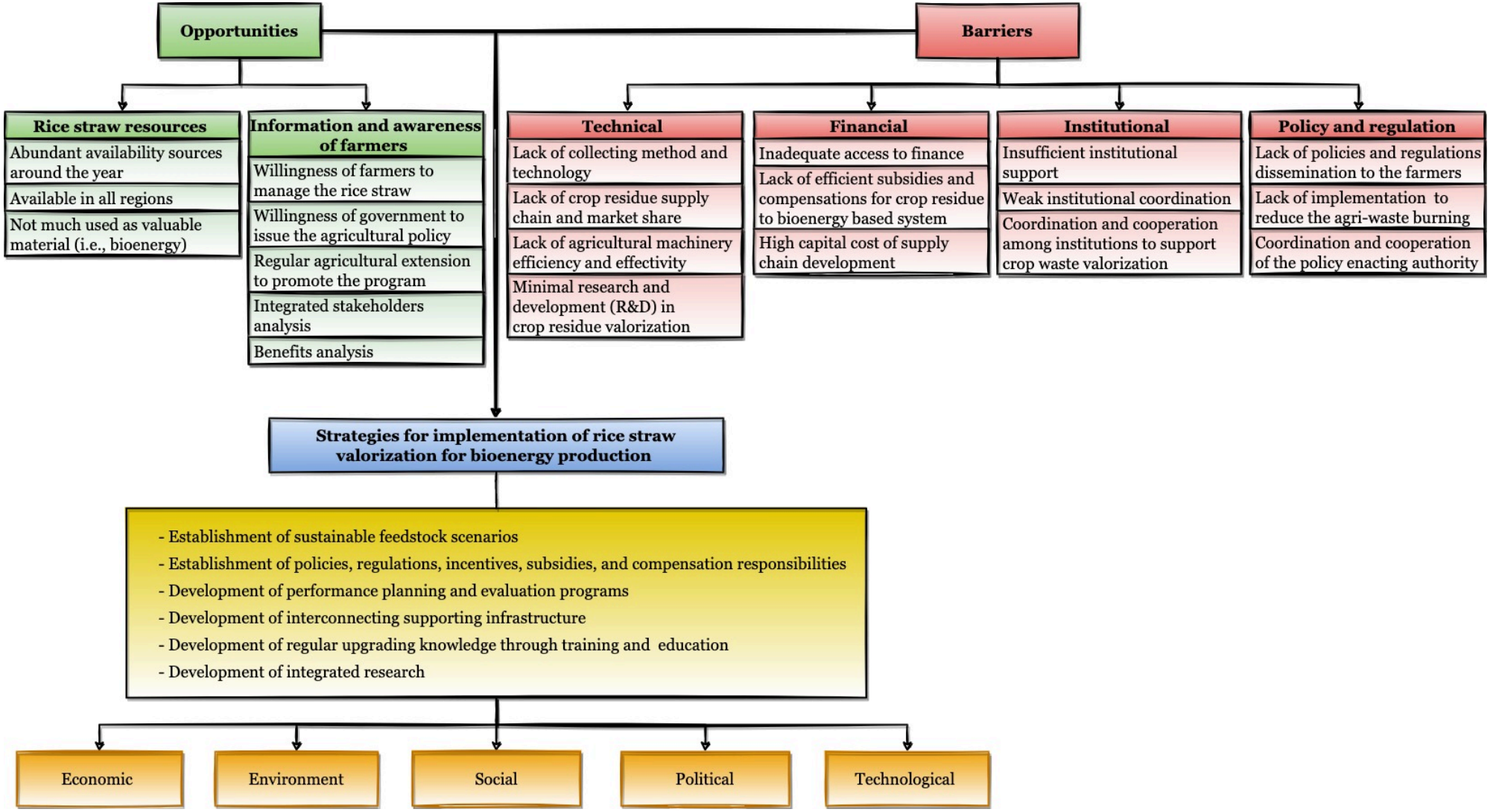


Figure IV-14. Opportunities, barriers, and strategies of rice straw valorization for bioenergy development

Although the government has issued policies and regulations for sustainable agriculture, its implementation still needs to achieve its goals. According to previous studies and field observations, less than 30% of rice straw can be utilized as a valuable material; however, this only applies to bioenergy generation. There is a requirement for an in-depth understanding of the biomass supply chain process in each echelon, starting from collection, handling, transport, storage, and selling to manufacture, preprocessing, conversion, and, more precisely, the business model for managing rice straw. Official institutions should coordinate and cooperate in developing design, planning, implementation, and evaluation performance. Although agricultural extension and farmer group involvement have been conducted to achieve food security, the primary goal is a better understanding of farmers' willingness to participate in the valorization program. In detail, an empowerment program to improve farmers' economic welfare can be initiated by utilizing agricultural residues as valuable materials. However, a massive potential due to the abundance of resources throughout the year should be fine, as a sustainable feedstock is noticed in the storage model, which minimizes deterioration. Policy and regulation terms, such as subsidies, incentives, and compensation for rice straw valorization, should be calculated through a comprehensive and multidisciplinary research and development study. Therefore, synergies and sustainability can minimize negative impacts and barriers. At the same time, there should be a precisely planned improvement in the supply and leasing of agricultural equipment and machinery, supporting infrastructure (i.e., distribution networking and market share), financial assistance, efficient technology development, and upgrading of residue value-added promotion. In line with these programs, strategies for effectively implementing rice straw management are based on farmers' opinions and expectations as future opportunities for maintaining the biomass supply chain.

5. Conclusion

Regarding rice straw valorization programs, farmers are the leading actors providing and guaranteeing sustainable feedstock in the biomass supply chain. Farmers' activities to utilize and manage rice straw as a residue are critical for determining the most suitable and efficient method and technology for constructing the rice straw supply chain. This is fundamental at the strategic decision-making level. In the social dimension, farmers' willingness and awareness to participate in the relevant issues of managing agricultural residue are essential for assisting sustainability. Furthermore, farmers' opinions regarding the availability of information and facilities to support crop cultivation are important factors in planning and evaluating government performance. At the same time, farmers' motivations significantly influenced their perceptions and expectations. As a result, it can contribute to the implementation of valorization programs, improvement of farmers'

behavior according to sustainable aspects, and enhancement of the efficiency and effectiveness of decision-making methods in bioenergy development.

In this study, empirical analyses show that various factors influence farmers' perceptions and expectations of rice straw valorization programs. Economic aspects, such as farmers' rice field area, production, and income, significantly influence the percentage of rice straw utilization. Applying rice straw for planting purposes, such as fertilizer and mulch, requires technique and knowledge, which are indirectly related to improving the competency of farmers through the availability of information. The government's role affects external factors that can originate from environmental aspects, such as the availability of physical and non-physical facilities, which affect farmers' understanding. For example, farmers who are active in agricultural extension have a better understanding of the application of agricultural residue as compost. Furthermore, the results revealed that the farmers' characteristics and environmental support factors would significantly influence their motivation in the decision-making process; they would stimulate the farmers' actions and direct their behavior toward their willingness and participation. Over 60% of farmers expected the government to promote and facilitate regular education and training, provide supporting facilities (e.g., agricultural equipment and machinery, a public warehouse, and a connecting road), and integrate cooperation among stakeholders to decide the optimum design and implementation of the biomass supply chain.

The government should implement various strategies to minimize the challenges and barriers and optimize the opportunities owned by farmers and their environment to foster the acceptability of generating valuable products, such as bioenergy. In addition, the availability of market share will be faster to promote farmers' decision-making regarding fast-growing social and economic factors. Therefore, the government should disseminate the newest methods and knowledge regarding rice straw management to guarantee the supply chain of bioenergy production. Simultaneously, issuing and enforcing sustainable environment policies and regulations to reduce the amount of residue burned openly is a solution to improve farmers' living conditions and achieve national goals on bioenergy production to reduce greenhouse gas emissions.

The limitations of this study should be addressed through a set of detailed questions correlated to farmers' awareness and understanding of how to implement agricultural residue valorization. Moreover, analyzing stakeholders' perceptions and participation, who are internal and external actors (e.g., governments, entrepreneurs, and academics), as a comparison, is a further reference to design and planning at the strategic decision-making level.

Chapter V. Capturing stakeholder participation to support agricultural residue valorization

1. Introduction

As mentioned in Chapter II, the Indonesian government has issued a national energy policy (KEN) to reduce fossil fuel dependency and increase bioenergy to approximately 5% of the energy supply by 2025. Furthermore, Presidential Regulation No. 22 of 2017 states that it is necessary to promote energy crops to accelerate the quantity and quality of bioenergy production (detail policies and regulations related to biomass energy as shown in *AppendixE*). It has been applied using crude palm oil (CPO) as a biofuel feedstock, which is gradually increasing, leading to land expansion and use changes. However, it should be noted that land expansion and use change will be feared and may cause adverse impacts, such as declines in local species and biodiversity, particularly in the first generation of biofuel (Tudge et al., 2021). Therefore, bioenergy policies should not lead to further land clearance to grow bioenergy crops but should use marginal land or existing biomass residue as second-generation biofuels.

The concept of agricultural waste patterns and priorities, determined from the most advantageous, minimized, or avoided to the least advantageous (e.g., landfilling, burning), will play a critical role in sustainable aspects, which are dependent on the development speed of new and affordable technologies in management. Combining residue and proper technology can mitigate greenhouse gases (GHG), providing sustainable waste management with cleaner production and renewable energy (Jeguirim and Limousy, 2018). However, agricultural residue collection, handling, and transport are more complicated owing to its physical properties, such as (i) high moisture content, (ii) low energy density (bulk density and calorific value), (iii) complex variable compositions that require more treatment, and (iv) seasonal resources (Cambero and Sowlati, 2014a) (Vassilev et al., 2015). It can increase the biomass supply chain (BSC) (Nunes et al., 2020b), which is estimated to be up to 50% of bioenergy production (Calderón et al., 2017); this will be discussed in the next chapter. As a result, a comprehensive evaluation is required to assess the potential of biomass residues to contribute to rural area development by integrating approaches and management in all sectors and involving all stakeholders.

At the long-term decision-making level, the success of bioenergy production is affected by the sustainable availability of feedstock, which farmers have determined to be leading suppliers. In Chapter IV, most farmers' willingness to supply residue was approximately 50–75% of the total residue for bioenergy feedstock. However, this should be supported by stakeholders' roles in providing technical and financial support as part of the BSC design. To answer the question of how to ensure the sustainability of the BSC by optimizing stakeholders' roles, and how can the

stakeholder transform the information and materials for the communities? However, stakeholders are often marginalized or ignored in traditional supply chain systems (Busse et al., 2017). This is one of the barriers and challenges that should be solved by considering geographical, political, social, environmental, and economic perspectives. It aims to make the decision-making process more accessible and complex by improving stakeholders' awareness of the comprehensive interactions between social and natural environments (Gold and Schleper, 2017). The BSC social system can be used to examine actors who play a role in promoting sustainability culture and values (Roth et al., 2017). To achieve the agricultural valorization goal, three decision levels of the supply chain (i.e., strategic, tactical, and operational) should be considered to develop new tools and methods for comprehensively analyzing stakeholders. First, stakeholders' opinions should be captured as valuable inputs for formulating and implementing an effective and efficient project because they can influence their awareness of recommending policies and regulations. It plays a critical role in the commercialization and widespread acceptance of bioenergy through the understanding and consistency of stakeholders (Schillo et al., 2017). Directly, positive and negative opinions affect their perception, which is a principal instrument for implementing a bio-economy in rural areas when producing bioenergy crops without omitting local society and culture (Rossi and Hinrichs, 2011). Another mandatory prerequisite is to maintain policymakers' willingness to appreciate sustainable schemes.

Furthermore, the instrumental approach is applied in three steps to analyze stakeholders' perspectives: (i) stakeholder identification by theoretical mapping, (ii) stakeholder categorization based on the interest and influence matrix, and (iii) stakeholder relationships to indicate conflict, complement, and cooperation categories (Horschig et al., 2020). However, three challenges should be noted in achieving the BSC goal: (Garcia and You, 2015)

(i) Multiscale is an essential component of supply chain design and operational coordination across various spatial and temporal scales while accounting for uncertainties.
(ii) The multi-objective model focuses on the supply chain design and optimization model while considering its goal and formulation, which is presented by an overview of sustainable aspects and a life cycle framework.
(iii) A multiplayer is a supply chain design decentralized decision-making process that can issue modeling and computation.

Due to the multiple objectives and scales are being strongly linked to the social dimension, it is essential to discover the three BSC challenges in a multi-actor context. Therefore, social issues require collaboration between multiple stakeholders and a complex methodology for their resolution, according to their primary objectives. Multi-actor identification and classification determine effective decision-making in bioenergy development (Grilli et al., 2015). This is clarified by the socio-economic model, which is applied to supply chain design to find the best action from

actors who play a significant role in citizen organizations (Roth et al., 2021). In the BSC, stakeholders sometimes include farmers as primary suppliers, the government as a public authority that issues policies and regulations for the sustainability program, and private companies as leading economic actors, scientific experts, social interest groups, and society. Stakeholder and community involvement, starting at an early stage via transparent two-way communication about the benefits and adverse impacts of the supply chain, can increase social acceptance (Gold, 2010).

This chapter aims to present stakeholder typologies to demonstrate willingness levels and to incorporate this information into the supply chain model as a fundamental method and component of the strategic decision-making level, which includes design in social aspects. Multi-correspondence analysis (MCA) was applied to identify the characteristics of the stakeholders who had similar responses in terms of their opinions, motivations, perceptions, and participation; thereby, their willingness level can be shown to answer the question of how specifically their role is to support agricultural residue valorization programs. Finally, mapping stakeholders is represented by their roles, which are incorporated into a classical approach to modeling stakeholder participation by considering their decision-making levels, institutions, and activities in the Indonesian context of resource potential, as mentioned in Chapter II.

2. Methodology

The success of agricultural valorization goals can be determined by stakeholder awareness and willingness to participate. This section develops three steps to model the stakeholders who play a vital role in the valorization programs (Figure V-1). The method focuses on stakeholders' decision-making level, from their opinion to developing perceptions that will lead to actual participation. The answers to some questions should be found: (i) who are the main actors involved? (ii) When are you involved in them? (iii) How does the process drive this?

According to Figure V-1, three steps were conducted to achieve the Chapter V objectives, which are described as follows.

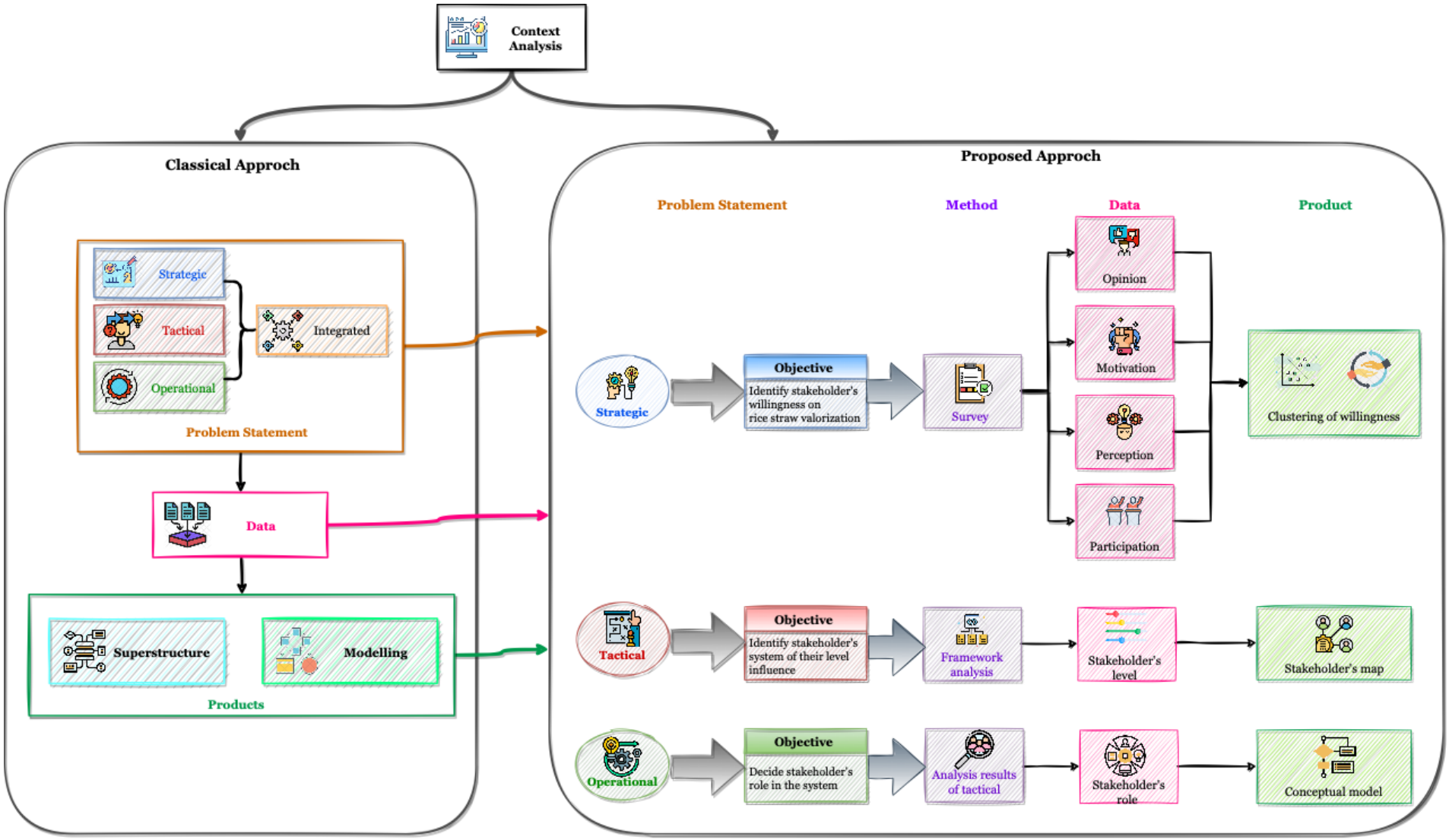


Figure V-1. Purposed method to modelling the stakeholders in agricultural residue valorization

2.1. Stakeholder willingness in agricultural residue valorization

2.1.1. Survey design

The first step concerns the strategic level, which aims to identify stakeholders' willingness to implement agricultural residue valorization by observing their willingness and influencing aspects according to the literature review discussed in Chapter III. To realize its objectives, a questionnaire was designed to assess the motivation and perception of agricultural residues, particularly rice straw utilization. The questions focused on their present opinions, willingness, and awareness to participate when the residues were applied as a bioenergy feedstock. The questionnaire was formulated in English and translated into Bahasa Indonesia. Before the formal survey and investigation, a trial survey was sent to 20 stakeholders in January 2021 to identify any possible misinterpretations or ambiguities in the questions and respondents' responses. The questionnaire was reviewed and modified according to the respondents' feedback in the pilot survey. The first section of the questionnaire provides the stakeholders' profile, which is set in a multiple-choice question and includes, for example, age, gender, education, working group, and working time. In the next section, the three Likert scales (low, moderate, and high) were used to show the stakeholders' responses related to (i) present rice straw utilization, (ii) motivation to support this program, (iii) understanding level to utilize rice straw, and (iv) perception of valorization. The detailed questionnaire can be found in Appendix B. Considering the multiple factors influencing stakeholder willingness, the active variables from all questionnaire sections are defined in Table V-1.

One hundred and fifty stakeholders, representing the government, policymakers, private companies, and scientific experts, were selected as respondents. East Java was chosen due to the following criteria, i.e.,

a. A previous study on farmers' perceptions was conducted in three regions of East Java (see Chapter IV).
b. It has the highest rice production in Indonesia; consequently, it has enormous potential for producing rice straw throughout the year.
c. Most local governments have supported agricultural development by issuing policies and regulations (e.g., sustainable food protection, annual rice planting time based on irrigated areas, and farmer empowerment programs), as described in Chapter IV.
d. It has a master plan for agricultural development that considers sustainable development goals.

2.1.2. Analysis data

First, descriptive statistics present the distribution trends and information from a dataset provided by stakeholders' responses to all variables, including their general profiles. Furthermore, multivariate analysis was applied to investigate the correlation between multidimensional data by

considering the simultaneous links between individuals and variables. The geometric perspective is used to present the interconnection of multidimensional data, and its analysis type depends on the variable (Husson et al., 2017). The categorical variable was used, and MCA was appropriate for identifying stakeholders' willingness and participation. Hierarchical clustering illustrates the links between variables (similarities or correlations) to group them. All statistical analyses were performed using the R software (R Core Team, 2021).

2.1.2.1. Multi correspondence analysis (MCA)

MCA identified different stakeholders with similar characteristics in their responses to some questions, which are classified as categorical variables. Summarizing a set of variables into a small number of orthogonal variables is called principal component. In this research, MCA offers two main advantages: (i) MCA allows the description of two individuals (stakeholders) who are close to each other when they have similar characteristics, that is, similar responses. This makes it simpler to illustrate factorial maps that are very useful in multivariate exploratory data analysis. (ii) MCA shows the correlation between variables and associated variables between categories when the two categories are close. Therefore, quantitative values (coordinate values of incidents in the system of axes defined by the principal components) can be used to identify their characteristics based on classification purposes.

The p eigenvalues are recovered from a matrix derived from Burt's matrix, and the latent variables (components) reproduce the most significant variance (inertia) among the observations in Burt's matrix in descending order. The total number of eigenvalues, p, is obtained by factoring in the dimension of the dataset, $p= n-k$, where k is the number of variables contained in the MCA, and n represents the total number of potential values for those variables. Categories with more significant sample sizes were closer to the center of the MCA map and explained a lower proportion of data variability.

2.1.2.2. Hierarchical clustering analysis (HCA)

HCA is an iterative process based on general linking data using the Ward criteria aggregation method to calculate the correlation among variables in each factor and other factors. A cluster analysis was performed to classify stakeholders according to their opinions, motivations, understanding levels, and perceptions to determine their willingness to support and realize rice straw valorization as a bioenergy raw material. The similarity variable was regrouped through a minimal Euclidean distance for ease of measurement, relevance, and reliability. Combining multivariate analyses is relevant for visualizing the correlated (or similar) variable and identifying close stakeholders' characteristics; the result can identify the least good and best correlation to create a recommendation.

The homogeneity of a cluster was exemplified by its internal inertia. Ward's method aggregates two clusters, where the growth of within-inertia is minimal at every algorithmic level

(minimizing the reduction of between-inertia). An indexed dendrogram represents the gain from within inertia.

2.2. Stakeholder mapping

The second step in this study concerns the tactical level to implement the aspects that are decided at the strategic level, i.e., the characteristics of the stakeholders according to the questionnaire results in the previous work. It aims to identify the stakeholders in the system and their impact levels. Whether individuals or institutions, stakeholders should realize their role in implementing agricultural residue-valorization programs. Consequently, the two stakeholders can be related to each other or to an institution, and in addition to sharing their roles, they can have typical assignments. Stakeholder mapping is essential for determining who will be considered and what role. A framework is created based on the decision level and is intended to classify stakeholders' roles into three levels:

a. Strategic level—a point that determines the sustainability objective of the study in the long term.
b. Tactical level—a point with a close correlation and/or influence to reduce risk in the medium term to achieve the study's objective.
c. Operational level—a point that directly correlates with and/or influences operational management and decision-making, which must be maintained in the short term to realize the study's objective.

Identifying stakeholders' roles and actions in a system is essential for modeling the participation of agricultural residue valorization according to stakeholder awareness and willingness. Stakeholder types and roles can determine certain conditions for drawing complex relationship diagrams. Specifically, the possibility of a relevant relationship link between each stakeholder can be clarified by deep context analysis and, depending on the field research situation, through interviews. There is no specific rule to determine who plays a vital role in this program, but stakeholders' willingness from step one can be considered based on the decision-making level. For example, senators who are decision-makers in issuing policies should be more motivated to improve their understanding and participation in valorization programs by issuing correlated policies and regulations, such as incentives, subsidies, and compensation. Aside from government employees, their awareness can be considered in the planning and coordination of institutions to support these programs. Therefore, the researcher has specific clauses to capture and analyze the primary actors to be categorized at each level based on their role and sustainability. Finally, a map of the stakeholders was created as the product of this step. This map will assist in the identification of social networks and a better understanding of individual mental models to promote all the aspects of sustainable development. In addition, the map of the

stakeholders provides a comprehensive view of the system, which is required to select participants with a complete understanding of the relevant facts.

2.3. Stakeholder modelling

After stakeholder mapping, the next step aims to translate the results of the first and second steps into a conceptual model related to the operational level at which the program will be implemented. Furthermore, interaction diagrams between actors who play a vital role in valorization were created by translating the resources and actions related to the actual problem before and after implementing the programs. It is a core step since it represents all interactions in a system, which is illustrated in the general interaction diagram shown in Figure V-2.

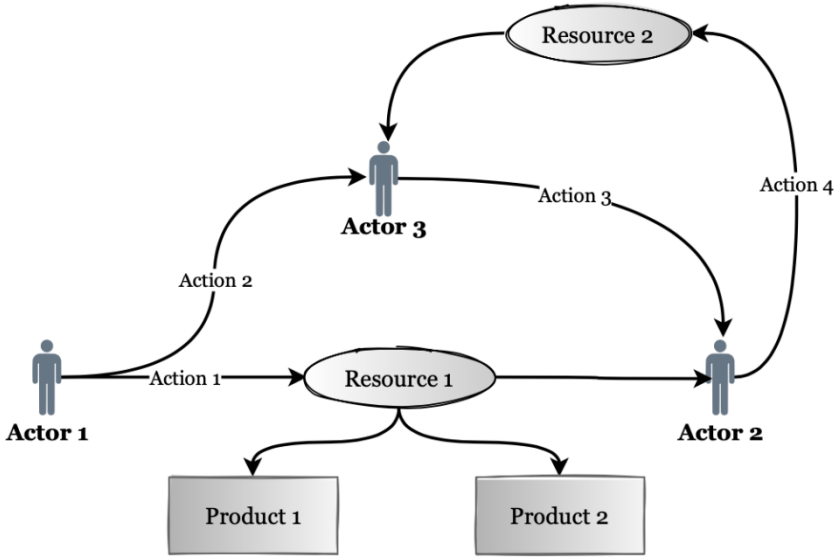


Figure V-2. Stakeholder interaction diagram

The essential key to stakeholder modeling is to show the detailed interactions from the interviews and questionnaire results of the stakeholders in the first step. It is necessary to create a record of each step, especially the interaction step of the co-modelling process, which typically generates the most significant amount of information. The different shapes and arrows connecting them can visually distinguish between the actors and resources. Simultaneously, the labeling in each arrow uses an action verb to provide additional insight into the depicted interaction. The main output of this step is a conceptual model of the agricultural residue valorization system. It identifies why and how a particular actor, resource, or relationship was mentioned, retained, discarded, or modified to increase a significant value in the model. Furthermore, the results are combined with the real problem from a previous study of farmers as primary actors.

Table V-1. Definition of variables from four factors and the corresponding coding

Code	Factor and variables	Type	Definition	Response code
Opinion of present agricultural utilization			*Stakeholders' thoughts describe preferences of how to utilize agricultural utilization particularly rice straw in the post-harvest period according to the reality in their region.*	
Frequency_OB	Frequency open burning	Categorical	The frequency of rice straw burning during post-harvest time compare to rice straw utilization as a valuable material.	1: Low 2: Moderate 3: High
Opinion_save_cost	Stakeholders' opinion of open burning can save cost	Categorical	Stakeholders' idea that describes preferences for open burning of residue post-harvest can save operational costs because it does not require much farm labor.	
Opinion_save_time	Stakeholders' opinion of open burning can save time	Categorical	Stakeholders' ideas that describe preferences for open burning of residue post-harvest can save operational time because it does not require much specific method.	
OB_contribute_pollution	Stakeholders' opinion of open burning can contribute air pollution	Categorical	Stakeholders' ideas that describe preferences for open burning of residue post-harvest can contribute to air pollution because it produces greenhouse gas emissions.	
Opinion_RS_purposes	Stakeholders' opinion of agricultural residue utilization purposes	Categorical	Stakeholders' ideas that describe preferences for agricultural residue can be utilized as valuable materials, such as animal feed, compost, and mushroom media planting.	
Motivation to support agricultural residue valorization			*The stakeholders encourage themselves or their environment to participate in the agricultural residue valorization program for bioenergy production.*	
Environment	Environment motivation	Categorical	The stakeholder has an encouragement to realize the agricultural residue valorization program to reduce open burning that has affected environmental problems, such as air pollution, water contamination, and soil erosion.	1: Low 2: Moderate 3: High
Politic	Politic motivation	Categorical	According to Presidential Regulation No. 22 of 2017, stakeholders are encouraged to use agricultural residue as a raw material for bioenergy production; it is necessary to promote crop residue to increase its quantity and quality.	
Social_economic	Social economic motivation	Categorical	The stakeholder is encouraged that agricultural residue valorization for bioenergy production can improve the social-economic quality of the community.	
Understanding level to support agricultural residue valorization			*Stakeholders' ability to capture and reveal how to use rice straw to support bioenergy production.*	

Understanding_feedstock	Understanding of feedstock	Categorical	As elaborated in the national energy plan, stakeholders can comprehend agricultural residue, particularly rice straw as an abundant source of bioenergy raw materials.	1: Low 2: Moderate 3: High
Understanding_governance	Understanding of good governance	Categorical	Stakeholders comprehend that valorization is a method to implement good governance of sustainable development.	
Understanding_socieco_quality	Understanding of improve social-economy quality	Categorical	Stakeholders comprehend that valorization can improve the social-economic quality of communities.	
Understanding_reduce_GHG	Understanding of reduce air pollution	Categorical	Stakeholders comprehend that valorization can reduce the practice of open burning during the post-harvest time; indirectly, it can also reduce greenhouse gas emissions generation.	
Understanding_technology	Understanding of technology improvement	Categorical	To realize the valorization program, stakeholders should provide the latest technology for harvesting, collecting, distributing, pretreatment, and producing bioenergy.	
Understanding_R&D	Understanding of research and development	Categorical	To realize the valorization program, stakeholders should continue to provide research and development to improve bioenergy quantity and quality.	
Understanding_cooperation	Understanding of integrated cooperation	Categorical	To realize the valorization program, stakeholders should provide integrated cooperation between each decision level actor.	
Understanding_infrastructure	Understanding of infrastructure improvement	Categorical	To realize the valorization program, stakeholders should provide supporting infrastructure for the bioenergy supply chain and production.	
Perception of agricultural residue valorization			*An activity and a process for stakeholders to determine the activities' responses, goals, and impacts, which correlate to the valorization program.*	
Perception_commitment	Commitment to reduce open burning	Categorical	Stakeholders' perception is that the valorization program will contribute to achieving the national energy plan for increasing bioenergy production to 5% of the energy supply in 2025.	1: Low 2: Moderate 3: High
Perception_regulation	Planning policies and regulations	Categorical	Stakeholders' perception is that to realize valorization program for bioenergy production, it is needed to plan and issue some policies that prohibit open burning in the field and regulate land-use change and sustainable agriculture practices.	
Perception_dissemination	Dissemination of policies and regulations	Categorical	Stakeholders' perception is that to realize valorization program for bioenergy production, it is needed to disseminate some policies and regulations that have been issued and correlated to the program.	

Perception_infrastructure	Supporting infrastructure	Categorical	Stakeholders' perception is that to realize valorization program for bioenergy production should provide supporting infrastructure from downstream to upstream.	
Perception_education	Regularly education and training	Categorical	Stakeholders' perception is that to realize valorization program for bioenergy production should provide regular education and training for each actor who has a role in the program at each decision-making level.	
Perception_market	Market share	Categorical	Stakeholders' perception is that market share must be provided to improve the participation of farmers in realizing the valorization program.	
Perception_collaboration	Integrated collaboration	Categorical	Stakeholders' perception is that integrated collaboration must be provided to improve the participation of farmers in realizing the valorization program.	

3. Results and discussions

3.1. Stakeholders' characteristics and profile

Age is one of the primary factors that determines stakeholder competency and experience. The most significant number of stakeholders were middle-aged (38–49 years old), with approximately 58 respondents (38.67%); the second group was the elderly (49–64 years old), with approximately 58 respondents (35.33%); and the last group of stakeholders was young, with around 39 respondents (26%) who were less than 27 years old. Therefore, over 50% of stakeholders have more experience and play a significant role in deciding public policies. However, as they get older than 60 years, they have less physical capacity and the onset of several functional limitations and health disorders, which indirectly impact their role. In addition, reaching the average retirement age (which in Indonesia is 60 years) implies a loss of the worker's role.

Highly educated stakeholders are likely to have more information to decide on specific policies. Half of the stakeholders graduated with a bachelor's degree (50%), followed by 57 respondents with a master's degree (38%), and 18 respondents with a doctoral degree (12%). Furthermore, more than 60% of the respondents worked in government offices (92 respondents) and had expertise in agricultural technology, environment, and social and economic areas. Furthermore, other respondents were researchers (23 respondents) who were experts in agricultural postharvest technology, 21 respondents were experts in the political field (14%), and a small number of respondents were in the agribusiness field (14 respondents).

Stakeholders' work duration is related to their work experience. Therefore, it determines the information that significantly affects their perceptions and decision-making roles according to the diffusion and innovation adoption theory by Rogers and the theory of planned behavior (TPB). The results showed that most stakeholders had experience working in their area for less than 20 years, reaching 74%, equivalent to 109 respondents, while nearly 26% of respondents had worked in their subject for more than 20 years (41 respondents). It was assumed that the work experience gained over time significantly improved workers' knowledge, skills, productivity, and performance.

Finally, the result of the stakeholder survey was to identify their willingness and participation in agricultural residue valorization, and 150 stakeholders responded to the questionnaire and interviews, including 114 males (76.00%) and 36 females (24.00%). Detailed stakeholder characteristics and profiles are shown in Figure V-3.

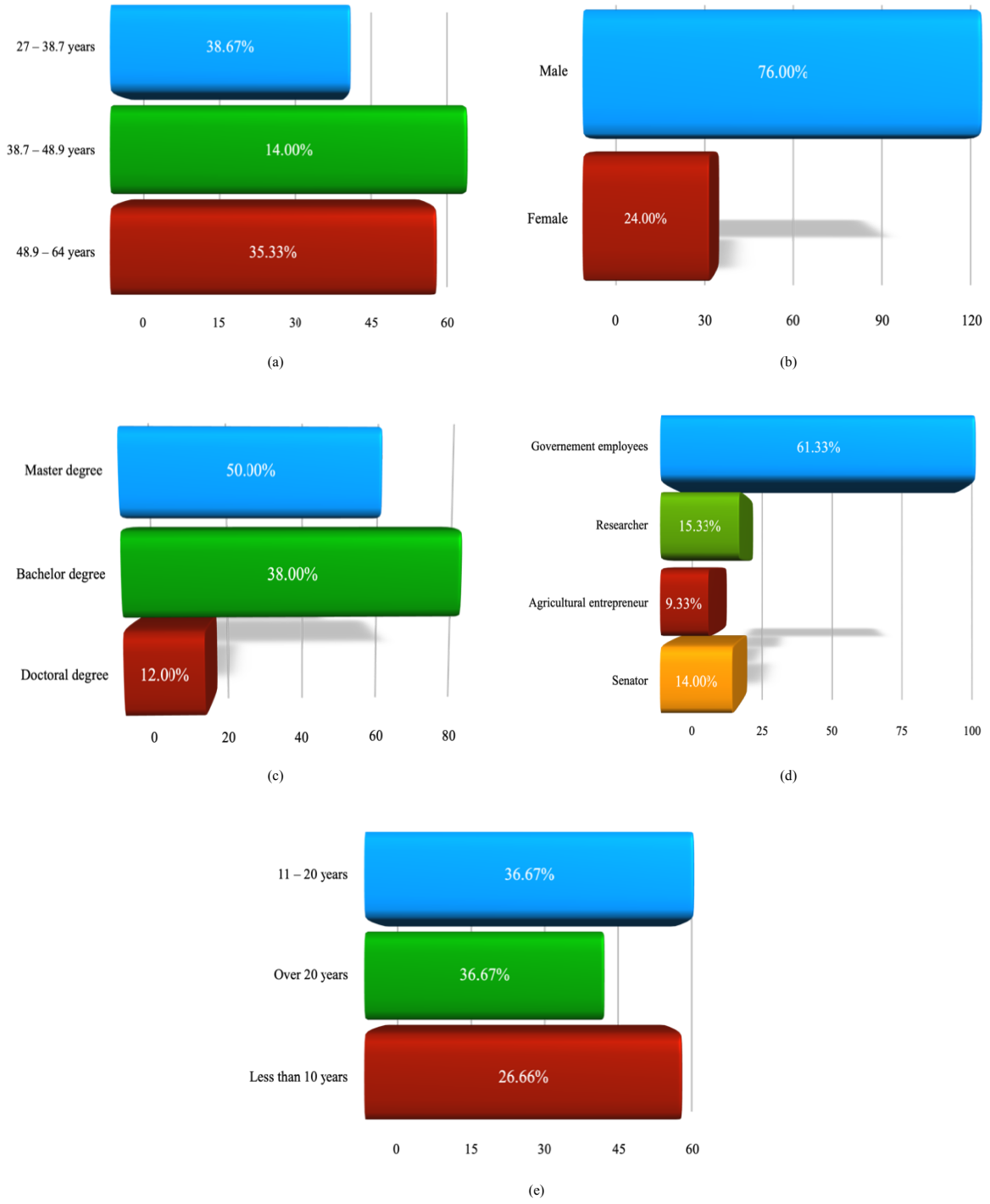


Figure V-3. Personal characteristics of 150 stakeholders: (a) age, (b) gender, (c) education, (d) occu[ation, and (e) work duration

3.2. *Stakeholder willingness in agricultural residue valorization*

3.2.1. *Stakeholder opinions*

When the BSC network is systematically designed and planned in the chain, abundant feedstock can significantly overcome biomass supply shortages to produce bioenergy. The first crucial strategic decision is to identify and select potentially suitable locations for BSC facilities

(Melo et al., 2009). However, one action should be taken to ensure sustainability, specifically, the effort to ensure feedstock availability. Therefore, an optimum strategy to realize the goals of residue valorization will be discovered by identifying stakeholders' opinions on agricultural residue utilization. Finally, the opinions of 150 stakeholders are presented in the interpretation graph of the MCA results, found in *Appendix G*.

The results of stakeholders' opinions show that almost 54% have moderate opinions regarding the frequency of rice straw burning. This means that open burning depends on weather conditions. Most of this practice occurs more in transition and wet seasons due to the fact that it is not very easy to manage rice straw, which has a high moisture content, and should provide more workers. Consequently, they believe that open burning is a simple method to save cost and time between harvesting and crop sowing, and approximately 60% of the stakeholders (90 respondents) have these opinions. Most open-burning practices are intentional and widespread among farmers who want to quickly eliminate agricultural residue because it is the cheapest, quickest, and most convenient method. Farmers frequently prefer burning to applying the residue for the following reasons: (i) controlling pests and crop diseases, (ii) eliminating weeds, (iii) improving tillage efficiency, (iv) lowering labor costs to remove agricultural residue in the field, and (v) collecting and transporting residue is complicated and requires supporting mechanical equipment. Consequently, these practices may contribute to GHG emissions of 7,300 kg CO2-equivalent per hectare and nutrient and biodiversity losses (Bhattacharyya et al., 2021). These statements contrasted with 61% of the stakeholders' opinions that open burning sometimes causes air pollution. However, almost one-third of stakeholders believed that open burning contributed to air pollution; therefore, they were willing to support the valorization program to improve environmental quality. Sixty-nine stakeholders were adamant that farmers used rice straw as animal feed and fertilizer. This means that they believed residue played a vital role in improving the social economy in rural areas. Bhattacharyya et al., (2021) reported that the estimated net profit from rice straw utilization as a bioenergy feedstock, such as bioethanol and biochar, reached US$183 per hectare; in comparison, burning can cause a net loss of US$ 107 per hectare to the economy and environment.

3.2.2. Stakeholder motivations

Motivation is a fundamental way to summarize stakeholder missions in valorization programs. It can predict the answer to the question: Will they reject or accept continuing to support and develop this program? The results for their motivations are shown in the interpretation graph of the MCA results, shown in *Appendix G*.

The results showed that stakeholders were highly motivated to support rice straw valorization, and none had low motivation. About 46%, 43%, and 48% of the stakeholders were motivated by the environment, politics, and economy, respectively. In contrast, nearly 50% of the

stakeholders had a moderate motivation level. Most stakeholders believe that implementing valorization programs will significantly reduce open burning activities. Furthermore, to achieve sustainability goals, they intend to determine the design and plan of rural empowerment models while considering policies and regulations, budget availability, and technological development. Therefore, synergy and integrated collaboration are required to optimize stakeholders' roles by identifying the level of actors' involvement in the BSC, which stakeholder mapping can illustrate.

Regarding environmental motivation, stakeholders were more concerned with reducing air pollution during the postharvest period compared to other opinions on environmental impacts (i.e., soil nutrient depletion and aesthetics). Therefore, residue utilization could positively impact the local economy and play a significant role in participating in the BSC, and stakeholders should identify sustainable biomass sources (Becker et al., 2013). For example, government employees working in agricultural offices should disseminate and educate farmers about the risks of open burning practices to the environment, human health, and economy, as well as the methods of utilizing rice straw as a valuable material. Among stakeholders, there should be synergy in providing an appropriate method and technology for collecting and managing residues; hence, researchers should assist in providing a solution by considering the socioeconomic conditions of users and environmental characteristics without omitting how the existing policies and regulations can secure that. It provides an illustration of BSC scenarios starting from resources, processes, and applications to provide social and economic benefits, which aligns with the results of socioeconomic motivation that most stakeholders have a high level of support for rice straw valorization.

In the context of bioenergy diffusion, the government's role is crucial in determining the planning, implementation, and supervision strategies correlated with energy security, regulation, funding, and social and environmental protection. The political aspect has become one of the criteria in the decision model of bioenergy production to analyze the national energy security and economic benefit of utilizing new energy sources (Amer and Daim, 2011). Political motivation related to implementing bioenergy resource diversification was based on Presidential Regulation No. 22 in 2017 of the National Energy General Plan (RUEN). The stakeholders believed that the government's regulations were issued as a reference document to develop the national electricity plan, which explains the role of biomass in improving the quality and quantity of bioenergy production. However, the structural barriers to developing biomass energy for large-scale production and commercialization are likely to apply to stakeholder intervention, particularly among policymakers. The government's intervention in biomass energy has been sufficient to this point, but awareness and participation in achieving national objectives should be gradually increased.

3.2.3. Stakeholder understanding level

The understanding level among stakeholders is expected to play a vital role in promoting valorization programs. Good governance is required, complemented by the provision of farming facilities and the integration of cooperation among government institutions, non-governmental organizations, industry, and society, to enhance research and innovation and generate circular valorization pathways, technology scalability, and market share stability. It is essential to set the design and planning objectives of innovations and solutions by communicating and building the community's awareness, thereby improving social acceptance. The results for their understanding level are shown by the interpretation graph of the MCA results in *Appendix G*. According to the analysis of stakeholders' understanding levels, approximately 47% of the stakeholders (57 respondents) had a high level of understanding that abundant agricultural residue resources have great potential for guaranteeing sustainable bioenergy feedstock. The stakeholders appreciate that the availability of rice straw as a feedstock material is abundant and needs to be optimally utilized. When applied as bioenergy, rice straw can generate approximately 3.4 GW with an efficiency factor of 20% (Rhofita et al., 2022). The utilization of rice straw for bioenergy production via thermal and biochemical conversion has increased significantly in recent decades (Lim et al., 2012). It continues to produce bioenergy (e.g., pellets, bioethanol, biodiesel, biomethane, and biohydrogen), which can create new jobs, increase marginal land exploitation, and improve local productivity through community empowerment (Sharma et al., 2020). Simultaneously, over 60% of the stakeholders (96 respondents) had a moderate understanding of the importance of good governance in agricultural residue management. Better sustainable governance should consider various actors and interests in this program; therefore, participation, monitoring, and risk assessment should be assured and accountable. However, it should be noted that environmental assessment, as a comparative analysis, should be used to evaluate various systems of production and technologies used in agricultural residue valorization to assist stakeholders in determining the planning and decision-making for BSC process improvement and commercialization without reducing the quality of the environment, economics, and social aspects. In this case, stakeholder understanding plays a vital role in constructing a solid perception to realize valorization goals. In conclusion, these findings indicate that stakeholders require the latest information to improve their capacity, skill, and mindset to propose a future conception before determining a long-term decision. At the strategic level, stakeholders should consider uncertain aspects to protect the robustness of valorization programs.

The understanding level of stakeholders is related to their motivation. Based on their knowledge, the application of agricultural residues can improve social, economic, and environmental sustainability. Based on these statements, approximately 55% of the stakeholders, or between 79 and 83 respondents, had a high level of awareness. Stakeholders' motivation and understanding are vital to the success of bioenergy development because both are the driving

forces behind their engagement, which positively affects long-term strategic development. Sustainable valorization can be fueled by knowledge and information exchanges among multiple stakeholders (How et al., 2019). Otherwise, in this process, stakeholders comprehend their roles and who is linked to them; thereby, the decision-making process is more concerned with emphasizing the importance of subjective norms (i.e., public image value) and minimizing institutional conflict in adopting valorization practices.

Finally, the findings of stakeholders' understanding of the essential benefits of technical support showed that approximately 57% of stakeholders (85 respondents) had a moderate level, and over 40% had a high level. Policymakers play an important role in the long value chain of agricultural residues by providing technical and financial assistance to farmers, researchers, and industry players. Constructing both formal and informal linkages should ensure aligned and comprehensive long-term development. This requires stakeholders to understand the essential benefits of technical support such as infrastructure, technology development, integrated cooperation, and research and innovation activities. At the strategic level, stakeholders should consider how to design and model technologies for commercializing biomass energy that is accessible to farmers and small and medium enterprises (SMSs). However, this technology is relatively expensive, and the design is based on something other than tropical biomass owing to its high capital expenditure (How et al., 2019). Moreover, biomass residue-based bioenergy technology conversion has been reviewed, and advanced technology could have been faster, but with lower efficiency, hindering commercial development (Tan et al., 2015). In line with technological development, supporting infrastructure for biomass logistics (i.e., storage and transportation) is required to solve the challenges of feedstock characteristics. Most agricultural residues, particularly rice straw, have low mass density, bulky materials, high moisture content, and scattered source locations, which result in a shorter shelf life and higher degradability. For example, in the transportation sector, the challenges of biomass characteristics encourage investors to decide on the risk of overload. However, penalties are inevitable, and road tolls are eliminated to reduce transportation costs. Considering sustainability benefits, stakeholders should understand how to determine better management to improve transportation quality by issuing green channels for policies and regulations (Hu et al., 2016). Stakeholders should be aware of this understanding to determine the selection technology and facility, as well as the policy and regulations that will be issued. Communication between stakeholders and their roles is a fundamental process that can be improved through integrated cooperation to enhance the quantity and quality of these technical aspects.

3.2.4. Stakeholder perceptions

Stakeholders, which consist of policymakers, government bodies, and the private sector, have complex perceptions of valorization development. Policymakers should harmonize the national goal of encouraging environmental protection, economic growth, and social welfare through the

utilization of agricultural residue as a bioenergy feedstock. At the same time, the government acts as a guarantor, obligated to make decisions on 1) how to develop this program by providing technical and financial support; 2) who are the actors involved in this program; and 3) how to manage collaboration with multiple stakeholders in the design, implementation, and evaluation while minimizing conflicts of interest. The private sector, including suppliers and industry players, must engage in long-term collaboration to achieve sustainable economic growth through integration. Finally, academics and researchers should review and predict the long-term implementation of valorization to provide suggestions and considerations to other stakeholders. Therefore, stakeholders' roles are multiple and correlated with each other, which strongly influences their perception of achieving the goals of the valorization program.

The analysis results for stakeholders' perceptions of agricultural residue valorization are shown in the interpretation graph of the MCA results in *Appendix G*. Half of the stakeholders, or 75 respondents, have a strong perception of supporting the valorization program. This is an excellent starting point for developing a methodology for implementing the procedure in the participation strategy of the valorization program. Perception is an important way to determine how stakeholders will design, model, and develop a system. This is a basis for providing new ideas to promote the sustainability of bioenergy production. It means they will have the strength, willingness, and awareness to achieve the national energy plan goals in 2025. In contrast, approximately 30% of stakeholders have a positive perception of the process of developing policies and regulations, as well as how they are disseminated. Sustainable policies and regulations should be designed and issued to protect the environment (e.g., reduce residue burning and improve land management and protection), improve economic growth (e.g., taxes, subsidies, and incentives for biomass residue application), and ensure social equity. Regarding policies and regulations, almost all regions have issued these to support the sustainable agriculture program; hence, it only requires an advanced methodology to incorporate the implementation of existing regulations and the residue valorization program by considering owned resources, the socioeconomic characteristics of communities, and environmental conditions. This is similar to the previous perception that approximately 30% of stakeholders have a high perception of providing facilities such as infrastructure, training and education, market share, and integrated collaboration.

3.2.5. Distribution and interaction among variable through MCA

MCA was used to identify the profiles of the stakeholders based on the correlation of their opinions (related to present agricultural residue in their region), motivation, understanding, and perception to achieve a valorization program though analysis of the 23 active variables.

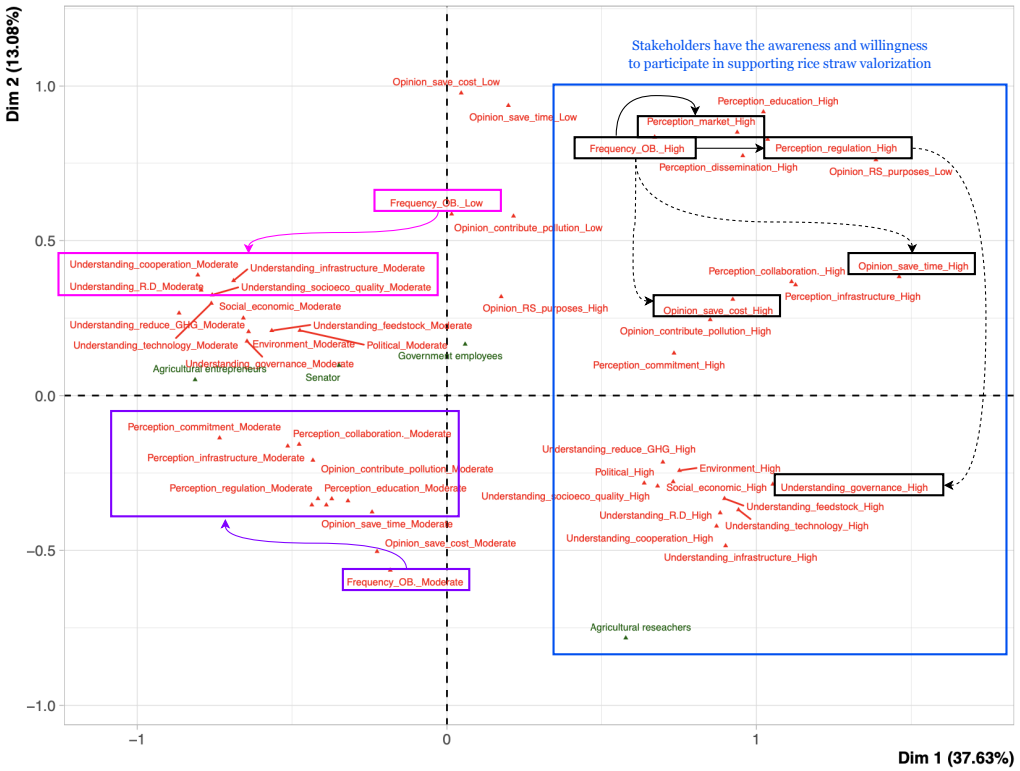


Figure V-4. Two first dimensions of MCA explaining the distribution of categorical variables

The MCA plot (Figure V-4) presents that the two-dimensional data described 50.71% of the total inertia, whereas the first three dimensions explained approximately 59% of the data. The x-axis of the biplot in Figure V-4 (Dim. 1, approximately 37.63% of the total variance) shows stakeholders' willingness and awareness spread (blue box). The majority of stakeholders in the first dimensions principal have high-value categories of perception of agricultural residue valorization (on the right), as opposed to lack of perception (on the left). More specifically, stakeholders who have an opinion on the frequency of open burning have a high opinion because they believe that managing and utilizing rice straw requires high operational costs and time (Figure V-4, shown by the dashed arrow). There is a close correlation between frequency and reason for open burning; thereby, it will affect their perception of how to realize valorization programs and mitigate the environmental problems caused by open burning, and policy and regulation should be issued to control and monitor program sustainability. At the same time, stakeholders, such as policymakers, should provide market share to attract farmers' participation in the valorization program and realize the national goal of improving economic and social welfare in rural areas (Figure V-3 is shown by a solid arrow). Moreover, good governance should be understood to set policies and regulations related to sustainable agriculture and the model management of agricultural residues, such as rice straw. In this case, good governance is a critical driver for managing the interaction between actors and the economy to set feedstock supply by considering three dimensions: commitment, awareness, and assessment of bioenergy management. As a result, a stronger perception among stakeholders to support agricultural

residue valorization can highlight the source of difficulty during program implementation, which is accompanied by high motivation and understanding as part of deciding long-term strategies.

The y-axis of the biplot (Dim 2, approximately 13.08% of the total variance) indicates that few stakeholders have experienced burning in their regions (Figure V-7 is shown by the pink box) and have a moderate correlation with their understanding; the solid pink arrow shows this. In short, they were only willing to support rice straw valorization programs with half of their intentions. Nevertheless, the realization of valorization should be supported through 1) comprehension to provide the applicable technology for the activities of harvesting, collecting, distributing, pretreatment, and energy conversion; 2) innovative research and development; and 3) integrated cooperation among stakeholders and the community, which aims to improve the quality of sustainability dimensions. Furthermore, stakeholders who have an opinion on the frequency of open burning periodically (bottom area) have a significant link to their moderate perception of supporting valorization (purple box). Indirectly, these were further analyzed by hierarchical ascendant classification (HAC) using the Ward method to describe the distance from each variable. The classification purpose was to highlight the significant correlation among variables, and the result is a dendrogram presented in Figure V-5. Three groups were obtained using the silhouette index (Rousseeuw, 1987).

Stakeholders' understanding of the support for agricultural residue valorization can be seen in their responses. First, stakeholders' motivations in political terms are closely linked to their understanding of feedstock availability. Stakeholders should answer the questions of how to realize better governance by issuing related policies and regulations that protect sustainability dimensions. Furthermore, researchers investigating bioenergy development should take note of the geographical settings to identify feedstock availability, which drives the creation of novel biomass-based value chains by increasing the level of understanding required to implement the economic framework policy (Silver et al., 2015). Stakeholders' socioeconomic motivation is related to their understanding of cooperation, infrastructure, and research and development. The socioeconomic aspect of the BSC's goals was to create new jobs in rural areas and promote good farm management to supply biomass residue to improve farmers' income. Stakeholders, particularly the government and researchers, should collaborate to increase farmers' participation by conducting researcher workshops, field days, on-farm demonstrations, participatory on-farm research, and farmer-led groups (Villamil et al., 2012); thereby, the quality of two-way communication between farmers, researchers, and the government could be bridged to tackle the bottlenecks. Lastly, stakeholders' motivation for environmental benefits by reducing greenhouse gas emissions is closely linked to understanding the level of technology and reducing GHG emissions. Indirectly, they comprehended that Government Regulation No. 79, 2014 on Energy Development is a governance guideline for the bioenergy model to improve social, economic, and environmental quality that could be achieved by agricultural residue utilization as recommending

future bioenergy development considering the sustainable feedstock availability and minimizing conflicts with food and has many benefits in all sectors.

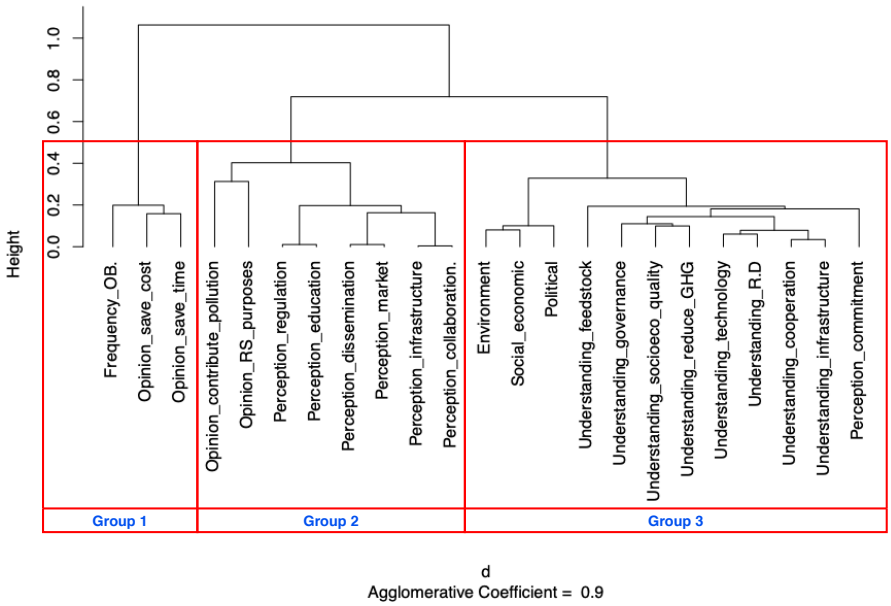


Figure V-5. Dendrogram of clustering variable

3.2.6. Hierarchical clustering analysis (HCA) to identify stakeholders' willingness

Hierarchical Agglomerative Clustering (HAC) groups stakeholders' responses according to their similarity, which is clustered into three distinct characteristics. Figure V-6 is a global representation of clustering in the factor map, and the characteristics of each cluster are described in Table V-2. The three groupings correspond to categories initially found in the MCA factorial plane, and the typology of stakeholders can be summarized as follows:

- Cluster 1 (53% of stakeholders) is shown in red. It is dominated by agricultural entrepreneurs and senators, who believe that open burning is rare because the residue is used as a valuable material, such as animal feed and fertilizer. The respondents appeared to lack the willingness and awareness to support valorization programs, which is evident from their motivation and perception.
- Cluster 2 (26% of stakeholders), as shown in green. Most stakeholders worked in government offices and had a moderate level of willingness and awareness to support the valorization programs. However, these depend on the situation; for example, during the wet season, valorization is crucial to mitigate open burning because most regions have a similar problem in managing rice straw with high moisture content.
- Cluster 3 (23% of stakeholders), shown in blue. Most stakeholders were agricultural researchers who understood that valorization is a vital program for conserving the environment, boosting the economy, and improving social welfare in rural areas. As a result, the respondents were eager and aware to support valorization programs.

Remember that most stakeholders (nearly 65% of respondents) are pessimist about realizing rice straw valorization potential because the main barrier to biomass valorization development is the need for more knowledge about biomass advantages and utilization and the logistical aspects of collection and organization. Therefore, mapping challenges and barriers is necessary to decide on precise strategies that consider sustainability aspects, technology, and politics, which will be discussed in the last section.

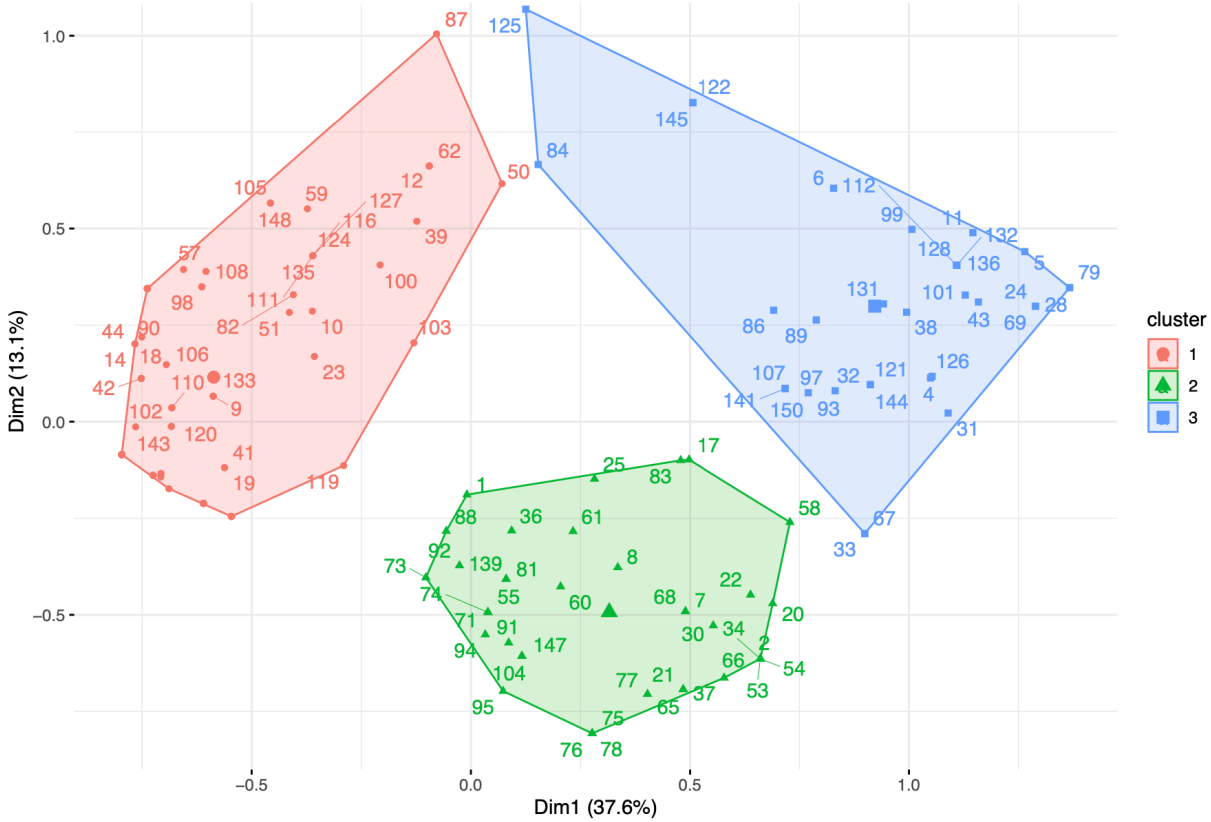


Figure V-6. Stakeholders' characteristics clustering in factor map

Table V-2. Description of stakeholders' clusters

Clusters	Number of farmers	Opinion of present rice straw utilization	Motivation to support rice straw valorization	Understanding to support rice straw valorization	Perception of rice straw valorization
Cluster 1	79	Over 60% of rice straw production is utilized as animal feed. Thus, the frequency of application is high.	Moderate level of motivation for all aspects of sustainability and legislation implementation.	100% of stakeholders have a moderate understanding to support rice straw valorization.	All stakeholders have a moderate perceived of the rice straw valorization program
Cluster 2	39	30-60% of rice straw production is utilized as valuable materials. Thus, the frequency of application is moderate.	High level of for environment aspect and legislation implementation	83% of stakeholders have a high understanding to support rice straw valorization.	60% of stakeholders have highly perceived of the rice straw valorization program.
Cluster 3	35	Less than 20% of rice straw production is utilized as animal feed. Thus, the frequency of application is low.	High level of motivation for all aspects of sustainability and legislation implementation.	100% of stakeholders have a high understanding to support rice straw valorization.	All stakeholders have highly perceived of the rice straw valorization program.

3.2.7. Overview of stakeholders' willingness and awareness to support agricultural residue valorization

In the current sustainable development system, knowledge about the perception of biomass residue management is essential for stakeholders to decide on valorization strategies to achieve national goals according to Presidential Regulation No. 22 for the year 2017 in the National Energy General Plan (RUEN). Valorization among farmers is an opportunity to expand their businesses, aiming to raise revenue from farming activities. According to a previous study, farmers could earn an extra income of around US$51.42 per tonne per hectare when they supply the residue. Furthermore, government officers should discover the best method and provide the technical and financial support required to implement this program. In contrast, for the research centers, valorization is a tool to address their resources and develop the technology to minimize the barrier of the BSC, and senators should be responsible for the policies and regulations that have been issued to guarantee sustainable agricultural implementation. Finally, the results of the first study may support the efficient allocation of human resources by mapping actors' willingness and awareness as fundamental actions to set long-term valorization strategies. The empirical evidence of this step concludes that different behaviors and attitudes of stakeholders toward their willingness and awareness make it possible to be divided into three groups, i.e., the "unwilling," the "willing-time," and the "innovative-sustainable." These three different actors' profiles can state their roles at three levels of the decision-making framework (i.e., strategic, tactical, and operational levels). In particular, they can encourage actual participation based on the roles of the actors, beginning with the planning, development, and implementation of the valuing program as comprehensive scenarios.

Fifty-three percent of the individuals interviewed were "unwilling," "uninterested," and "unaware" unaware of rice straw valorization. They worked as agricultural entrepreneurs and senators with a moderate level of motivation for sustainability and regulation implementation. Furthermore, they had a moderate level of perception of the value of the program. They have issued and disseminated policies and regulations for sustainable agriculture. They should also provide physical and nonphysical facilities that farmers and communities can use to maintain and boost economic development. These stakeholders believe that farmers always utilize the residue as valuable material after harvest. Consequently, they understood that the availability of rice straw as a feedstock depends on the weather. During the wet season, the availability of rice straw accounts for more than 70% of production.

The second group is "Willing-Time," which represents one-fourth of respondents. These stakeholders are working in the government office, which believes that valorization can be applied when residue is abundant during the wet season. This was caused during the dry season, and most farmers use rice straw for approximately 50% of production for feed and planting purposes, such

as mushroom planting media and fertilizer. Approximately 50% of the residue is available as bioenergy feedstock. They are highly motivated by the fact that the valorization program is fundamental to mitigating environmental issues and implementing policies and regulations such as national energy plans and goals. Even though actors have a medium level of competence in agricultural policy and regulation, they affect their perception of supporting the reduction of open burning postharvest. However, they were willing to support this program by implementing their understanding of each decision-making process.

Actors who are highly willing and aware to support rice straw valorization correspond to the "Innovative-Sustainable", that agricultural researchers represent. The actors are familiar with sustainable aspects supported by technological innovation; therefore, they have the competency to promote and realize national bioenergy goals. They are involved in activities to reduce the challenges and barriers to BSC implementation through research and cooperation with other stakeholders. Furthermore, they recommend the findings to policymakers to provide technical and financial support, and also understand that implementing valorization requires continuous feedstock availability. The actors also understood that policies and regulations should be disseminated through regular counseling and education. Therefore, they are highly willing to support the valorization program by creating novel innovations to assist in decision-making.

As a result, stakeholders' willingness and awareness are used to map and model their roles in strategic decision making considering sustainable aspects. The purpose of these steps was to contribute to sustainable development by simultaneously achieving food and energy security for social welfare.

3.3. Stakeholder mapping

A previous study (Chapter IV) presented approximately 50–75% of biomass residue, that is, rice straw, which was used optimally; moreover, the farmers left the straw in the field and burned it. Therefore, the feedstock's potential is enormous, and it can continue to supply bioenergy production. Consequently, multiple issues arise, including air pollution, soil quality degradation, biodiversity degradation, water body contamination, and human respiratory disorders. However, to implement this program, it is necessary to improve the organizational system by considering the role and interaction of multiple actors and institutions in BSC activities, which are part of the valorization programs. The distribution of stakeholders and their institutions according to their role in each decision-making level are shown in Figures V-7 and V-8.

Figure V-7 shows that stakeholders were constructed by considering the results of their willingness and awareness to support the valorization programs. As explained in the previous section, the actors' distribution refers to the decision level of the supply chain process, that is, the strategic, tactical, and operational levels. The actors at the strategic level play a role in determining

the long-term decision, which is related to financial investment and national policies for regulating the design, development, and implementation of this program. For instance, the Ministry of Agriculture manages and maintains rice straw supply and product standardization through institutional management optimization. As shown in the previous section, governments have been issuing sustainable agricultural policies in several cities in the East Java province.

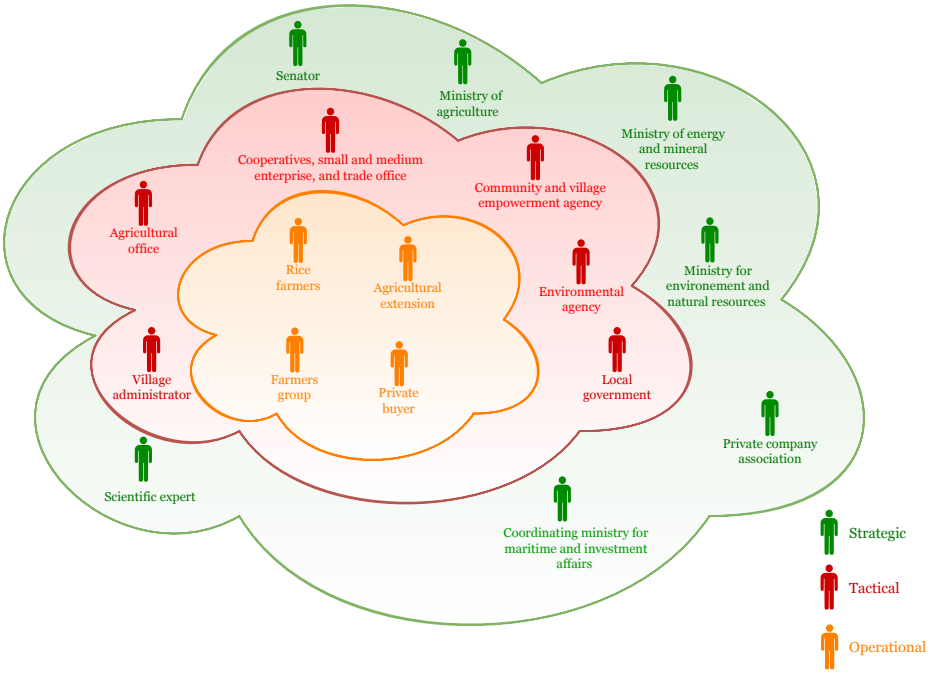


Figure V-7. Stakeholder map for valorization program

Furthermore, interconnections with other stakeholders should be strengthened to accelerate the implementation of all processes, starting from upstream (i.e., resources) to downstream (i.e., the application of rice straw). In this study, scientists contribute by providing pilot models in domestic technology production that utilize local resources and have the potential to encourage domestic production of technology through comprehensive research and development. Transferring technology in the long term is also a priority for participating in valorization by providing education, training, and counseling to other stakeholders and communities. Simultaneously, the stakeholder at the tactical level refers to the regional level of a decision made and related to the production plan in the middle term (i.e., determining the quantity of rice straw that can be generated in each period and how the supply and stock methods interact). In this case, the agricultural office oversees the implementation of policies issued by the national government regarding sustainable agriculture, while the environmental officer assists in mitigating the environmental problems caused by rice straw before (i.e., burning in the field) and after developing valorization. Finally, at an operational level, the actors' role in a short-term period decision is made, which provides sustainable rice straw at the right time for harvesting. Rice farmers play a vital role, and agricultural extensions should promote government planning.

However, global actors' roles were specified according to their institutions and actual situations, as shown in Figure V-8.

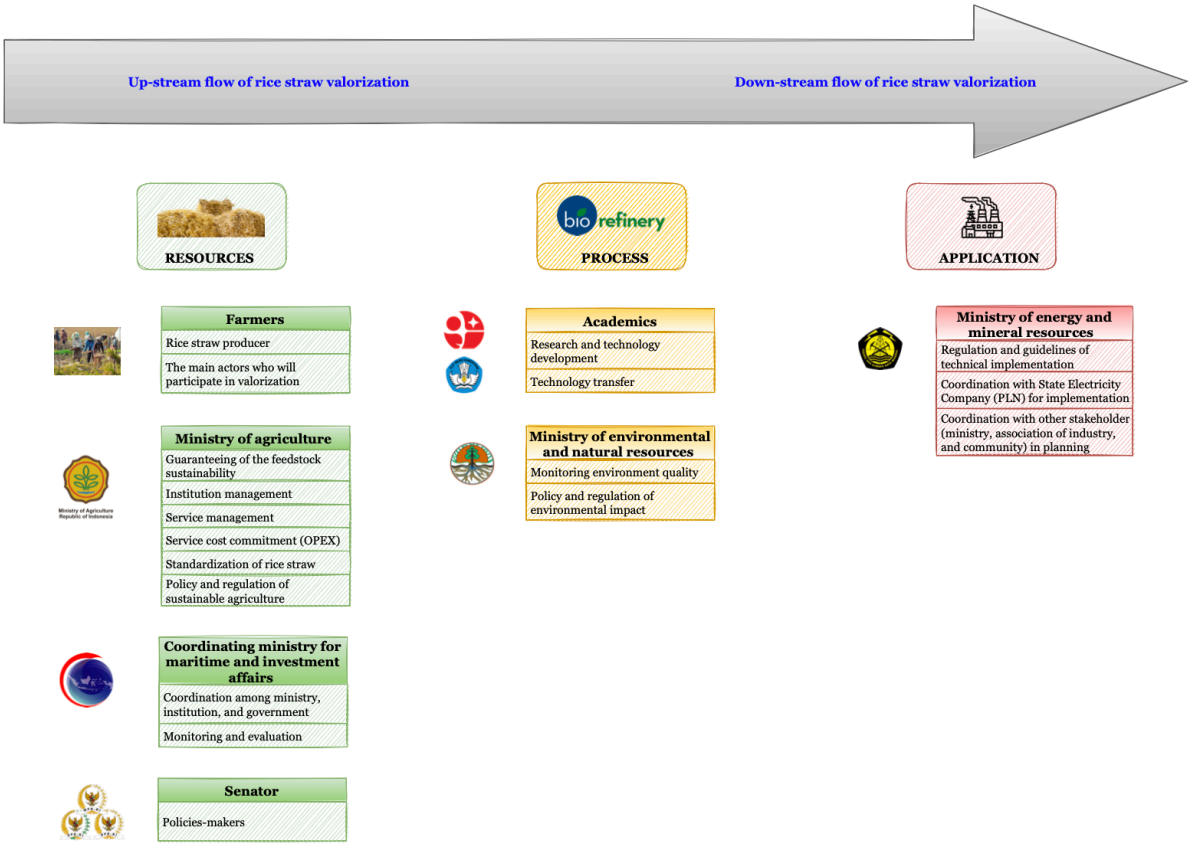


Figure V-8. Detail stakeholders mapping according to their institution and role

3.4. Stakeholder modelling

The modeling process was organized by analyzing the farmers' interview results, government body workers, and business actors. As explained in the last step (section on stakeholder mapping), the objective was to mash up the interconnection of a link to present comprehensive actors' roles according to their decision-making level. In practice, stakeholder modeling was started by identifying farmers' opinions of present rice straw management and their willingness to participate in rice straw valorization. Almost 75% of farmers perceive and expect better residue management to improve their economic and social quality and reduce post-harvest open burning, which causes pollution. Generally, rice straw produced as the first residue of farming activities is utilized as animal feed (almost 25% of production) and compost (around 5% of production), and over 70% of rice straw is burned in the field as part of conventional activities during the post-harvest period. It has provided financial benefits when trading rice straw to supply the activities of growing mushrooms and vegetables, as well as animal feeding and bedding, and these have been applied in some countries such as Vietnam, India, Cambodia, and the Philippines (Aquino et al., 2020) (Thuc et al., 2020). Even the commercialization of straw as a biofuel has been realized in

China, the US, Italy, and Brazil (Ren et al., 2019). Therefore, in the future, the valorization program can potentially be developed and promoted as a sustainable program through rural empowerment by involving the government to accommodate straw processing facilities, agricultural entrepreneurs to drive the rural economy, and communities involved in the model cooperation program. Although the practices still need to be ready for farmers to adopt, these programs are a simple solution for reducing residue burning. Figure V-9 shows the interaction diagram of rice straw utilization according to the farmers' role from farmer' opinions.

Furthermore, stakeholder modeling can be observed in their willingness and awareness to determine their acceptance of maintaining the valorization program (see the first step). Integrating the perspectives of farmers and stakeholders into a model is shown in Figures V-10 and V-11 by considering before and after the implementation of the valorization program, to identify their role and how their interaction corresponds to the decision-making level.

In the actual case, Figure V-10 presents the actors who had relevant interactions prior to the agricultural residue valorization programs. First, at a strategic level (green icons), three actors (senators, government, and researchers) have been determining long-term plans in sustainable agriculture sectors, as stated in the Republic of Indonesia Law No. 22 for 2019. Some actors' roles have been implemented; for example, senators as policymakers have been issuing policies and regulations to actualize sustainable farming by considering the environmental capacity to mitigate climate change. A previous study found that most cities in East Java province have policies and regulations on sustainable food protection, cropping patterns in irrigated areas, farmer protection and empowerment, and agricultural facilities and funding. At the same time, the government provided technical and financial assistance (e.g., agricultural equipment and machinery and subsidies for fertilizer prices and farming insurance) to help farmers in cultivation management that had been distributed through farmer groups annually. Researchers have reviewed and modeled the environmental impact of agricultural residue burning and investigated the optimum methods of residue application as valuable materials. During the strategic decision-making process, the researcher recommends to policymakers and the government the optimum method to develop and manage the residue for valorization, considering sustainability aspects, technological development, and the political situation in the future. At the tactical level, actors' roles (red icons) describe how they distribute information and provide technical and financial support from the government. It also includes their role in disseminating policies and regulations issued by the government. For example, the agricultural office, in which agricultural extensions distribute information and other assistance to farmers. Furthermore, environmental issues due to open burning are concerning and should be mitigated by environmental agencies through integrated communication and actions in a supervision system. Finally, at the operational level (orange icons), rice straw utilization by farmers was emphasized, as explained in a previous study.

Furthermore, Figure V-11 depicts the role of agricultural extension in changing farmers' residue utilization practices, which further implies that the main challenge is how to boost farmers' acceptance of adopting sustainable residue management practices by recommending them to other actors to create a market and how to change the system and construct complex relationships among multiple actors and levels, even though increasing the quantity and quality of cooperation with other institutions is required to assist and provide market share. For example, establishing a link between SME agencies and farmers through village cooperatives (KUD) can provide necessary services to improve residue quality. This activity can be collaborated by the community and village empowerment agency to determine the optimal program for farmer empowerment, considering the regional potential and environmental capacity to improve the farmers' economy. Furthermore, farmers should switch from the traditional method of collecting and handling rice to a more mechanized and modern method (e.g., using a combined harvester) to increase the quantity of residue, and the support and services related to collecting, handling, transporting, and distributing rice should be made known by clarifying who the actors or institutions are responsible for these activities. Moreover, technical facilities (i.e., the public warehouse and transportation network) have been constructed and managed by the public works office; their utilization can promote the implementation of the valorization program. To maintain optimal supply chain costs, all actors and institutions should calculate financial costs, particularly investment costs. As a result, rice straw valorization as a bioenergy feedstock should be developed to be more appealing and innovative in terms of sustainability dimensions by optimizing the roles of actors and institutions at the scale of integrated collaborations and communications.

Cross-sectoral communication and coordination at similar and dissimilar decision levels are challenges that should be resolved soon. In this case, policymakers, such as senators and the government responsible for long-term planning, development, implementation, and evaluation of the programs, need to collaborate with other actors from government bodies, businesses, and communities to establish a good governance structure for valorization. The principle of cross-actor collaboration requires a multidisciplinary overview that does not naturally promote growth. However, a multisystem architecture approach is essential for coordinating, supervising, facilitating, and maintaining sustainable actions to achieve national and sustainable development goals. In short, enabling and sustaining collaboration and creating a new institution to accommodate bioenergy production are essential processes, as shown in Figure V-10 in blue icons.

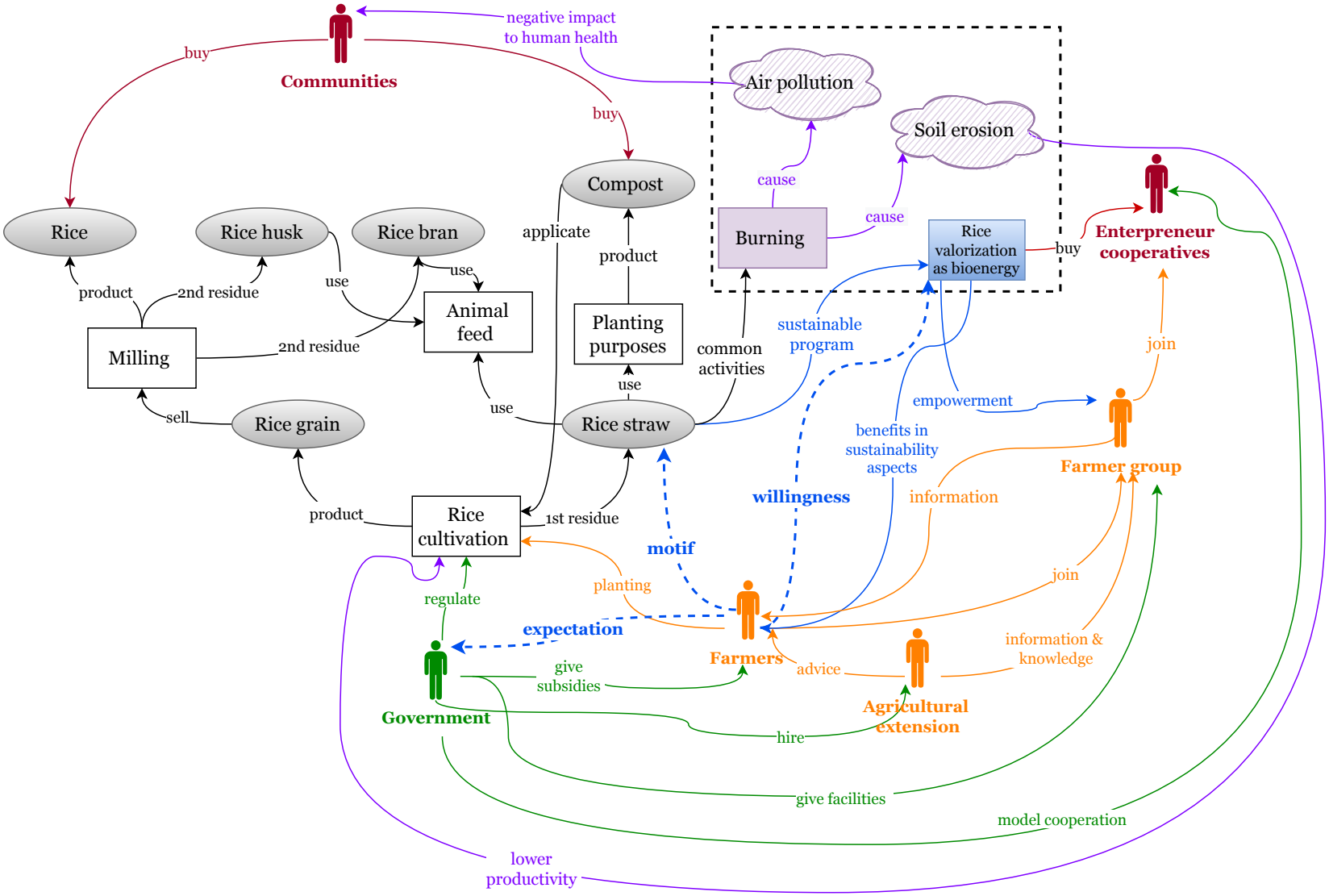


Figure V-9. Interaction diagram of rice straw utilization considering farmers' role

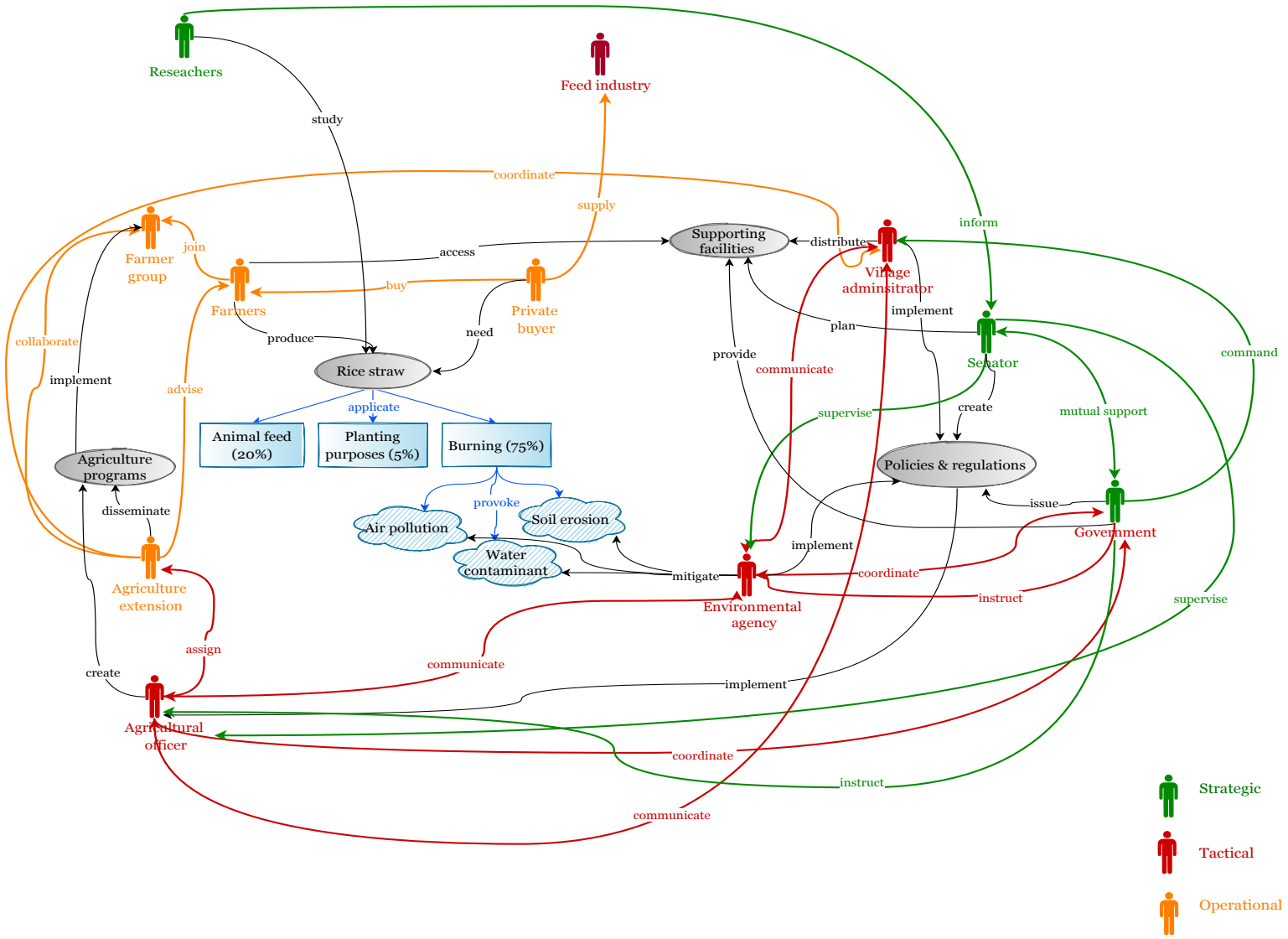


Figure V-10. Interaction diagram of before rice straw valorization activities

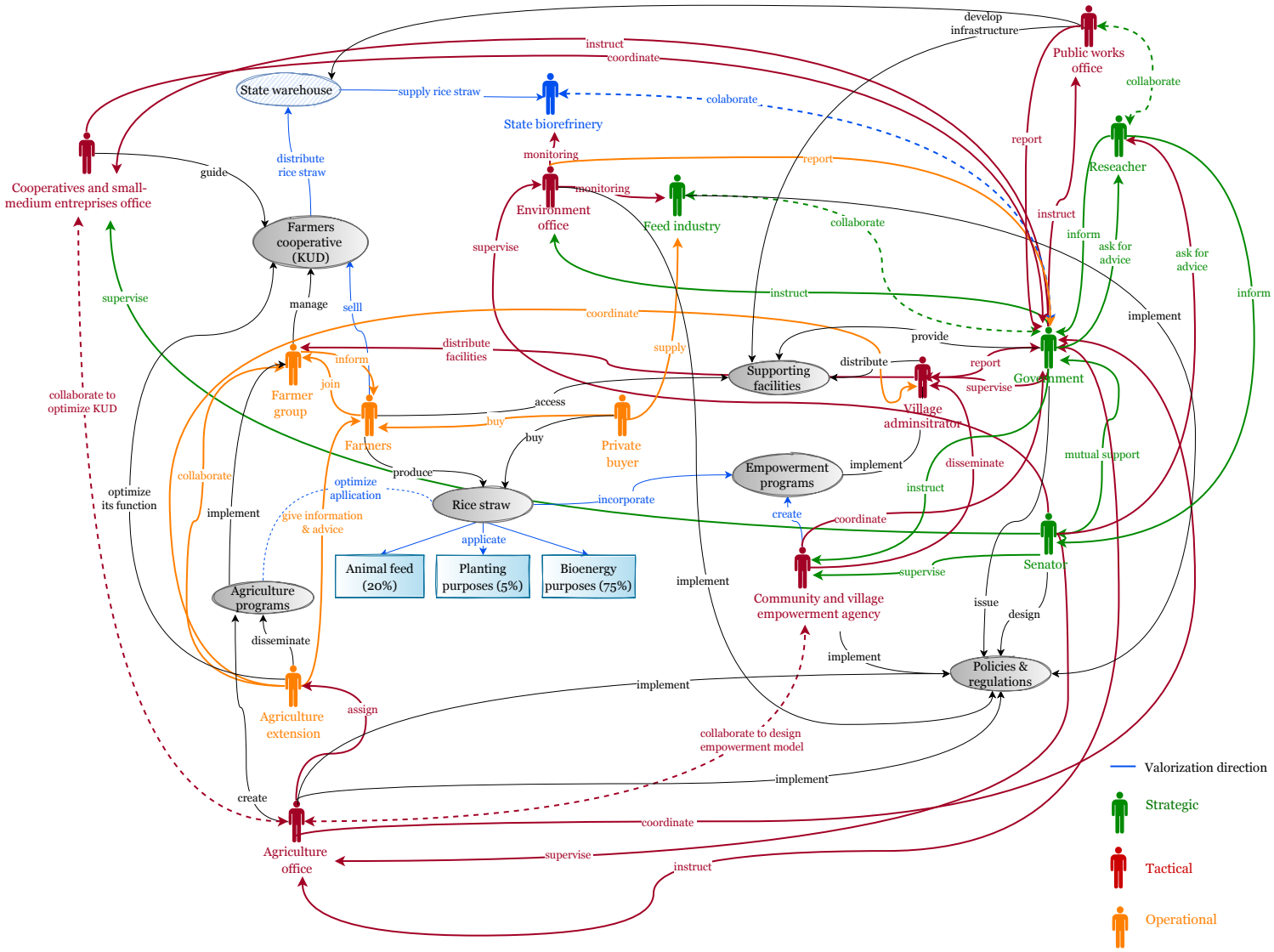


Figure V-11. Interaction diagram of rice straw valorization activities

4. Conclusions and perspectives

Lack of information and government trust often lead to social conflict in the community; therefore, it is a primary challenge for stakeholders to plan the strategy and disseminate up-to-date information, technical knowledge, and skills. This study presents a scenario of stakeholders' decision-making by integrating their opinions and willingness to identify and manage actors, and how their processes affect rice straw valorization. The three proposed methodologies also describe the objectives, constraints, and context analysis required to depict the optimal model: stakeholder willingness analysis, mapping their influence and correlation, and determining their role. The first methodology groups the stakeholders' willingness into three categories, i.e., "unwilling," "willing-time," and "innovative-sustainable." Most stakeholders recognized that using agricultural residue was a way to improve farmers' socioeconomic situations while also mitigating environmental issues. This is associated with their motivation to support rice straw valorization through good governance by implementing the principles of accountability, transparency, efficiency, participation, and fairness.

Second, stakeholder mapping should include an investigation to determine who is participating, what their role is, when they define decision-making, where decision-making is held, and how to realize and evaluate goals. In this study, we developed a model to show that actors, activities, resources, and products at each decision-making level are critical to implementing valorization programs. Identifying stakeholders by hexa-helix stakeholders as a global conclusion can be an option to present their role, as shown in Figure V-12. To detail its concepts, we include the media as second-tier stakeholders who will contribute to disseminating new information to communities to improve their awareness and willingness levels toward the rice straw valorization program. However, in future implementation, an appropriate methodology should be developed to solve the questions of (i) how the procedure is to communicate and diffuse information and material; (ii) when it will be implemented; (iii) where is the distribution channel; (iv) whom the involvement actors are to disseminate; (v) who are the receiver actors; and (vi) what are the policies that will protect it.

Finally, illustrations of the interaction between the actors involved can be described by stakeholder modeling according to the results of the first and second steps. Stakeholders' role identification before and after implementation of the valorization shows a new institution that collects rice straw from the leading actor (farmers), that is, the farmer cooperative (KUD). New policies and regulations are required to sustain the continuity of the valorization program, particularly the determination of the residue price, standardization to maintain quality, and availability of market share.



Figure V-12. Hexa-helix analysis of the stakeholders in valorization program

Stakeholders' involvement in valorization programs should consider the issues that impact activities and decision-making, as well as stakeholders' expectations, although they may have an interest or opinion that is inconsistent with their goals. A complex investigation is needed to determine the extent of their contribution to sustainable development, especially in food and energy security and community empowerment programs. Therefore, social responsibility practices can be applied to identify stakeholders' involvement and interests and the sustainability of the programs, according to ISO 26000. The relationships among stakeholders, programs, and societal expectations in this study are shown in Figure V-13.

Integrating social, economic, environmental, technical, and political knowledge is critical when considering a transdisciplinary methodology for providing a modeling system to gather how stakeholders can be involved. In the future, a new methodology using a mathematical optimization model (i.e., multi-objective, multilevel, game-theoretic, etc.) can be investigated. The agent-based model theory should consider identifying stakeholder participation in rice straw valorization, which has been implemented.

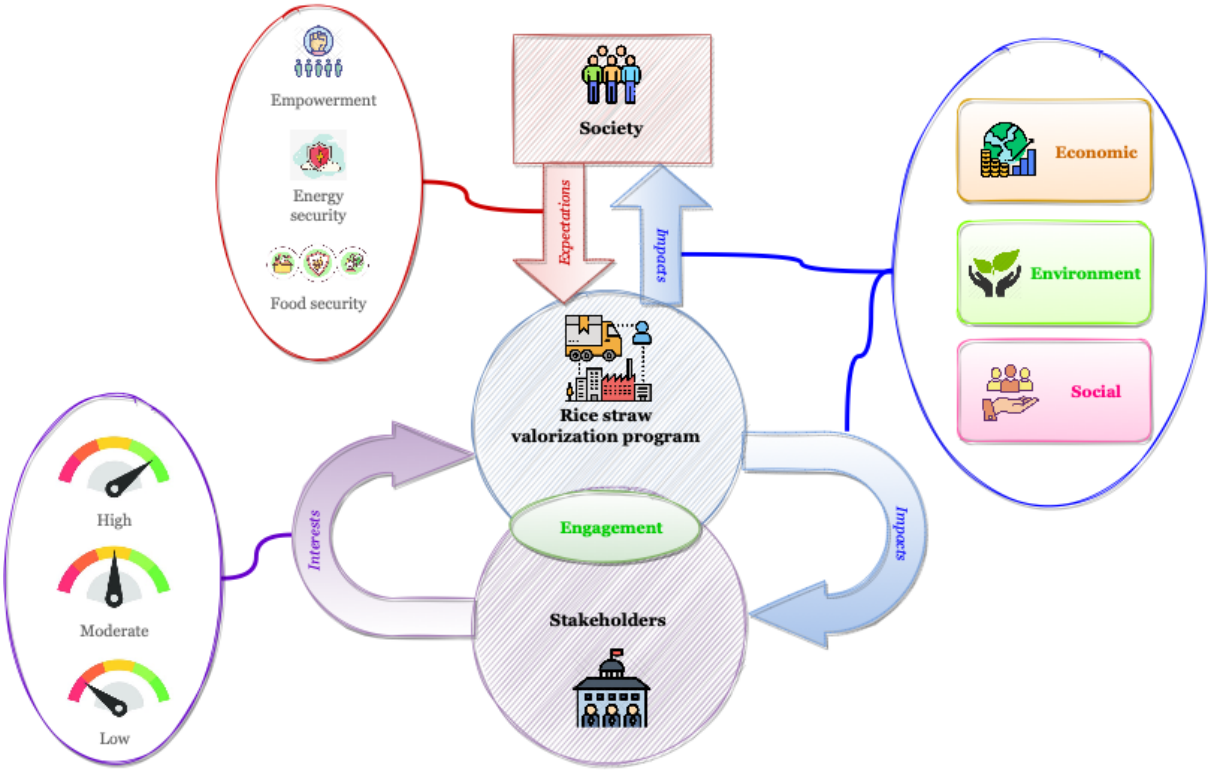


Figure V-13. Relationship between an organization, stakeholder and expectation of society according to the ISO 26000

Chapter VI. Tactical planning level of the agricultural residue supply chain: a real case in the economic aspect

1. Introduction

Regarding biomass residue resource location, the obstacles are the scattered availability and lack of accurate data describing production and application (Cambero and Sowlati, 2014b; Vassilev et al., 2015). Although agricultural residue, primarily rice straw, is a plentiful resource that is available throughout the year, it is not optimal to take advantage of its potential for developing bioenergy (Dutta et al., 2022; Saleem, 2022; Wee et al., 2012). However, in long-term design and planning, stakeholders' willingness to participate is fundamental to determining the sustainability of the material supply, as described in the previous chapter. Moreover, the selection of the size, capacity, and location of biomass supply chain (BSC) echelons (e.g., biomass procurement, transportation, storage, distribution, and production) should simultaneously consider the minimum operational cost, limitations of network performance, and fulfillment of the time-accuracy demand (Mohammadi and Harjunkoski, 2020). Therefore, it is essential to assess the productivity and interconnectedness of the supply system by considering risk, uncertainty, sustainability, and resilience (Garcia and You, 2015) to estimate the profit level in bioenergy production (Gunasekaran et al., 2004). These have a direct impact on the supply chain's stability and sustainability as an integrated system that is highly correlated with one another. The results indicate economic losses when a process is unsuitable (Atashbar et al., 2016).

To address these challenges, Barbosa-Povoa, (2014) described the optimization technique as a significant contribution to tackling the complexity problem in designing and managing supply chains, and some experts have applied this method to investigate real problems in the BSC (Barbosa-Povoa, 2014; Sargent, 2005; Stephanopoulos and Reklaitis, 2011). Moreover, they have highlighted how to consider decision-making as an integrated process to address the supply chain in multiple aspects, that is, multiple scales, objectives, and players (Barbosa-Povoa and Pinto, 2020; Garcia and You, 2015). Consequently, process supply chains are knowledge and skills that have been actively and extensively correlated in time and space dimensions (Barbosa-Povoa and Pinto, 2020). Designing and planning analysis at strategic, tactical, and operational decision levels consists of increased economic growth balanced by environmental and social quality improvements (Ahmadvand and Sowlati, 2022; Yue et al., 2014b). At the decision-making level, it is essential to notice the time dimension, which influences materials and product flow to enhance the productivity of the process and minimize the cost and environmental impact (Roth et al., 2021). To determine the maximum profit and performance of production planning and logistics operations in BSC potential, two scenarios with centralized and decentralized distribution

networks were evaluated (Patel et al., 2019). As a result, an optimization model should be developed to be closer to reality by developing novel strategies for agricultural residue utilization to accomplish its objective, which will be investigated in this chapter.

The previous chapter discussed the potential of biomass residue to achieve the national energy goal, as stated in Indonesia Presidential Regulation No. 22 of 2017, by optimizing its application to produce approximately 5.5 GW and 26 GW of electricity in 2025 and 2050, respectively. However, the main challenge in realizing this goal is the lack of a BSC network model. In contrast, feedstock availability from rice straw reached 75.97 million tonnes annually, equivalent to 3.4 GW of potential power, with an efficiency factor of 20% when all residues are utilized (Rhofita et al., 2022). On the other hand, sustainability aspects should be highlighted in the context of rice residue-based power generation to describe the significant benefits of its application, such as studies that investigated greenhouse gas emission mitigation (Abdelhady et al., 2014; Gadde et al., 2009; Prasara-A and Gheewala, 2017; Shafie et al., 2014), economic feasibility as financially and profitability (Delivand et al., 2011; Ramamurthi et al., 2016; Shafie et al., 2012b), and selling rice residue to the local energy market is a better solution for achieving community welfare and energy security in rural areas (Singh, 2015b). This indicates that the utilization of rice residue can be applied to develop bioenergy generation in the form of pellets and briquettes, while considering sustainability dimensions (Arévalo et al., 2017).

In this chapter, the classical approach is the basis for discovering how a multi-actor can manage a system at different levels (Figure VI-1). Previously, the strategic decision-making level was more focused on the social aspect, which aims to investigate farmers' willingness to supply rice straw as bioenergy feedstock after deducting animal feed and other purposes (e.g., fertilizer, mulch, and mushroom planting media); therefore, the available amount of rice straw can be estimated and will assist in setting a research scenario for BSC. Another important key is stakeholder support, which should be known in order to realize valorization programs. A survey was conducted to determine their willingness and participation, raising the question of what facilities are currently available. What services should the government provide? Moreover, how is the strategy used to implement programs? This can be solved to minimize the lack of a BSC. As a result, this chapter focuses on the tactical decision-making level in the medium term to address how to organize efficiency in economic aspects for optimal material flow, transportation, and storage, considering centralized and decentralized distribution networks as part of reducing the BSC challenge. The objective of this chapter was to answer the following research question:

- To what extent does feedstock availability contribute to supply chain performance sustainability?
- Which storage scenarios can be implemented to mitigate the risk of stock shortages?

- How reliable is the economic viability at the tactical level for modeling a year-long analysis of the operational costs and flow of materials?

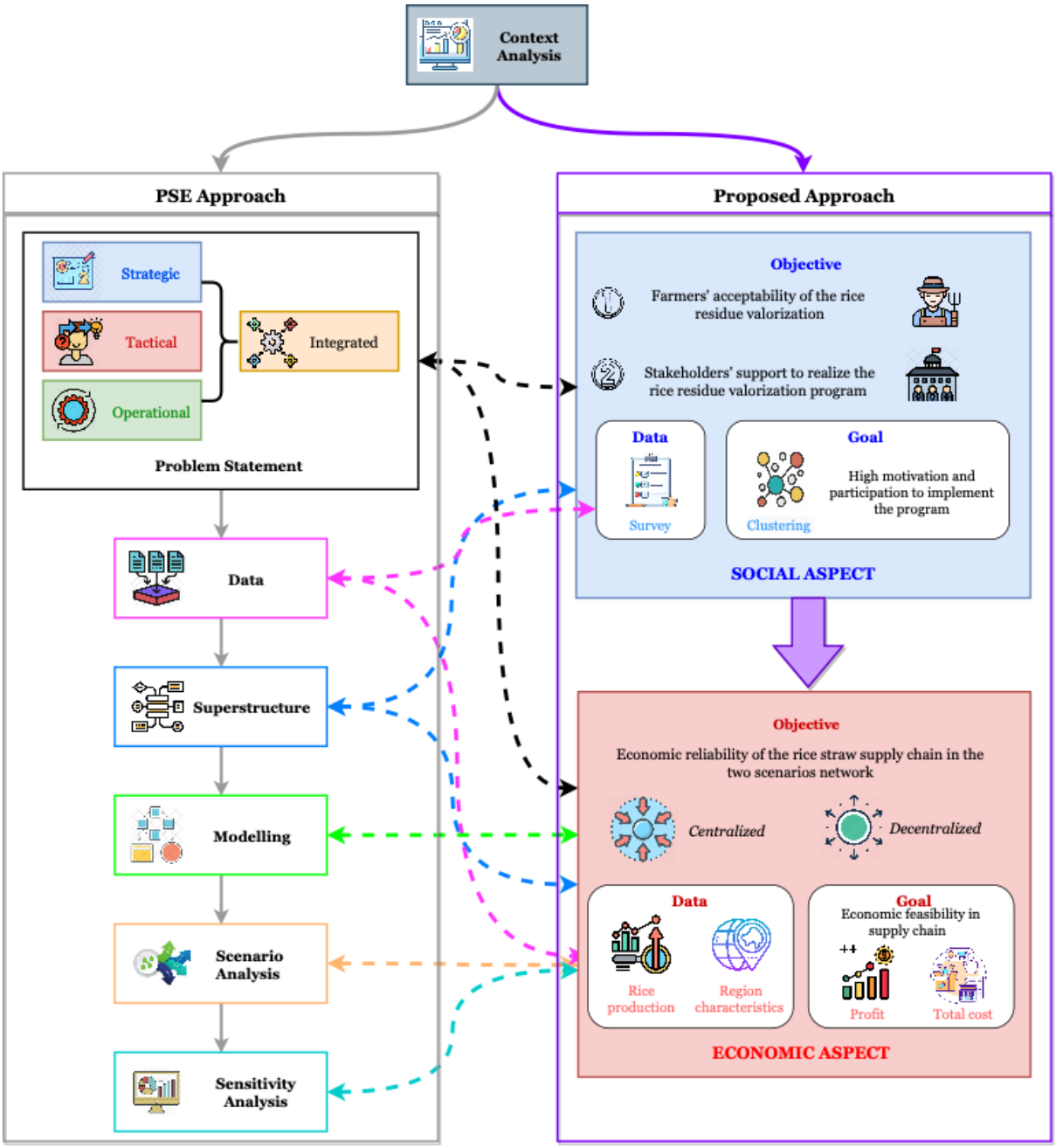


Figure VI-1. Incorporate between classical approach and proposed approach

2. Study area

The model was applied to the efficiency of the rice straw supply chain in East Java Province, Indonesia to define the maximum profit. The detailed location of the case study is shown in Figure VI-2. The location of the biorefinery facility in the Jenu sub-district, Tuban, was preselected to correspond to the following criteria: (i) location within the Tuban industrial park within one kilometer of a major state road; (ii) location within less than ten kilometers of a port; (iii) location around the power plant within 14 km; and (iv) the maximum raw materials within a radius of less

than 120 km of any selected purchasing materials to support the production of more than 20 tons per hour. Furthermore, four regions were selected as raw material suppliers for several reasons according to a previous study: (i) the close distance to the pellet production and power plant; (ii) sustainable rice production every year; (iii) post-harvest time, when the availability of rice straw is abundant and not optimally utilized; therefore, it is an inexpensive material; and (iv) high support from the stakeholders, which is proven by their willingness and awareness. The distance between the biomass purchasing location and storage facilities is shown in *Appendix H*.

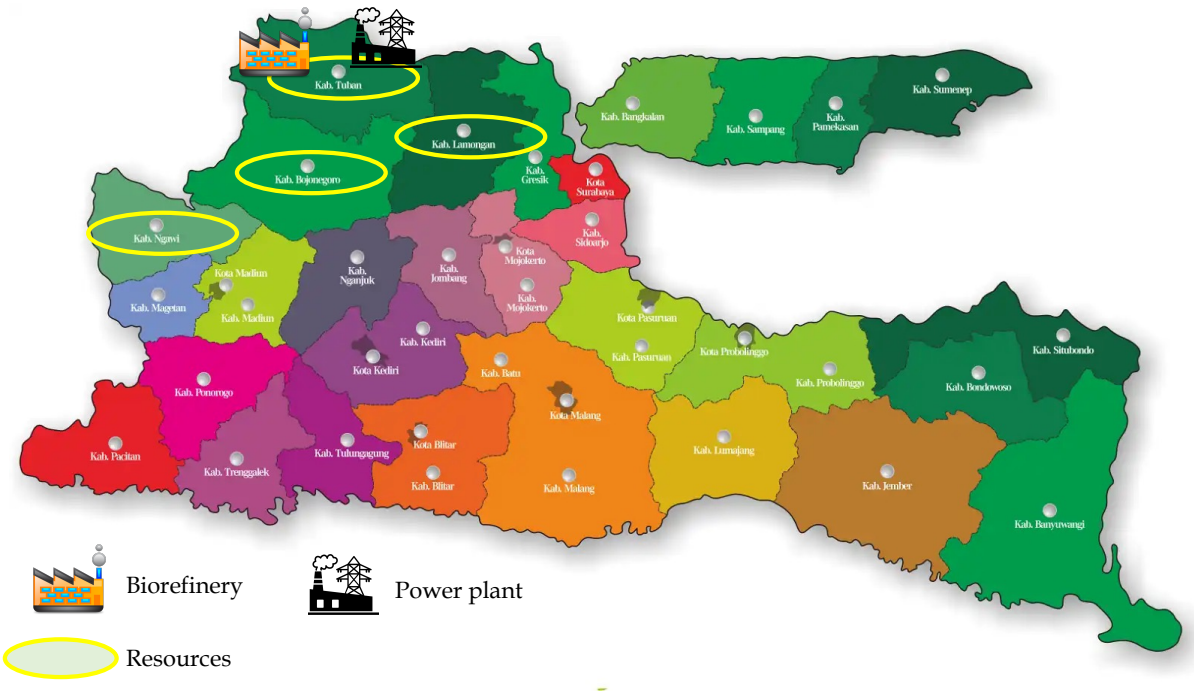


Figure VI-2. Case study location of biomass residue supply chain

3. The optimization models

3.1. Model variables and parameters

The model is established for optimizing the quantity of biomass procured, stored, and used to produce pellets each month during a one-year planning horizon at tactical decision in biomass supply chain. The maximization of profits is the main objective of developing the model by revealing two critical parameters that influence the supply chain performance: the production capacity and the amount of storage and transportation units. Furthermore, the principal components of the model, i.e., decision variables, parameters, constraints, and objective function, will be defined in this section. Table VI-1 shows the notation and definition of decision variables and parameter settings applicable to the developed model.

Table VI-1. List of indices, variables and parameters of the model

Indices	
H	Biomass purchasing location (regions); index h ∈ H
I	Storage location (regions); index i ∈ I
T	Period (Jan, Feb, …, Dec); index t ∈ T
Variables	
$A_{h,t}$	Amount of biomass procured from each biomass purchasing location *h* in the period *t* (tonne)
$C_{h,i,t}$	Amount of biomass transported from each biomass purchasing location *h* to storage facility *i* in the period *t* (tonne)
$D_{i,t}$	Amount of biomass transported from each storage facility location *i* to biorefinery *j* in the period *t* (tonne)
E_t	Amount of pellet transported from biorefinery to power plant in the period *t* (tonne)
F_t	Amount of pellet utilized in power plant in the period *t* (tonne)
$IVBI_{i,t}$	Inventory level of biomass at storage facility location *i* in the end period *t* (tonne)
$IVBJ_t$	Inventory level of biomass at biorefinery in the end period *t* (tonne)
$X_{i,t}$	Amount of biomass stored in storage facility location *i* in the period *t* (tonne)
Y_t	Amount of biomass processed as pellet in biorefinery in the period *t* (tonne)
Z_t	Amount of pellet produced from biorefinery in the period *t* (tonne)
Parameters	
η_p	Conversion factor of biomass to pellet (tonne product/tonne raw material)
$Avb_{h,t}$	Availability of biomass from each biomass purchasing location *h* in the time period *t* (tonne)
$dist1_t$	Distance from biomass purchasing location *h* to storage facility location *i* (km)
$dist2_t$	Distance from biomass storage facility location *i* to biorefinery (km)
$dist3_t$	Distance from biorefinery to power plant (km)
$dist4_t$	Distance from biomass purchasing location *h* to biorefinery (km)
$ratio_{h,t}$	Ratio of biomass quantity purchased from location *h* (%)
cap_p	Weight capacity of pellet process at biorefinery (tonne)
Ωt	Deterioration rate transportation of biomass (%)
Ωs	Deterioration rate storage of biomass (%)
δ_b	Purchasing cost of biomass ($/tonne)
δ_p	Production cost of pellet ($/tonne)

δ_t	Transportation cost of biomass ($/tonne)
δ_s	Storage cost of biomass ($/tonne)
Ir	Discount rate (%)

3.2. Objective function

The objective function is used to maximize the profit will be illustrated in Equation (VI-1), which is calculated by the cash inflow (total revenue) and cash outflows (total cost) in a specific period.

$$\text{Profit}_t = \sum_{n=1}^{t} \frac{1}{(1+ir)^t} * [\text{Total Revenue}_t - (\text{Biomass Purchase}_t + \text{Transportation Cost}_t + \text{Production Cost}_t + \text{Inventory Cost}_t)] \quad \text{(VI-1)}$$

The revenue is calculated by considering the selling price and amount of the pellet products, which is given in Equation (VI-2).

$$\text{Total Revenue}_t = \sum_{p \in P}(\delta_p * \text{Tpju}_{p,j,u,t}) \quad \text{(VI-2)}$$

The total cost is composed of biomass procurement, transportation, storage, and production costs, which is expressed in Equation (VI-3).

$$\text{Total Cost}_t = \text{Rice straw Purchase}_t + \text{Transportation Cost}_t + \text{Storage Cost}_t + \text{Production Cost}_t + \text{Inventory Cost}_t \quad \text{(VI-3)}$$

In more detail, biomass procurement is calculated by considering the biomass price, the ratio of biomass quantity utilized as bioenergy in each biomass purchasing location, and the availability of biomass production based on the production data. Equation (VI-4) is shown the biomass procurement cost in this study.

$$\text{Biomass purchase}_t = \sum_{h \in H} \sum_{t \in T}(\delta_b * \text{Ratio}_{h,t} * \text{Avb}_{h,t}) \quad \text{(VI-4)}$$

The transportation cost depends on the distance between each facility of biomass supply chain (i.e., biomass source, storage, biorefinery and power plant) and the amount of transported biomass. In the decentralized scenario, there are three transportation costs, i.e., (i) biomass is transported from the harvesting area to a storage facility in each region; (ii) biomass will be transported from the storage facility to the biorefinery; and (iii) pellets as a product will be transformed from the biorefinery to the power plant. In contrast to the centralized scenario, the transportation cost is the summation of transportation from the biomass purchasing location to the storage facility around the biorefinery area and the pellet is transported from the biorefinery to the power plant. Equations (VI-5) and (VI-6) show the scenarios of decentralized and centralized detailed transportation costs, respectively.

$$\text{Transportation Cost}_t = (\sum_{h \in H} \sum_{t \in T} \delta_t * C_{h,i,t} * \text{dist1}_t) + (\sum_{t \in T} \delta_t * D_{i,t} * \text{dist2}_t) + (\sum_{t \in T} \delta_t * E_t * \text{dist3}_t) \quad \text{(VI-5)}$$

$$\text{Transportation Cost}_t = (\sum_{h \in H} \sum_{t \in T} \delta_t * C_{h,i,t} * \text{dist4}_t) + (\sum_{t \in T} \delta_t * E_t * \text{dist3}_t) \quad \text{(VI-6)}$$

The production cost refers to pellet production that covers all the costs associated with grinding, densification and drying processes. Equation (VI-7) shows the calculation of the production cost, which depends on the maximum production capacity.

$$\text{Production Cost}_t = \sum_{t\in T}(\delta_p * Y_t) \quad \text{(VI-7)}$$

The inventory cost can refer to the storage cost paid in each period based on the total rice straw stored at the end of the last time plus the total rice straw stored in the current month; furthermore, it is multiplied by the storage cost in each period. In more detail, Equations 8 and 9 show the calculation of inventory costs in decentralized and centralized scenarios, respectively.

$$\text{Inventory Cost}_t = \left(\sum_{i\in I}\sum_{t\in T}\delta_s * \text{IVBI}_{j,t}\right) + \left(\sum_{t\in T}\delta_s * \text{IVBJ}_t\right) \quad \text{(VI-8)}$$

$$\text{Inventory Cost}_t = \sum_{i\in I}\sum_{t\in T}\delta_s * \text{IVBI}_{j,t} \quad \text{(VI-9)}$$

3.3. Model constrains and mass balance

The constraints and mass balance of the model are listed considering the supply chain facilities below.

1. Biomass feedstock supply

The feedstock used in this case study is rice straw, transported to the storage facility and biorefinery by truck. The raw material procurement location considers the rice production data from the government office for several years. At the same time, the location selection of rice straw suppliers should consider the proximity of the biorefinery location due to the short transportation distance to simplify long-term contracts and relations among the stakeholders. Other points should be remembered since agricultural operations depend on the weather. When the unfavorable weather significantly impacts the feedstock, storage, and distribution activities; therefore, the amount of biomass procurement cannot be precisely known in advance, and alternative locations for biomass purchasing can be set when the situation is uncertain, but it provides a higher biomass price. However, in this study, the influence of weather as an uncertainty factor will not be a detailed explanation.

Specifically, the total amount of biomass transported from each harvesting location source to the storage facility should not exceed the available biomass production in each period. Biomass availability ($Avb_{h,t}$) is the total amount of biomass procured from harvesting location *h* in each period *t*. Constrain (VI-1) restricts the availability of raw material at each supply source.

$$A_{h,t} \leq \text{Avb}_{h,t} \qquad \forall h \in H, t \in T \quad \text{(VI-1)}$$

Furthermore, the biomass purchasing from each location selection *h* will be transported to the storage facility in similar regions if the decentralized scenario, while for the centralized scenario, the biomass procurement will be transported to the biorefinery area, as stated in Constraint (VI-2).

$$C_{h,i,t} = \sum_{h\in H}\sum_{t\in T} A_{h,t} \qquad \forall h \in H, t \in T \quad \text{(VI-2)}$$

2. Biomass storage facility

The total biomass stored in each period is the amount of biomass transported from purchasing location *h* after considering the deterioration rate of transportation (Ωt), is represented in Constraint (VI-3).

$$X_{i,t} = \sum_{h \in H} \sum_{i \in I} \sum_{t \in T} C_{h,i,t} * \Omega_t \qquad \forall h \in H, i \in I, t \in Tq \qquad \text{(VI-3)}$$

The biomass storage capacity is limited and known, depending on the total biomass production in each location selection and production capacity. Storing more than a certain level will affect the hiring of the additional operator and material handling equipment, and the risk of storing will continue to increase, such as self-heating fire, dust explosions, and excessive gases released during storage. Therefore, every period's storage level should be lower than or at the same level as the maximum available storage level of the storage capacity, which is shown in Constraint (VI-4).

$$X_{i,t} = \max X_{i,t} \qquad \text{[For all t]} \qquad \text{(VI-4)}$$

In the current period, the total biomass stored should be similar to the amount of biomass intake after reducing the deterioration rate of transportation (Ωt), plus the total biomass at the end of the period. At the end of the current period, the total biomass stored should be similar to the amount of biomass stored at the end of the previous period after reducing the deterioration rate of storage (Ωs) and the amount of biomass transformed to biorefinery to be used for pellet production in the current period. In detail, the amount of biomass storage in each storage facility located in the last period (if t = 12, in the previous year y-1) is the initial inventory of the first period (it means t = 1) in the current year, while the raw material storage in each period (t > 1). This constraint ensures that managers can establish an initial storage condition for the future period in the next year. Therefore, the mass balance of the biomass in the storage facility in each period t is represented in Constraint (VI-5).

$$\left[(1 - \Omega_t) * C_{h,i,t}\right] + IVBI_{i,(t-1)} = \sum_{i \in I} \sum_{t \in T} X_{i,t} + IVBI_{i,t} \qquad \forall i \in I, t \in T \qquad \text{(VI-5)}$$

3. Biorefinery

The biomass stored at the storage facility in each location unit will be transported to the biorefinery by truck each period. During transport, the biomass quantity will reduce according to the deterioration rate of transportation. Furthermore, the biomass is transformed into pellets by considering the production capacity, which may not be exceeded in each period, as shown in Constraint (VI-6).

$$\sum_{t \in T} Y_t \leq cap_p \qquad \forall t \in T \qquad \text{(VI-6)}$$

The amount of biomass converted may not be all processed; thus, the inventory level in the biorefinery should be noted. Therefore, in the current period, the total biomass intake at pellet processing is the biomass transported from the storage facility in each location, reducing the deterioration rate of transportation plus the inventory left from the last period after being utilized as a raw material for pellets and the deterioration rate of storage. It should equal the amount of

biomass processed as a pellet in the biorefinery and inventory in the current period. Thus, the mass balance of biomass in the biorefinery is presented in Constraint (VI-7).

$$\left[(1-\Omega_t) * D_{i,t}\right] + IVBJ_{t-1} = \sum_{t\in T} Y_t + IVBJ_t \qquad \forall t \in T \qquad \text{(VI-7)}$$

The production amount of pellet in biorefinery is converted by a conversion factor (η_p) is shown in Constraint (VI-8).

$$Z_t = \sum_{t\in T} Y_t * \eta_p \qquad \forall t \in T \qquad \text{(VI-8)}$$

4. Power plant

The amount of pellet transported to power plant equals the total pellet production in each period, is shown in Constraint (VI-9).

$$\sum_{t\in T} E_t = \sum_{t\in T} Z_t \qquad \forall t \in T \qquad \text{(VI-9)}$$

Furthermore, the amount of pellet utilized at power plant is equal to the total pellet transported to power plant considering the deterioration of transport, is represent in Constraint (VI-10).

$$F_t = (1-\Omega_t) * E_t \qquad \forall t \in T \qquad \text{(VI-10)}$$

4. Results and discussions

4.1. Model assumptions

In the case study, the specific data required for optimization modeling, i.e., rice straw availability in each region and the detailed cost of each supply chain process. The rice straw production data was derived from the calculation of the rice production and the physical properties of residue (i.e., moisture content and residue-to-product ratio). Furthermore, the availability factor of residue that could be utilized as bioenergy (pellet production) was known from the previous study (a farmer survey in this area) after deducting the application of animal feed and planting purposes. In detail, the assumptions used to optimize the biomass residue supply chain are as follows.

1. Biomass procurement
    - The biomass procurement locations are defined based on the rice harvesting areas on a district basis. The biomass is assumed to be uniformly distributed across the sub-district area in each region.
    - The centroid of the starting point of transportation in the sub-district, which is located in the center of the government.
    - The biomass procurement quantity cannot exceed the center of storage capacity in each region, depending on the production capacity.
    - The price of biomass purchasing has been assumed to be fixed due to its being taken as waste. However, in the sensitivity analysis, it will be decided as anticipated when the implementation of policy and regulation cannot be realized and the economic mindset of stakeholders has been changed.

2. Biorefinery facility
    - The biorefinery produces pellets whose raw material is rice straw.
    - The pellet production capacity is 20 tonnes per hour, which means the total production per month is approximately 14400 tonnes; the biomass feedstock requirement is approximately 17,000 tonnes per month.
    - The conversion factor of pellets production is 88.1% (Ishii and Furuichi, 2014).
    - The scenario analysis uses a variety of production capacities to identify the optimum economic viability at the tactical level, i.e., 10, 20, and 50 tonnes per hour.
    - The biorefinery facility operates on a 24/7 schedule.
3. Transportation
    - The transportation radius is assumed to be less than 150 kilometers.
    - Biomass feedstock is only delivered by diesel truck.
    - Transportation expenses, including loading and unloading fees.
    - Various deteriorations of transportation were applied, and the constant values 3% of biomass weight were used each month for control analysis. Whereas for scenario analysis, deterioration of transportation depended on the seasons (5, 3, and 1% of biomass weight in rainy, transitional, and dry seasons, respectively).
    - Deteriorations of transportation of the pellet from the biorefinery to the power plant were a constant 0.5% owing to its short distance and location in a similar area.
4. Storage
    - The storage capacity depends on the biorefinery's production capacity and the supply in the respective zone.
    - The deterioration of storage depends on the storage type.
5. Others
    - The moisture content is constant throughout the supply chain at approximately 20%.
    - Typically, December and January are peak wet seasons in some regions where floods affect supply chain disruptions. It will be anticipated to more use the raw material in a close district location to a biorefinery facility to minimize the risk of transportation and storage.

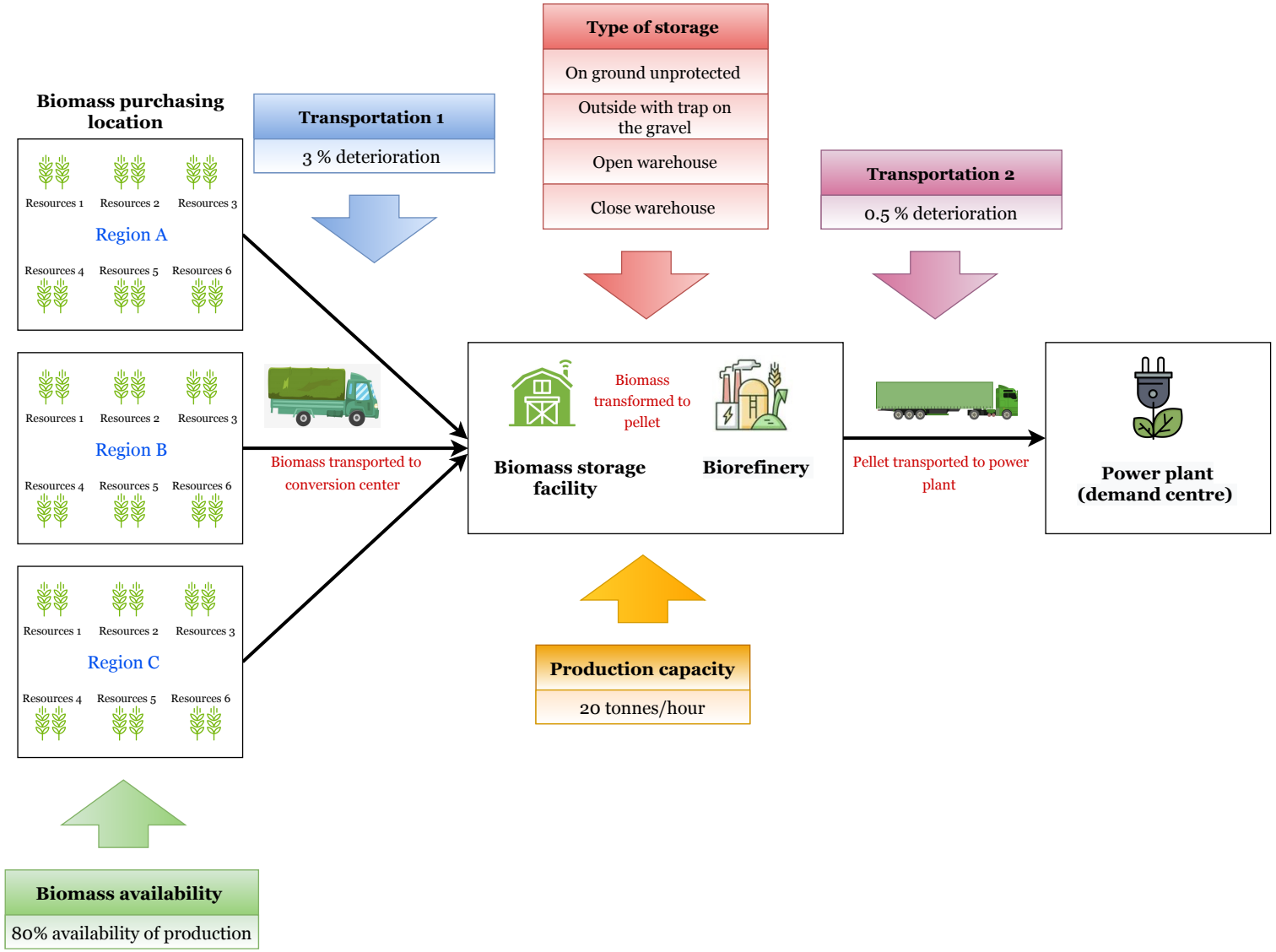
4.2. Case study

Rice production data from 2021 were used to calculate the optimization model for pellet production from rice straw. The 80% material availability was applied to determine the feasibility and economics of the storage conditions based on the interview results of the farmers, as shown in Chapter II. Two system distributions, centralized and decentralized, were utilized to discover the optimal results of four storage types: (i) closed warehouse, (ii) open warehouse, (iii) semi-

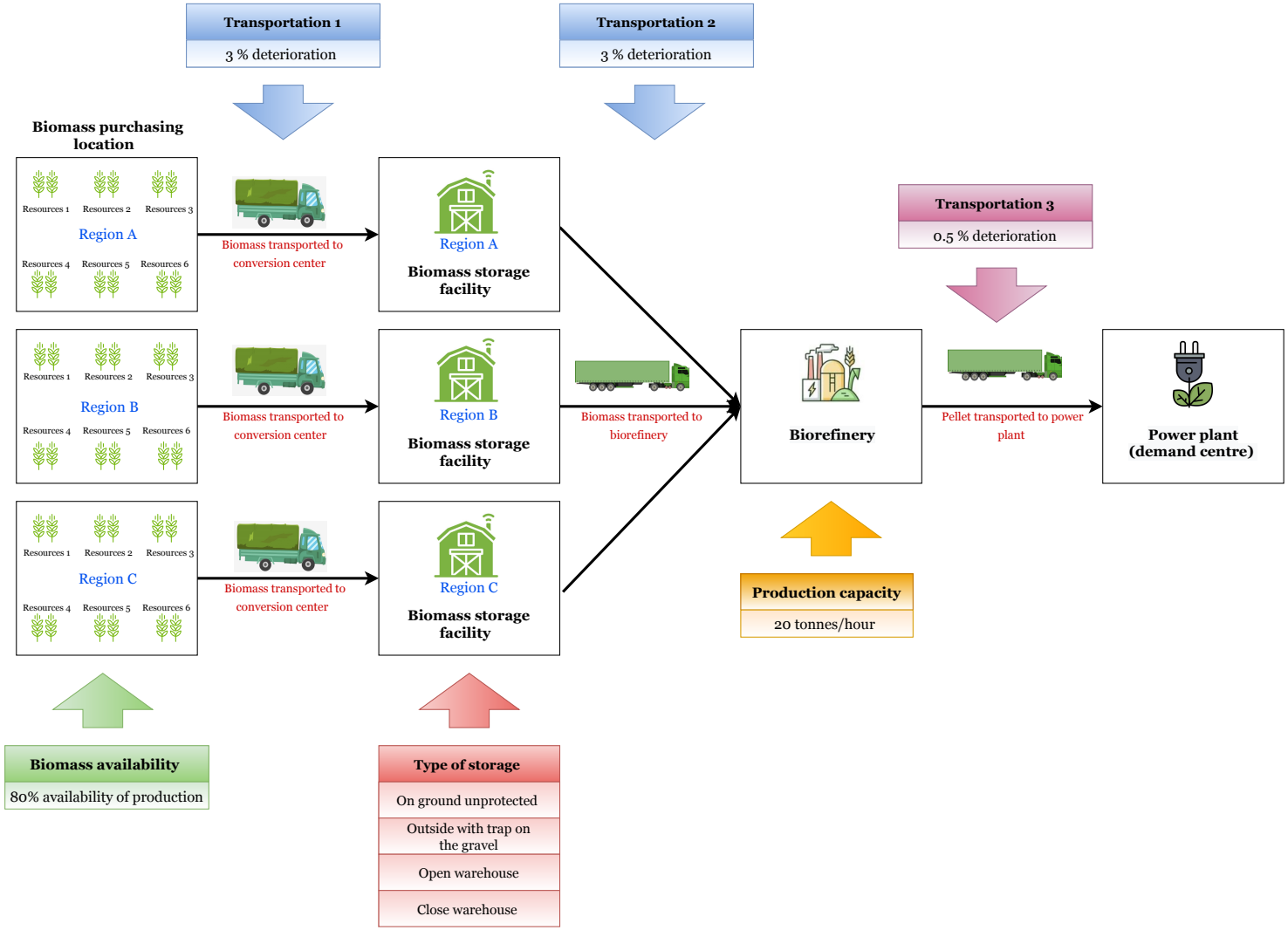
permanent covered by the outside with a trap on the gravel, and (iv) uncovered or unprotected ground. The details of the storage conditions are listed in Table VI-2, and the superstructure of the base scenario is shown in Figure VI-3.

Table VI-2. Characteristics of the various storage types

Storage Type		Advantages	Disadvantages	Life span	Losses material
Solid cover	Closed warehouse - permanent storage structure which iron roof, enclosed all sides, concentrated floor, and foundation	Lowest dry mater losses (less than 5%), and full protection from weather (rain, sunlight, and bleaching)	Highest capital cost, highest operational cost, poor air ventilation, and straw has to be transported and handled to and from the shed	20 years	2%
	Open warehouse - permanent storage structure which iron roof and all side open with pole frame structure	Lower dry mater losses (less than 10%), good ventilation, and simple structure	High capital cost, straw protection from the wind and rain need additional cover, and straw has to be transported and handled to and from the shed	20 years	5%
Semi-permanent cover	Outside with trap on the gravel	Lower dry matter losses than uncovered stacks, quick and simple to install, and easy to relocated	Wind can affect security of the cover, rainfall can collect on the cover, and UV exposure and birds can decrease life span	5 years	7%
Uncovered	On ground unprotected	Simple and low capital and operational cost	Highest straw losses (over 25%), higher rates of straw spoilage due to the weather	Highly variable depending on the climate and site maintenance	15%

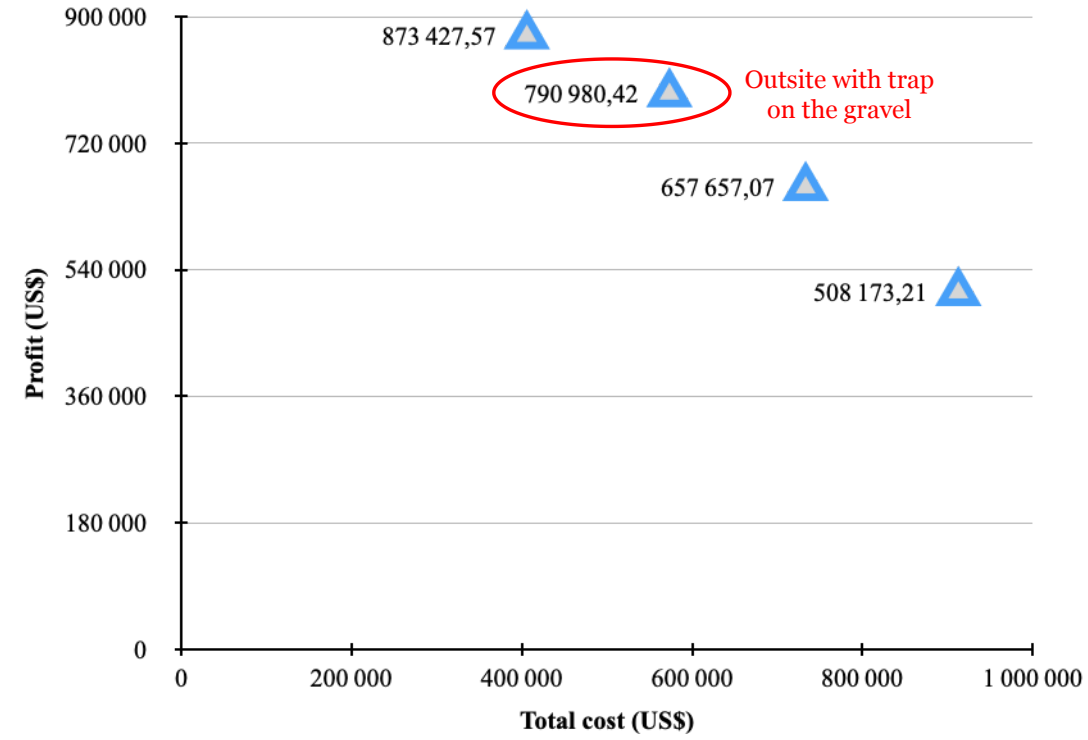

Biomass purchasing location
Resources 1
Resources 2
Resources 3
Region A
Resources 4
Resources 5
Resources 6
Region B
Region C
Transportation 1
3 % deterioration
Type of storage
On ground unprotected
Outside with trap on the gravel
Open warehouse
Close warehouse
Transportation 2
0.5 % deterioration
Biomass transformed to pellet
Biomass storage facility
Biorefinery
Biomass transported to conversion center
Pellet transported to power plant
Power plant (demand centre)
Production capacity
20 tonnes/hour
Biomass availability
80% availability of production

(a)

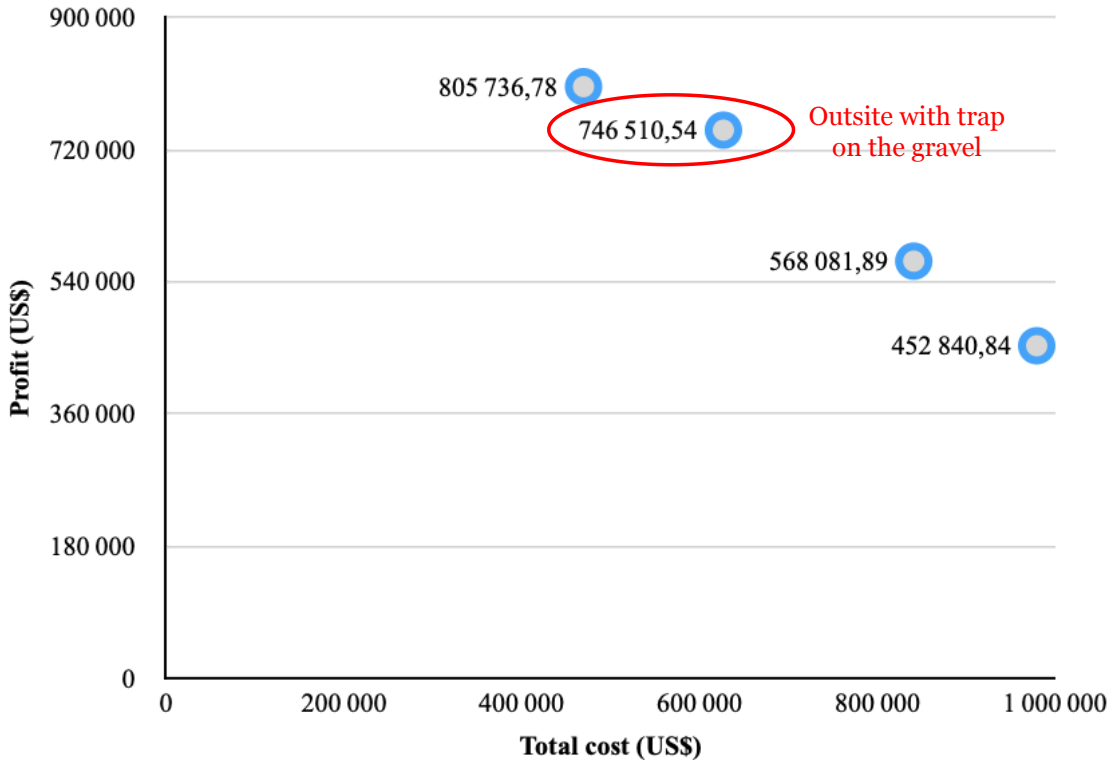


(b)

Figure VI-3. Model superstructure for the scenarios: (a) Centralized and (b) Decentralized



(a)



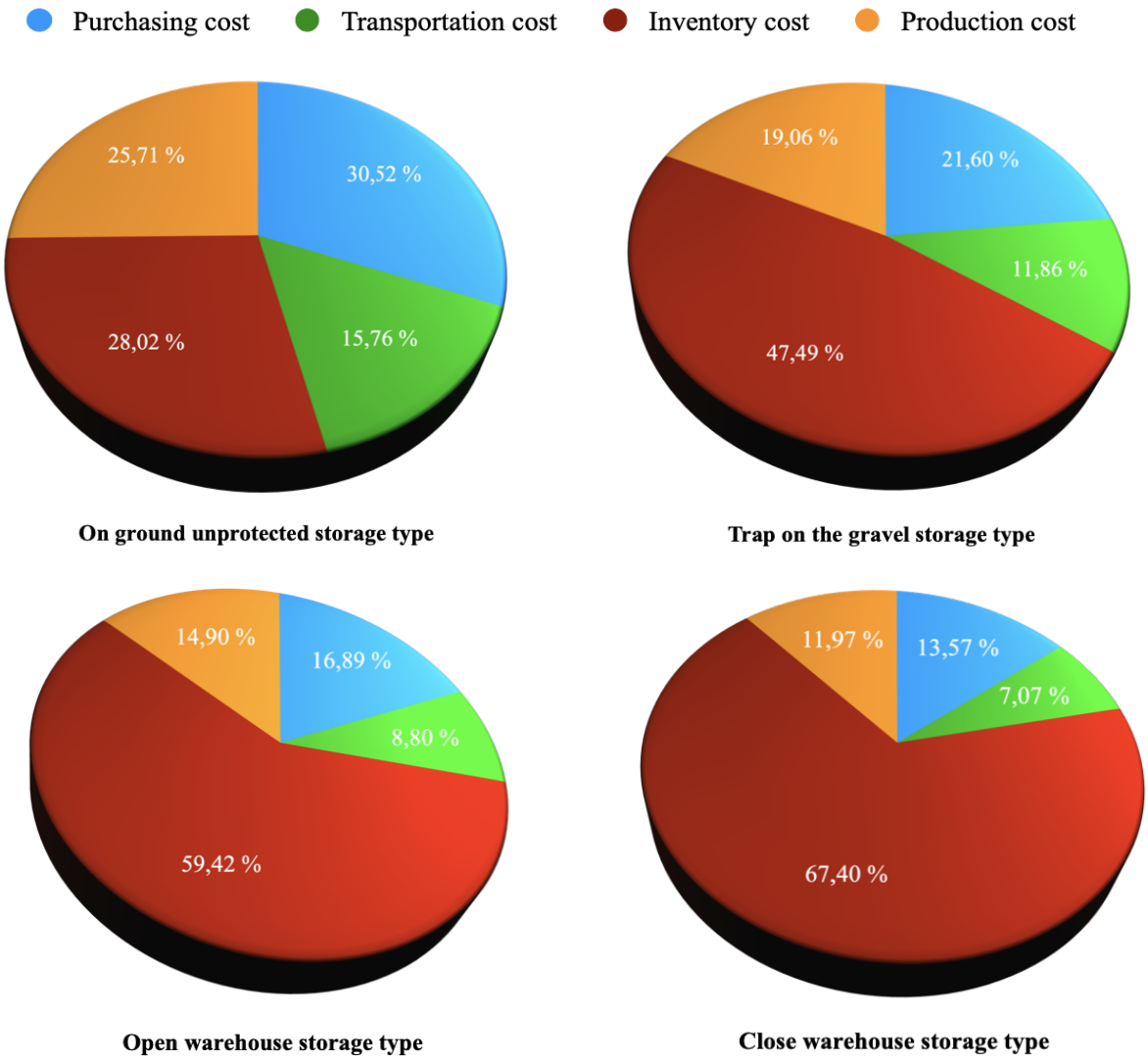
(b)

Figure VI-4. The optimization model results based on the various storage types for types for the scenarios: (a) Centralized and (b) Decentralized

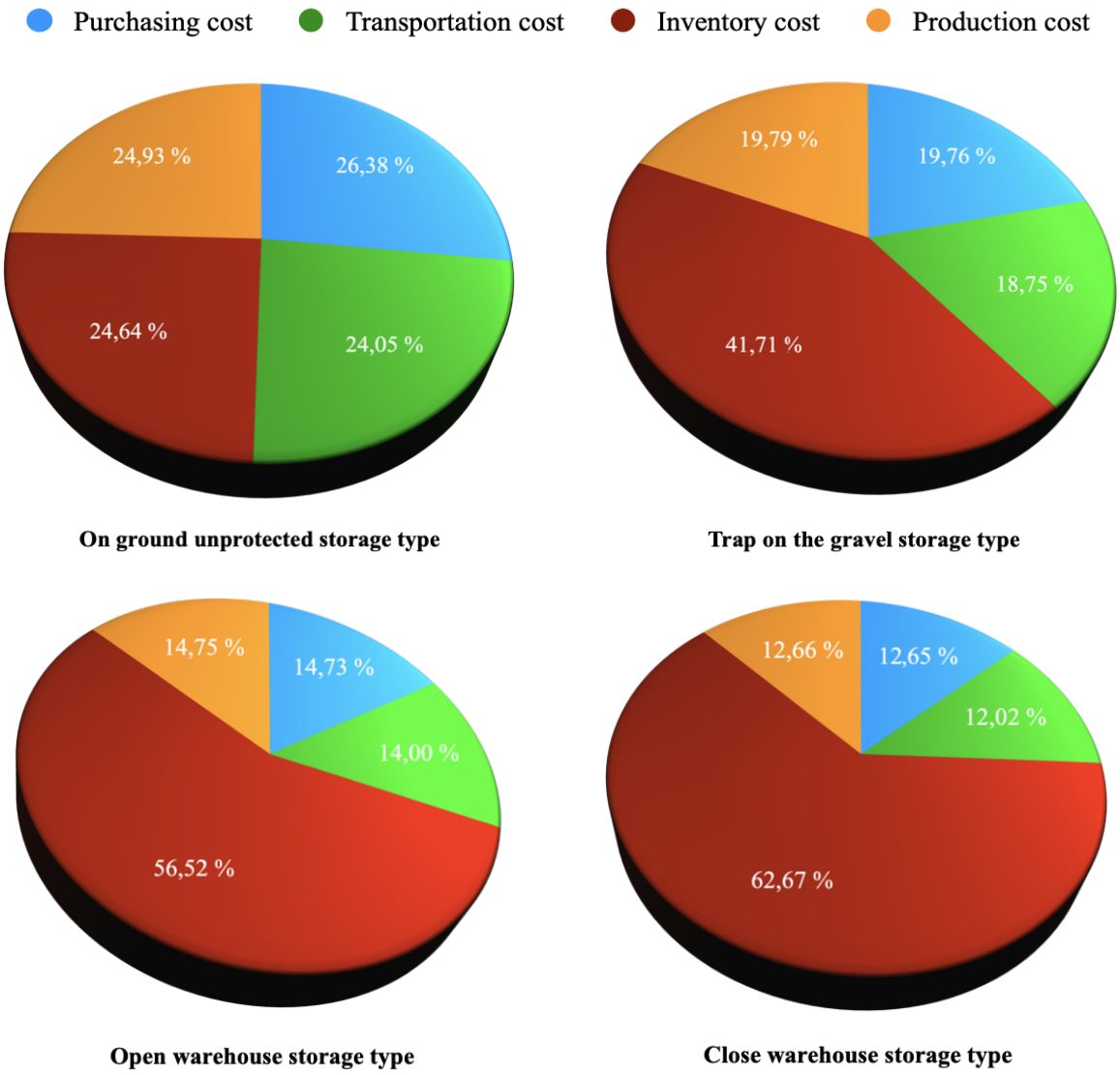
The results of the model based on various storage types are shown in Figure VI-4. Compared to other types, the model's optimum rice straw storage is achieved using a semi-permanent cover

storage type, that is, outside with a trap on the gravel. Its application leads to a significant cost reduction for inventory (i.e., biomass handling and storage) and minimalization of biomass material losses, which aims to save costs in BSC implementation. In this study, the results are contrasted with the proposed multi-agriculture biomass approach; the result indicates that the expensive storage solution (i.e., open and closed warehouses) can be applied to anticipate the storage space and loss problems, which are caused by the biomass moisture content and durability(Rentizelas et al., 2009).

In this view of economics, the revenue generated by the various storage types was around US$1.5 million per month, with 20 tonnes of production per hour for both the centralized and decentralized scenarios. The profit of the semi-permanent covered storage type was approximately US$0.7 million per month, which was higher by 17% and 36% than an open and closed warehouse and 10% lower than on-ground unprotected storage in the centralized scenario. This is 13% higher than the decentralized scenario implemented simultaneously. Significant differences existed in the total cost of each storage type for both scenarios. The closed warehouse storage type required a two-fold increase in total cost compared to the on-ground, unprotected storage type. Moreover, a covered storage facility with a pole-frame structure and a metal roof, for example, an open and closed warehouse, must account for more than 50% of the total operational cost. While the on-ground, unprotected storage type required 28% of the total inventory cost, storage losses do not involve special handling. As a result, quality degradation, higher biomass losses, and dangerous fire or microbe formation occur during inventory and affect pellet production. In conclusion, the total cost of the centralized scenario was 5% lower than that of the decentralized scenario, in which inventory costs accounted for over 25% of the total cost in all scenarios. Inventory costs encompass approximately 45.11% of the total cost, which is relatively higher than that in our study (Akhtari et al., 2014). Figure VI-5 shows the different cost components of the various storage types.


Purchasing cost
Transportation cost
Inventory cost
Production cost
25,71 %
30,52 %
28,02 %
15,76 %
On ground unprotected storage type
19,06 %
21,60 %
11,86 %
47,49 %
Trap on the gravel storage type
14,90 %
16,89 %
8,80 %
59,42 %
Open warehouse storage type
11,97 %
13,57 %
7,07 %
67,40 %
Close warehouse storage type

(a)

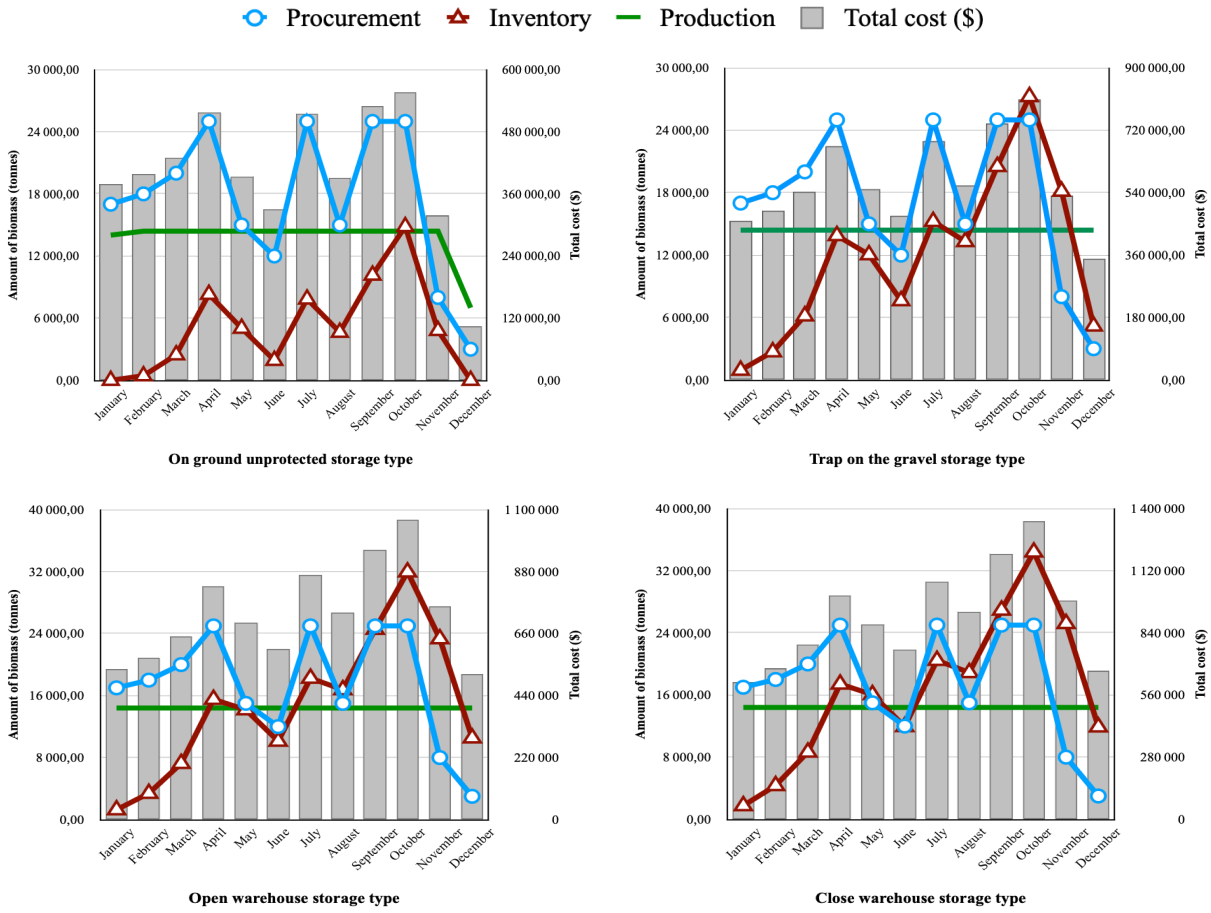


(b)

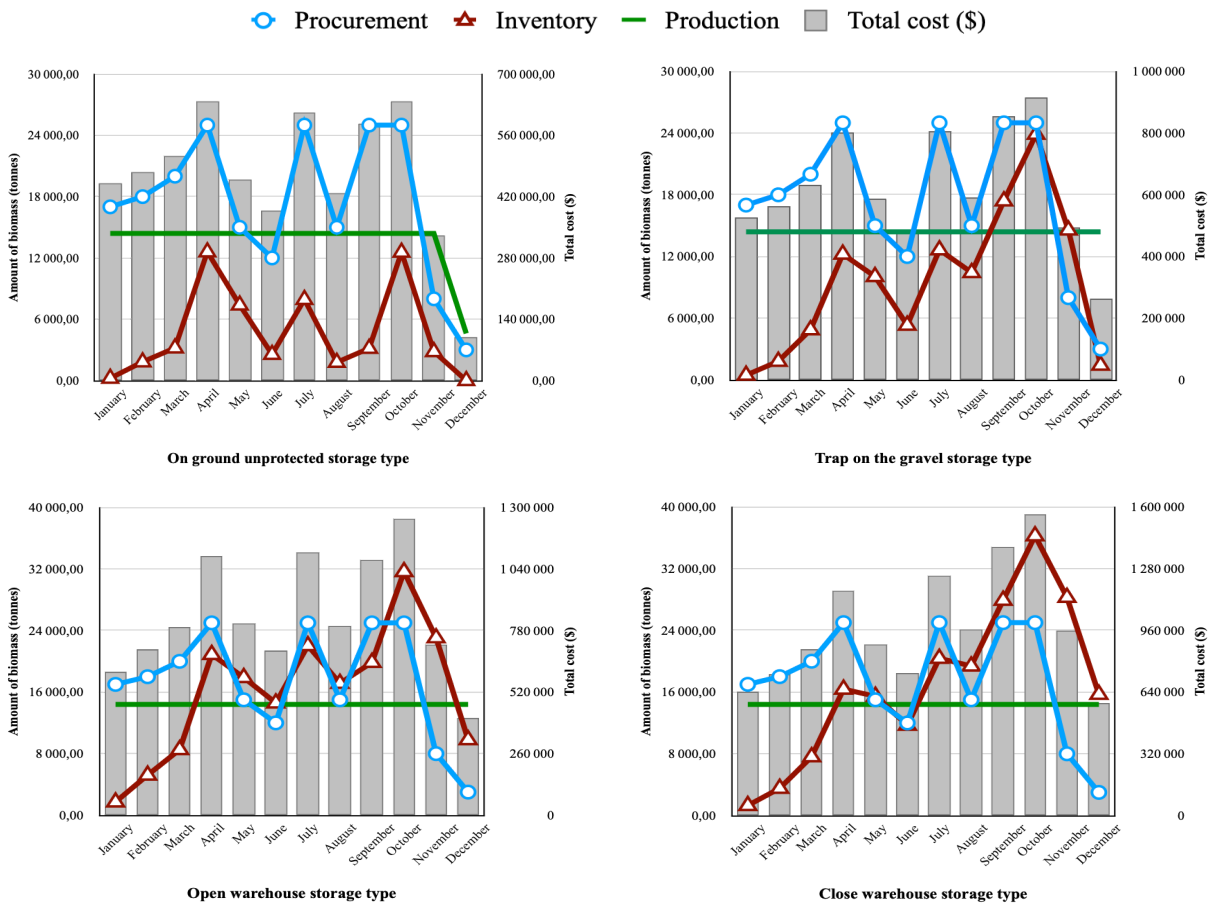
Figure VI-5. Total operational cost based on the various storage types for the scenarios: (a) Centralized and (b) Decentralized

Figure VI-6 shows the optimum feedstock availability per month. The bar graph represents the operational monthly cost measured by calculating procurement, inventory, and production quantities at different times. The total cost in October was higher than in other months for both scenarios. Moreover, in the closed warehouse, the total cost reached nearly US$1.4 million for the decentralized scenario and US$1.3 million for the centralized scenario. The profit is negative because the revenue is 10% lower than the total cost. Furthermore, the blue line indicates biomass procurement, whose initial amount was 18,000 tonnes; after reducing production, the profile inventory was less than 1,000 tonnes depending on the storage type. The optimum storage profile gradually increased until April and then decreased until August. The maximum amount reached 25,000 tonnes in April, July, September, and October, which followed the rice-harvesting season in Tuban for both scenarios. Before the weather turns rainy and rice harvesting becomes uncertain,

it is worth noting that the peak of inventory in October was one and a half times the raw production materials for the three storage types (except on-ground, unprotected storage). As a result, an increase in inventory is required to maintain feedstock sustainability in November and December during the high-rain season. Because the harvesting time and area are limited, the inventory stock must be sufficient to meet the production demand of nearly 14,000 tonnes per month. However, biomass is purchased for only a quarter to half of the production capacity. Hence, the planning of inventory sustainability is needed to minimize the operational cost by noticing the investment cost and loss problems during storage. The availability of storage space should be noted due to the fact that it is correlated to the economic cost. An estimated 1% of the cultivation area should be provided to stock rice straw by considering weather conditions and technical factors (Kadam et al., 2000).



(a)



(b)

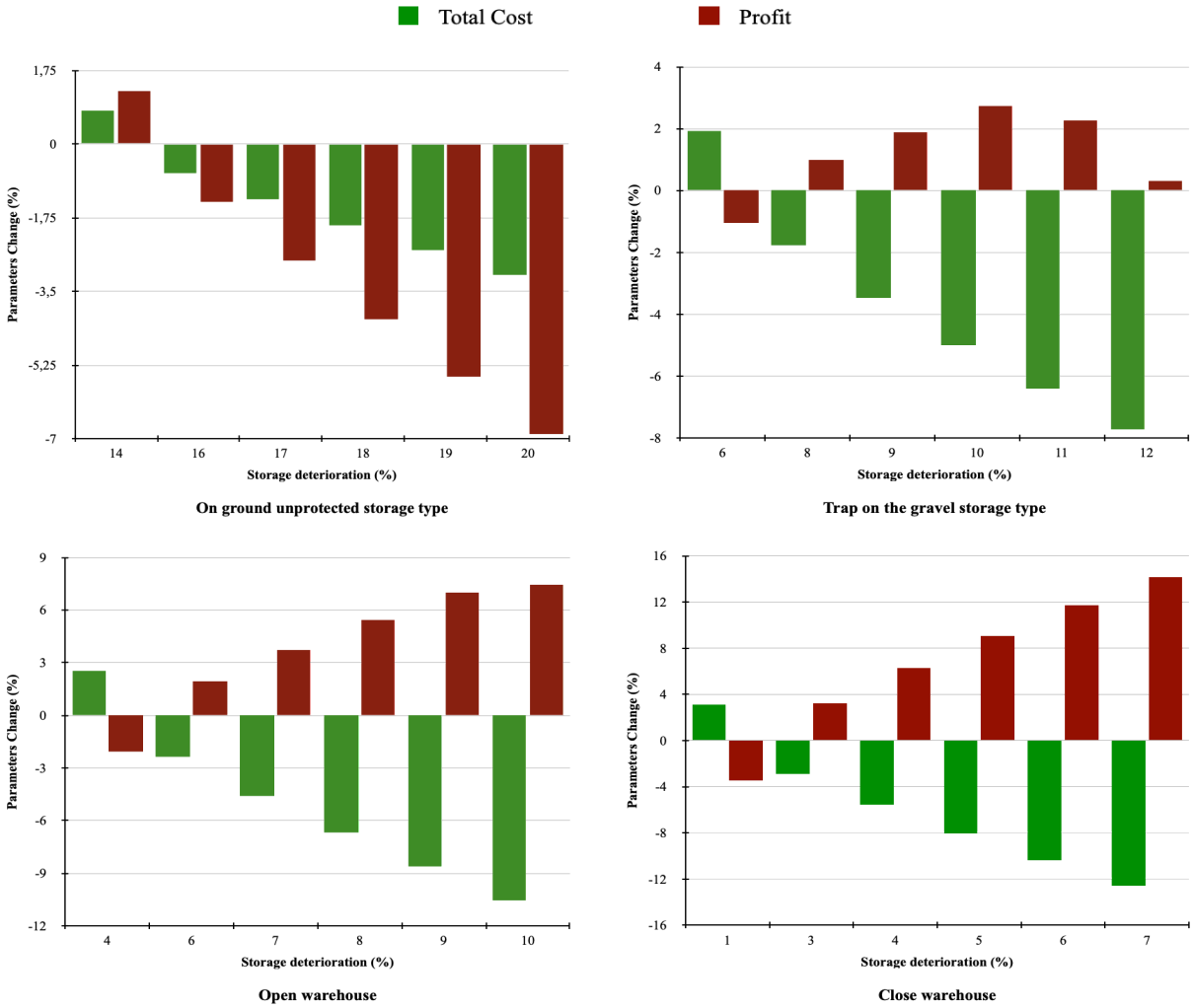
Figure VI-6. An optimum amount of the biomass procurement, inventory and production in each month based on the various storage types for the scenarios: (a) Centralized and (b) Decentralized

4.2.1. Sensitivity analysis

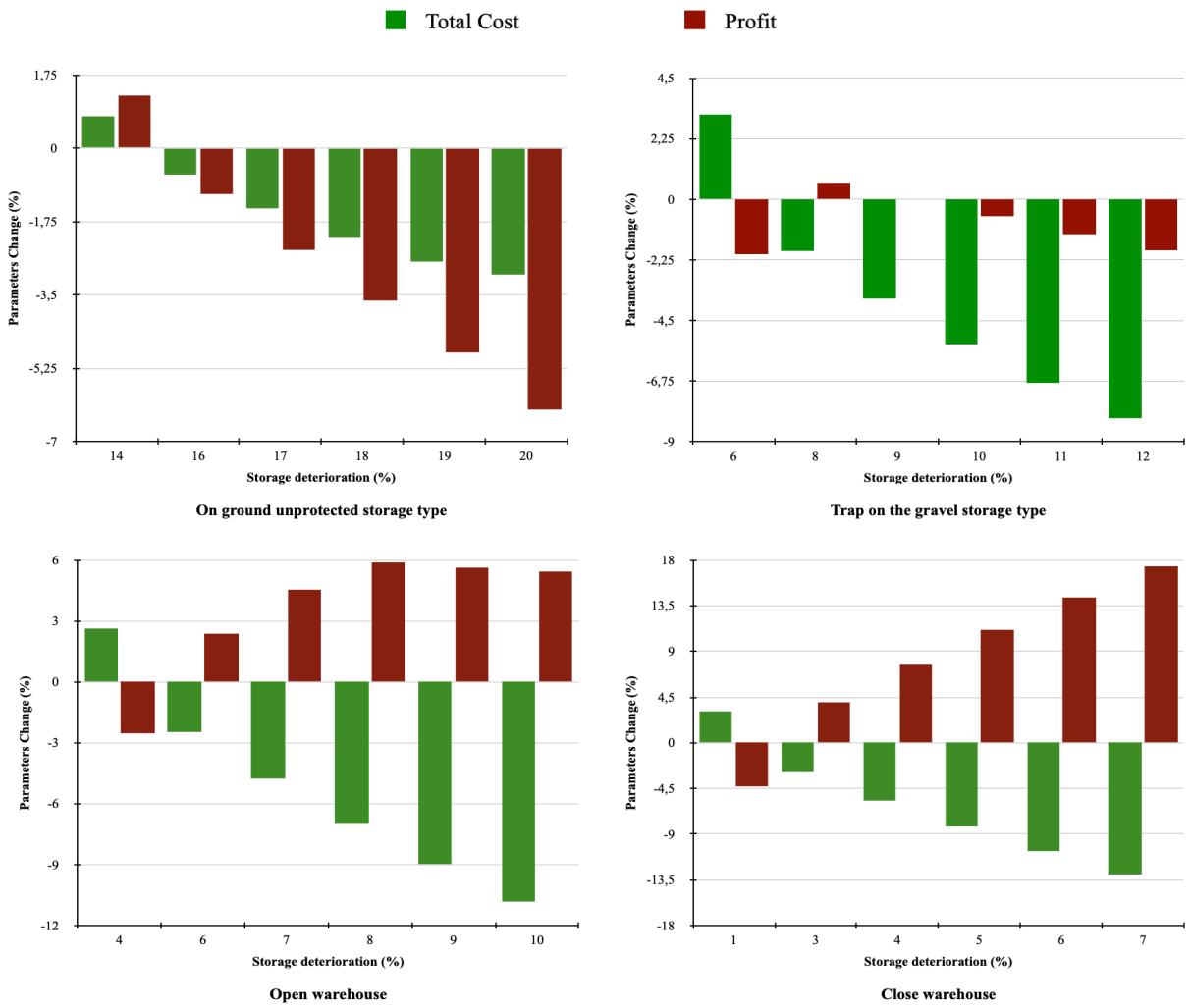
This part investigated the sensitivity analysis to discover the impact on the optimum total cost and profit when a parameter of storage deterioration is changed. Figure VI-7 shows the correlation between the economic feasibility and various storage deteriorations.

Figure VI-7 depicts the connection between the total cost and profit and various storage deteriorations ranging from -1 to +5 of the set deterioration value, as shown in Table VI-2. This indicates that material flow significantly correlates with inventory and production costs, which greatly impacts economic feasibility. The green bar graph indicates the total cost, which significantly decreases when the storage deterioration is higher than the scenario value. Furthermore, the red bar indicates profit, which significantly influences the storage type and distribution network model. Applying the distribution model of the centralized scenario to on-ground unprotected storage, the profit continues to decrease when the storage deterioration is higher than that in the scenario (15%). In contrast, other storage types have increased profits along with changes in deterioration values. It can be concluded that the maximum deterioration storage was 15% by implementing the on-ground unprotected storage type; in contrast, the other storage

types did not significantly influence economic feasibility. However, implementing the trap on the gravel storage type by 12% of deterioration increased the profit at a minimal value by approximately US$ 2,600. It can be noticed that its deterioration value is an absolute limit to maintaining the economic feasibility of rice straw valorization in this case.



(a)



(b)

Figure VI-7. Effect of storage deterioration for economic feasibility based on the scenarios: (a) Centralized and (b) Decentralized

Implementing the decentralized scenario distribution model shows a significant decrease in the total cost and profit for the storage types of on-ground unprotected and trap on gravel. This result is the opposite of that of storage in open and closed warehouses. Therefore, the maximum storage deterioration in this distribution scenario was 9% to comply with the economic feasibility, which was influenced by the inventory level and decreased by approximately 22%. There is a highlighted point when the storage of rice straw by the trap on the gravel method resulted in zero inventory in December when the deterioration storage was 8% and started from 10%; it was a similar condition in January due to the highly rainy weather conditions that will affect rice straw availability. In this case, in all scenarios of the distribution model and storage types, the highest and lowest total costs occurred in October and December, respectively. The distribution of material flows on procurement, inventory, and pellet production is correlated to the economic feasibility found in *Appendix I*.

4.3. Scenario analysis

The availability of feedstock, categorized as active and passive resources, plays a vital role in the biomass supply chain. The active category is characterized by some conditions, i.e., (1) low price of biomass due to its association with the collecting cost; and (2) low competition of biomass for other applications (e.g., feeds and industry raw materials) due to its correlation to feedstock availability. These situations must involve cross-sector participation and all stakeholders; for instance, the government issued the policies and regulations as the guidelines for efficiency and competition of resources through assessing the potential and balance of biomass in each region. The creation of incentives and financial support, market strategies, and logistical infrastructure should be prepared to support the sustainability of the supply chain. Raising awareness and the willingness of farmers and communities to utilize biomass waste is essential to changing their mindset, which is necessary for creating new jobs in the bioenergy field. Our previous study discovered that nearly 75% of rice residue is burned in the field to save time and money before the next planting. Therefore, it can be a sustainable feedstock in pellet production due to its abundance at the time. Contrarily, the passive category can be reflected by (1) the high price of biomass purchasing; (2) the intense competition of biomass application with other purposes; (3) the lack of stakeholder awareness and participation; and (4) the lack of policy and regulation that govern a unified framework and attractive supporting systems of biomass residue utilization. This situation is called resource efficiency, and low-quantity feedstock can be used as bioenergy materials. Finally, abundant raw material implies high biomass availability (approximately 75%), whereas moderate and low feedstocks, had 50% and 25% biomass availability, respectively.

It is highlighted that rural development through the community empowerment model is an opportunity to improve economic, social, and environmental qualities. Moreover, it includes the context of bioenergy development, which is crucial in mitigating climate change, and the biomass supply chain in all sectors to realize sustainable development goals. Furthermore, centralized and decentralized distribution models can be considered in active and passive conditions by considering the awareness and willingness of the stakeholders, which were obtained from the survey in the previous study. In conclusion, the six scenarios are applied to show the economic viability and set the amount of sustainable feedstock as shown in Figure VI-8. A centralized and decentralized distribution model has also been applied to determine the optimum result, considering the various biomass availability and production capacity as shown in Figure 6-8.

1. Scenario 1 (HC): the abundant biomass feedstock (75% of biomass availability) and the distributed storage model were centralized (high-centralized scenario, or HC);
2. Scenario 2 (MC): the moderate biomass availability (50% of biomass availability) and the distributed storage model were centralized (moderate-centralized, or MC);
3. Scenario 3 (LC): The feedstock efficiency (25% of available biomass) and the distributed storage model were centralized (low-centralized, or LC);

4. Scenario 4 (HD): the abundant biomass feedstock (75% of biomass availability) and the distributed storage model were decentralized (highly decentralized scenario, or HD);
5. Scenario 5 (MD): the moderate biomass availability (50% of biomass availability) and the distributed storage model were decentralized (moderate-decentralized, or MD);
6. Scenario 6 (LD): the feedstock efficiency (25% of biomass availability) and the distributed storage model were decentralized (low-decentralized, or LD).

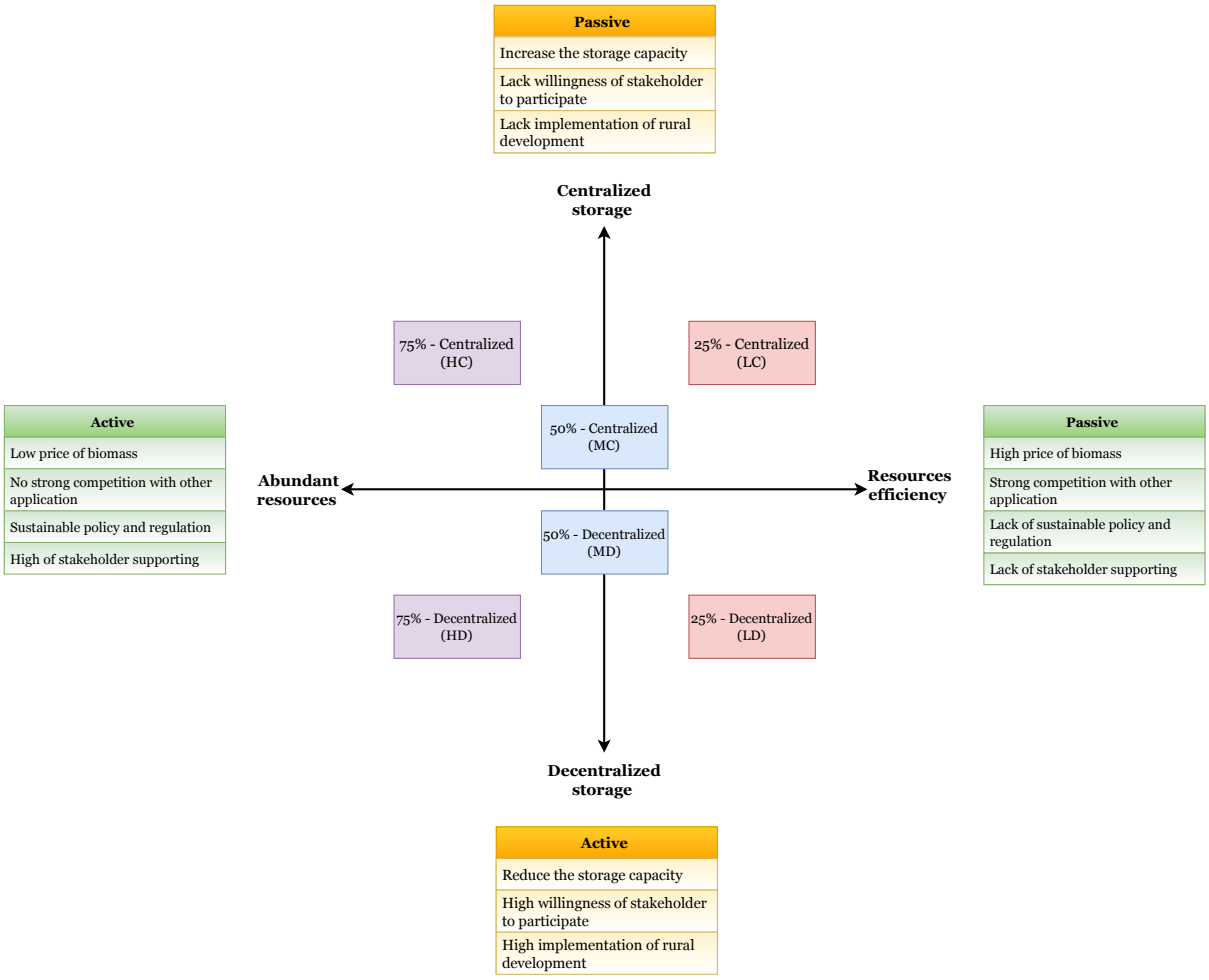
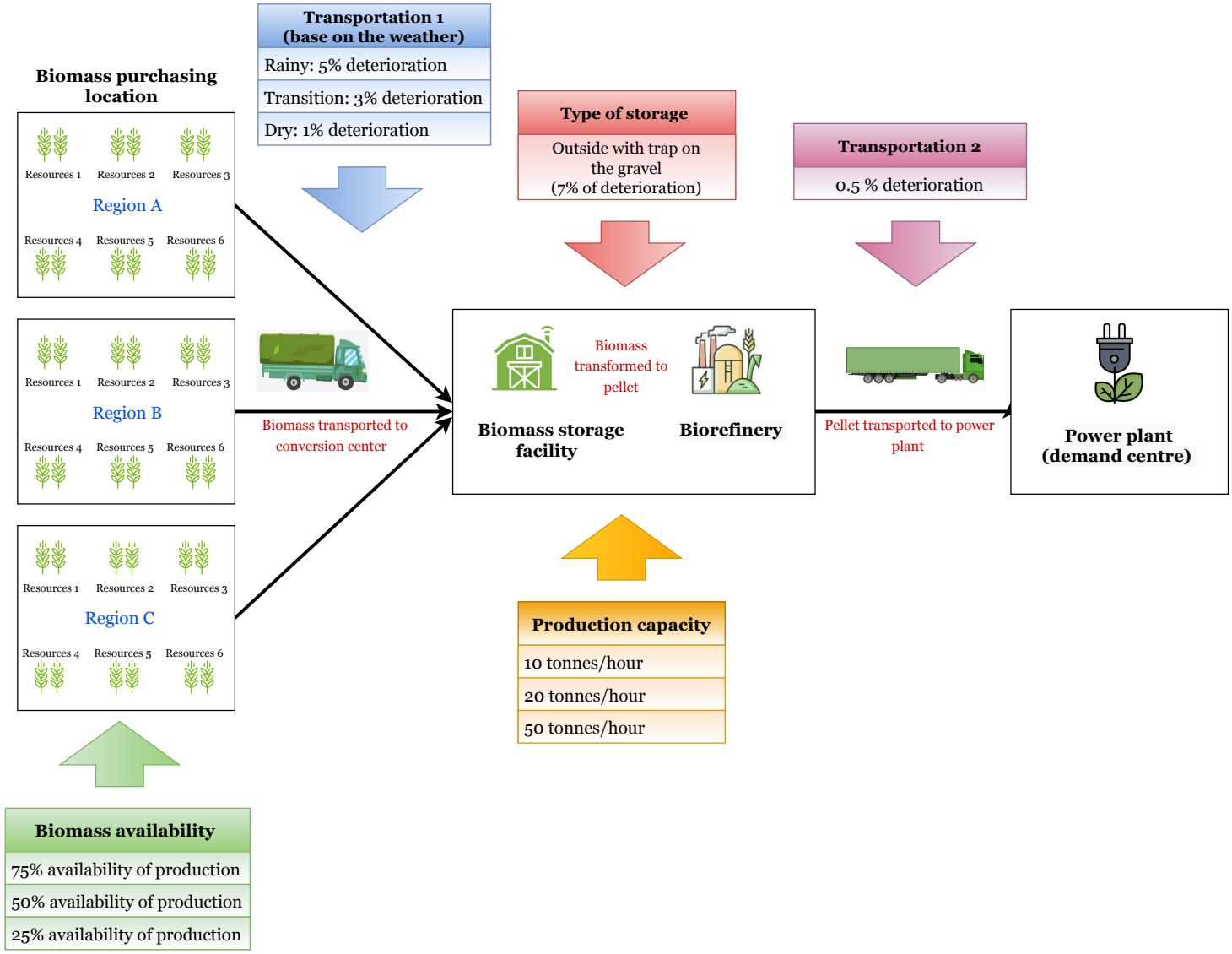
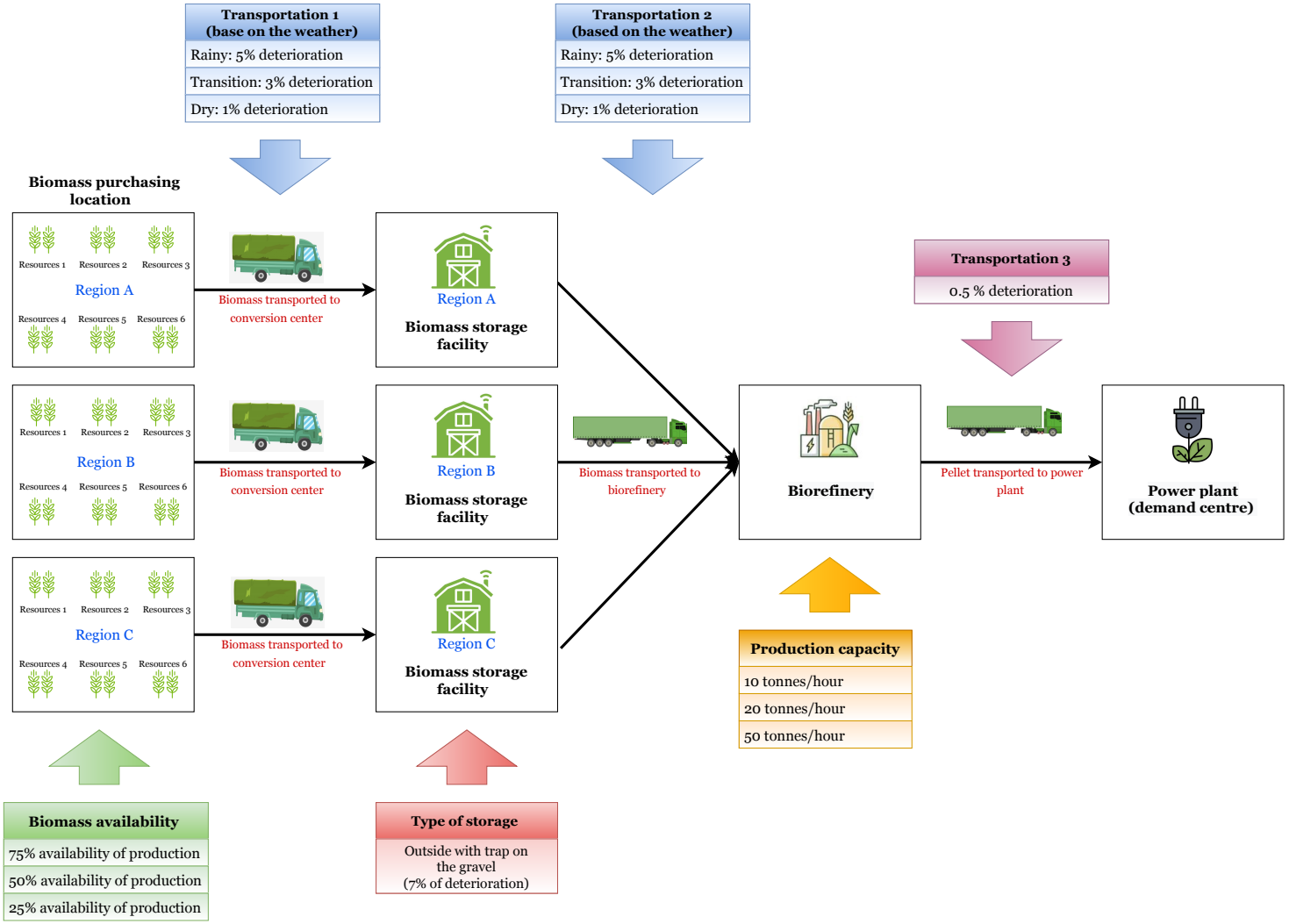


Figure VI-8. Scenario model to evaluate economic viability


Transportation 1
(base on the weather)
Rainy: 5% deterioration
Transition: 3% deterioration
Dry: 1% deterioration
Biomass purchasing location
Resources 1
Resources 2
Resources 3
Region A
Resources 4
Resources 5
Resources 6
Region B
Region C
Type of storage
Outside with trap on the gravel
(7% of deterioration)
Transportation 2
0.5 % deterioration
Biomass transported to conversion center
Biomass transformed to pellet
Biomass storage facility
Biorefinery
Pellet transported to power plant
Power plant
(demand centre)
Production capacity
10 tonnes/hour
20 tonnes/hour
50 tonnes/hour
Biomass availability
75% availability of production
50% availability of production
25% availability of production

(a)



(b)

Figure VI-9. Model superstructure of scenario analysis for the distribution model: (a) Centralized and (b) Decentralized

Figure VI-10 depicts the total profit and total cost for different scenarios. The various production capacities (i.e., 10, 20, and 50 tonnes per hour) are applied to assess the economic viability. The results show that changing the production capacity has a significant impact on the total cost and profit in each scenario. The production capacity of 10 tonnes per hour requires 7,200 tonnes of biomass per month to produce approximately 6,800 tonnes of pellets, earning nearly $0.8 million in all scenarios. When the decentralized distribution model was applied, it had a lower profit, approximately 28.04%, whereas the total cost was higher, at 47.98% than the centralized model. In all scenarios, over 45% of the total cost was utilized for inventory, while production spent less than 20%. Furthermore, at 20 tonnes of production capacity, scenarios LC and DC have a lower 2.45% of revenue (US$1.4 M) than other scenarios because the biomass feedstock is lower than 2.75% of the production target of approximately 14,400 tonnes per month. There was a 12% difference in profit between the centralized and decentralized models. Most decentralized models had a profit of around $0.7 million, while the total profit of the centralized model was over $0.75 million. The total cost was 22% less than the decentralized model ($ 0.13 million). However, up to 35% of the total cost was utilized as inventory and less than 20% as procurement and production costs. In contrast, decentralized models used more than 40% of the total cost for inventory and less than 15% for transportation costs. At a production capacity of 50 tonnes per hour, scenario LD has the lowest profit; it was lower by 9.54% (US$1.6 million) than scenario LC, while the total cost was higher by 13.94% (US$1.55 million). Scenario HC's highest revenue and profit were approximately US$3.8 million and US$2.05 million, respectively. It indicates that monthly production was the highest and total cost was the lowest compared to other scenario models. It did not reach its maximum production capacity of 36,000 metric tons per month, which is the proportion of biomass procurement and inventory cost that was 22 and 40% of the total cost, respectively. The reduction in profit partly arises from the increasing cost of inventory and transportation. In detail, the total operational cost for both distribution models are shown in the *Appendix J*.

Figure VI-11 shows the optimum amount of biomass feedstock per month. The bar graph presents the total monthly cost, which differs depending on the biomass collection and inventory, and its various scenarios have significantly different values. At 10 tonnes per hour of production capacity, the lowest total cost was in December, along with the decline of biomass procurement and inventory, which is less than 10% of the biomass remained on both distribution models despite the amounts of procurement and production being similar, reaching 8,533 and 7,200 tonnes, respectively. Although the maximum amount of biomass procurement (10,000 tons) is supplied in January to ensure feedstock availability before the seasons change, the amount of biomass storage is less than 30% of production capacity. It continues to rise until a peak in October, with Scenario LC having the highest inventory, approximately 20% of the maximum production capacity. Furthermore, biomass availability also influenced monthly supply; in scenarios LC and LD, the biomass procurement was obtained from three regions, i.e., Bojonegoro, Tuban, and Lamongan.

Whereas in other scenarios, biomass is only supplied from Tuban, considering the closer distance to the pellet factory and the availability of harvesting enough to meet the production demand during a year.

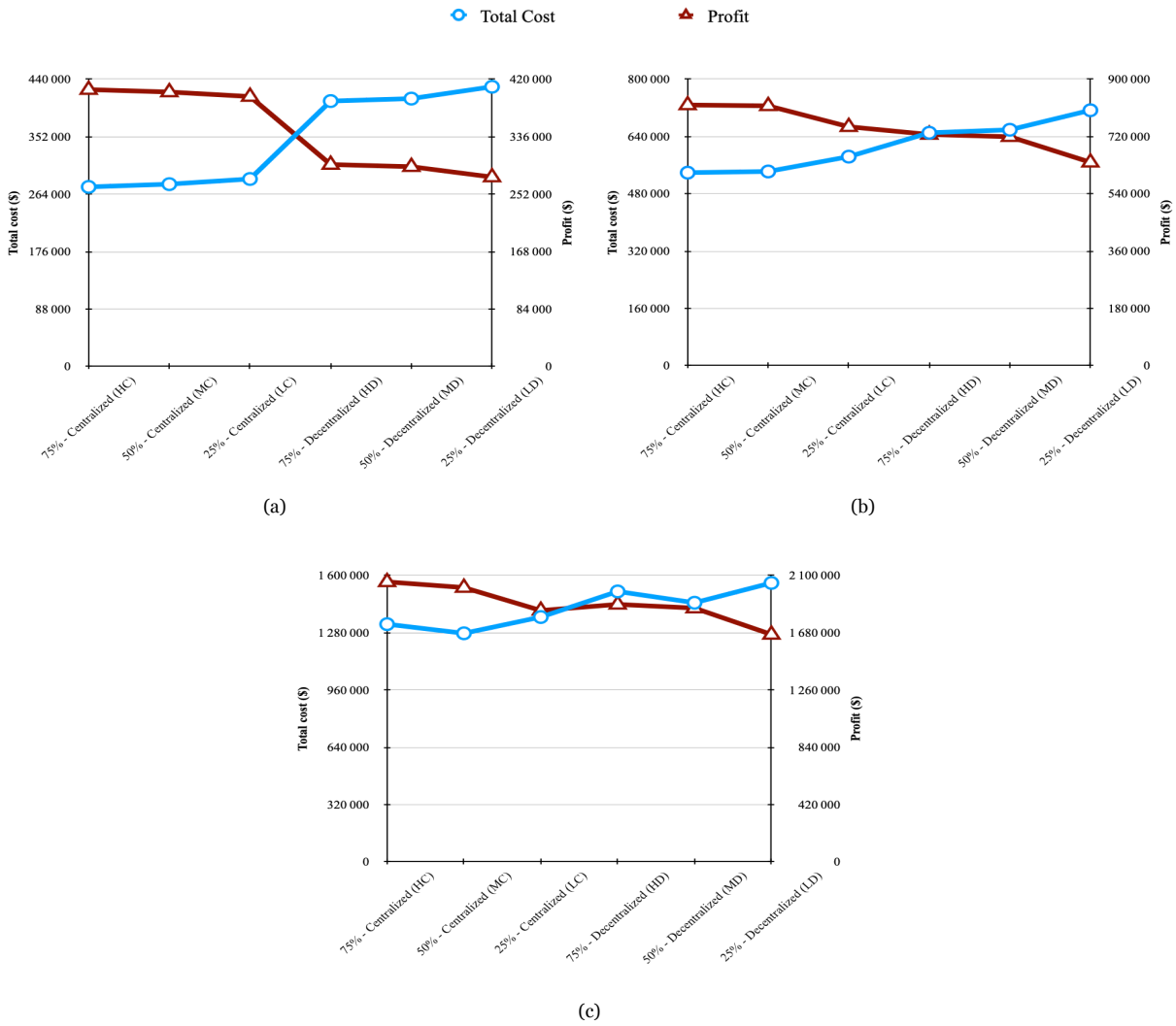


Figure VI-10. Comparison of total operational cost and profit in each the scenario analysis breaks down for the capacity production: (a) 10 tonnes per hour; (b) 20 tonnes per hour; and (c) 50 tonnes per hour

The optimal amount of biomass feedstock for a 20-ton-per-hour production capacity is shown in Figure VI-11(b). The monthly biomass procurement and production were approximately 17,000 and 14,000 tonnes for all scenarios, depending on availability. In the first quarter, the maximum biomass purchased in scenarios LC and LD was 20,000 tonnes, which is 30% lower than in other scenarios, and reached 30,000 tonnes in October. However, scenarios LC and LD had 50% biomass stock at the end of December, while in January, they had the lowest pellet production, around 30.55%, reaching 10,000 tonnes. Considering limited availability, the monthly biomass stock should reach 12,000 tonnes to reduce this problem. Moreover, it should be noted that harvesting occurs between March and April for the first time and between June and August for the second

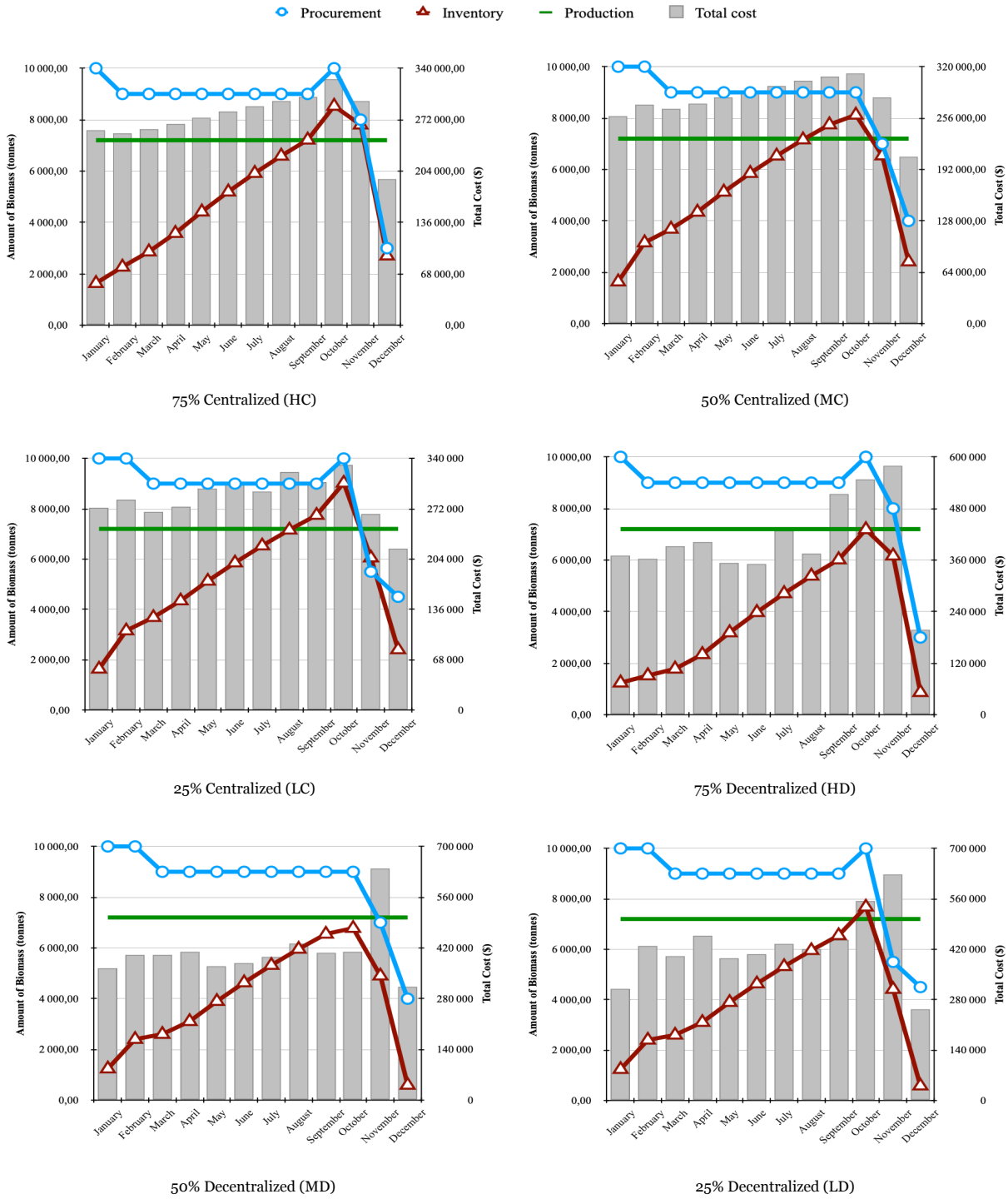
time; thereby, inventory planning is essential to maintaining production sustainability. At this point, Tuban could supply the product demand due to the abundant stock in HC and HD. In contrast, other scenarios were purchased from four regions, i.e., Bojonegoro, Tuban, Lamongan, and Ngawi. As a result, to obtain the optimum cost value, resource availability and the distance between resources and the processing unit should be considered to minimize the losses during distribution.

At the same time, the optimum amount of biomass feedstock for a 50-ton-per-hour production capacity shows that the maximum amount of biomass purchased was 60,000 tonnes in March and April during the harvesting season. The total stock inventory at the end of the month was 34,000 in April for the scenario LC, which impacts the increase in total cost (see Figure VI-10(c)). The total biomass procurement differs between scenarios HC and MC; HC and LC have a different amount of approximately 3.60% and 4.47%, respectively, as with the production. Due to the limited raw materials in January, the pellet production could not reach the target production of 36,000 tonnes per month. The maximum production was 96% and 29% for scenarios HC and LD, respectively. However, at the end of December, it can store approximately 10–30% of its biomass to supply the raw material demand for the following year.

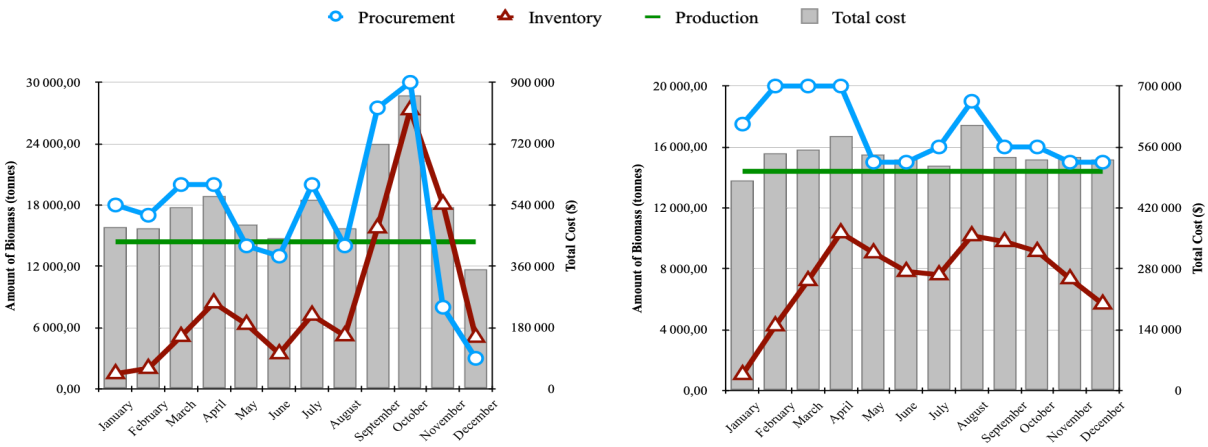
Based on the results, the profit of the centralized distribution model was 28, 13, and 8% higher than the profit of the decentralized model when the production capacity was 10, 20, and 50 tonnes per hour, respectively. A decentralized model suffers from high transportation costs due to biomass sites in several regions and long-distance locations from the site of biomass treatment. However, the centralized distribution model has more benefits in reducing biomass handling and treatment, although it requires high capital costs (de Jong et al., 2017a). The biomass supply chain could be considered a centralized system with integrated entities between collection sites, production facilities, and distribution facilities, all of which cooperate (Yue et al., 2014b). However, the competition of biomass (i.e., the availability, utilization, and price) and the limitation of information as a consideration led to the decision to shift the strategy to be more flexible and adaptable to reduce transportation and inventory costs (Mohammadi et al., 2021).

Furthermore, the availability of various feedstocks is critical in planning the continuity of monthly biomass stock. Maintaining the amount of biomass stock at around 30% of production capacity per month can meet production demand. For instance, scenario HC has a higher biomass stock than scenario HD, which reached 24, 28, and 31% when the production capacity is 10, 20, and 50 tonnes per hour. Decentralized models provide more impact on biomass deterioration during transportation, handling, and storage due to the complex system and will decrease profit. However, it benefits the social aspect, i.e., more decentralized facilities will create rural employment and additional income and jobs in local regions. More detail, providing a new job will increase opportunities for learning, training, and educating the community, improving the

meaningful information needed to contribute to energy security and reduce poverty (Mohammadi et al., 2021).

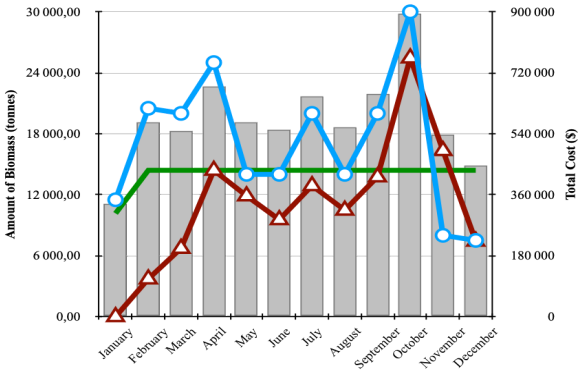


(a)

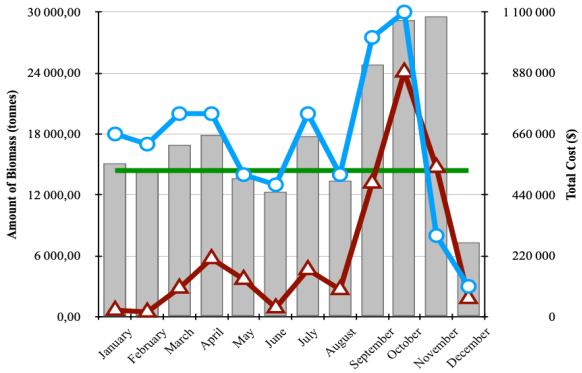


75% Centralized (HC)

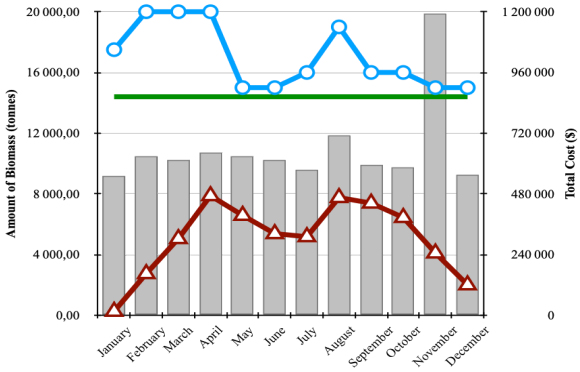
50% Centralized (MC)



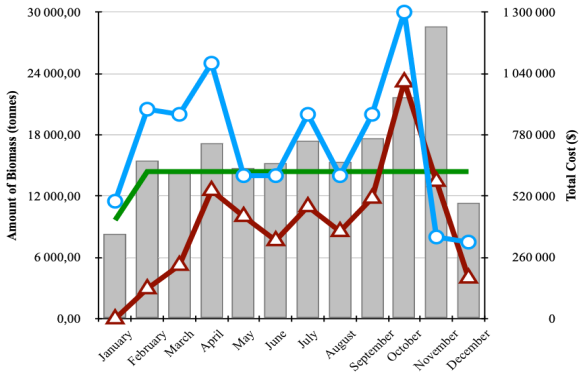
25% Centralized (LC)



75% Decentralized (HD)

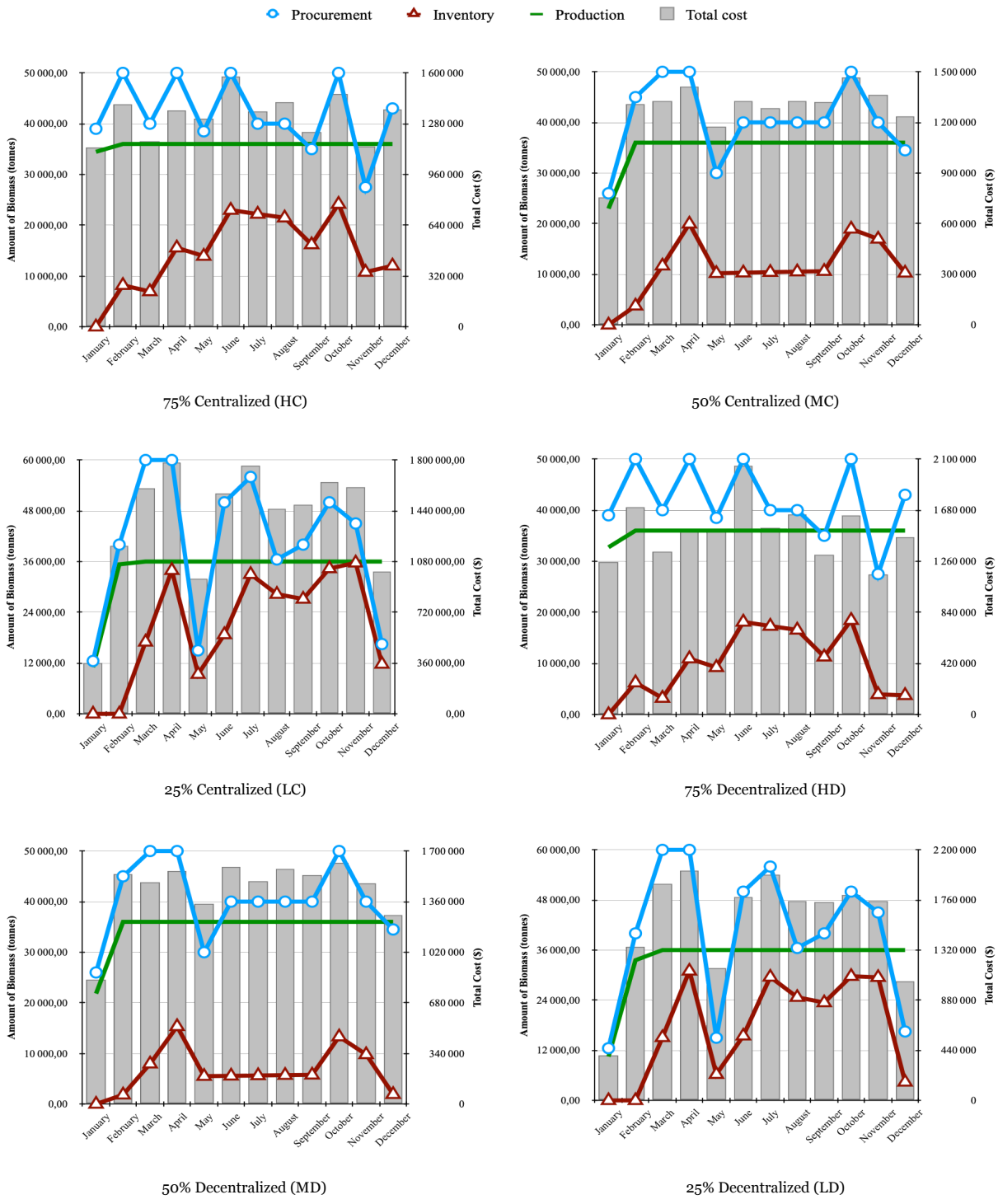


50% Decentralized (MD)



25% Decentralized (LD)

(b)



(c)

Figure VI-11. An optimum amount of the biomass procurement, inventory and production in each month based on the scenarios for the capacity production: (a) 10 tonnes per hour, (b) 20 tonnes per hour, and (c) 50 tonnes per hour

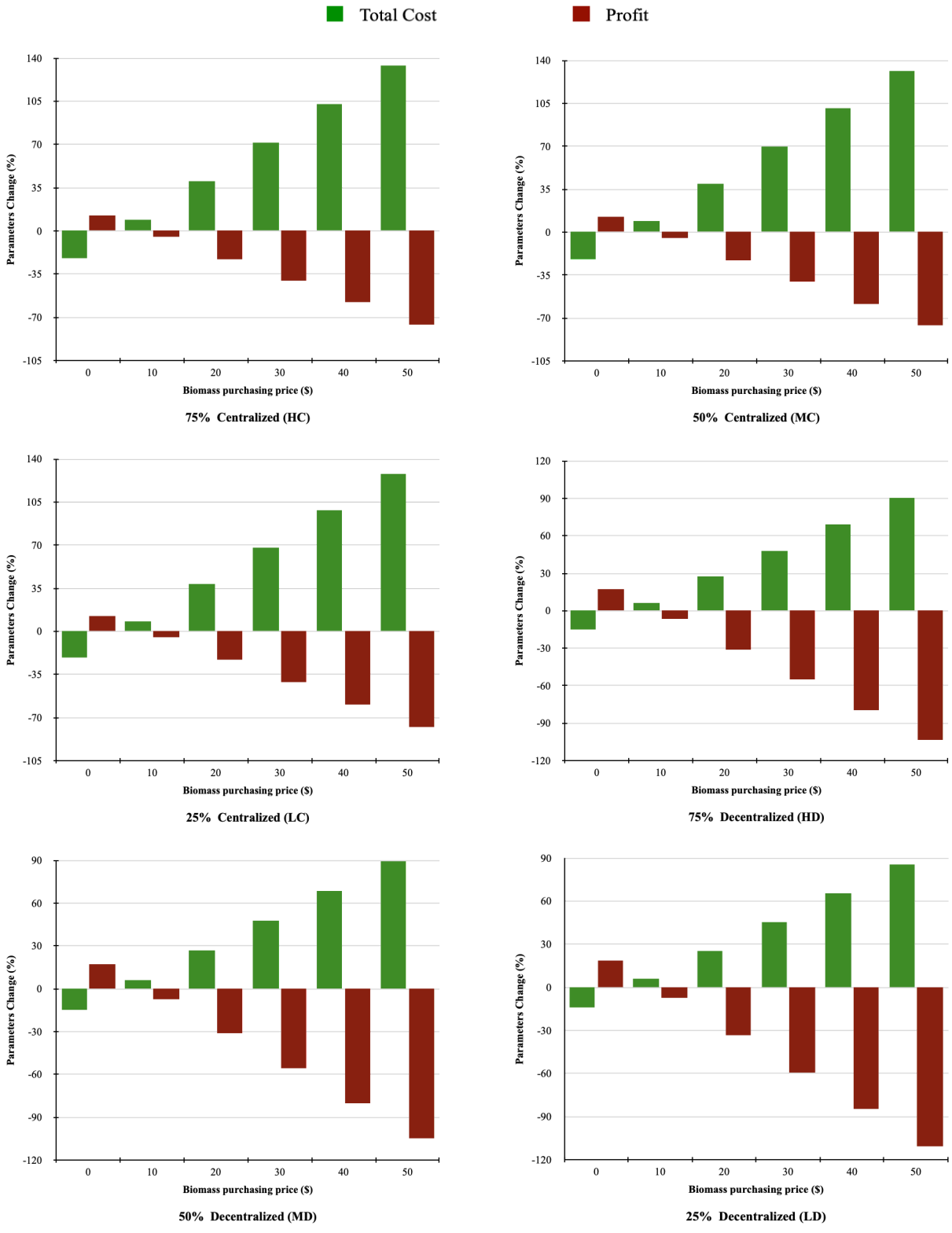
4.4. Sensitivity analysis

This section investigated the impact of some critical parameters, i.e., biomass purchasing price, and pellet production cost, due to their significant impact on operational cost. A sensitivity

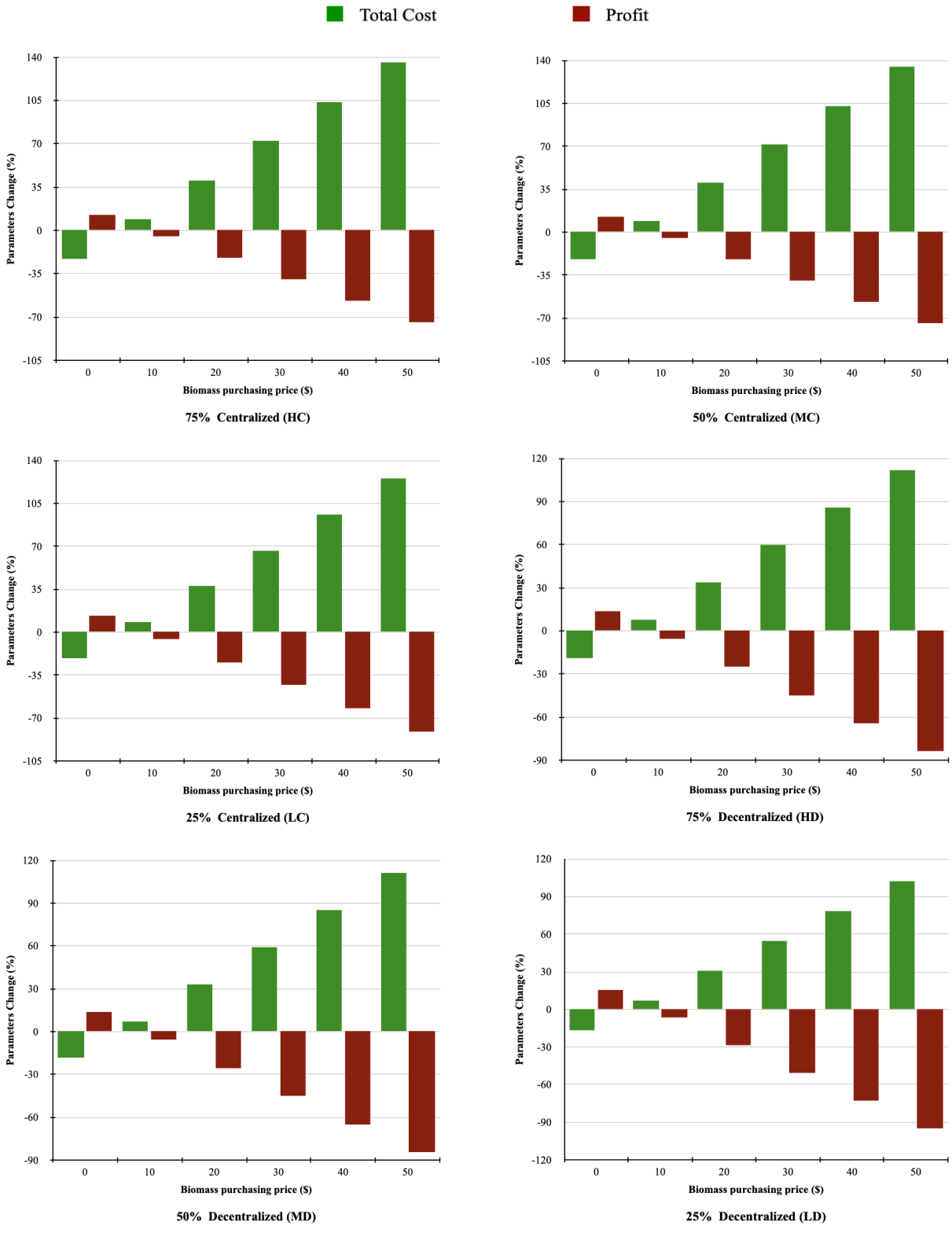
analysis is conducted to learn the impact of the total cost of the biomass supply chain when some parameters change, thereby discovering the optimum profit.

4.4.1. Sensitivity to biomass purchasing price

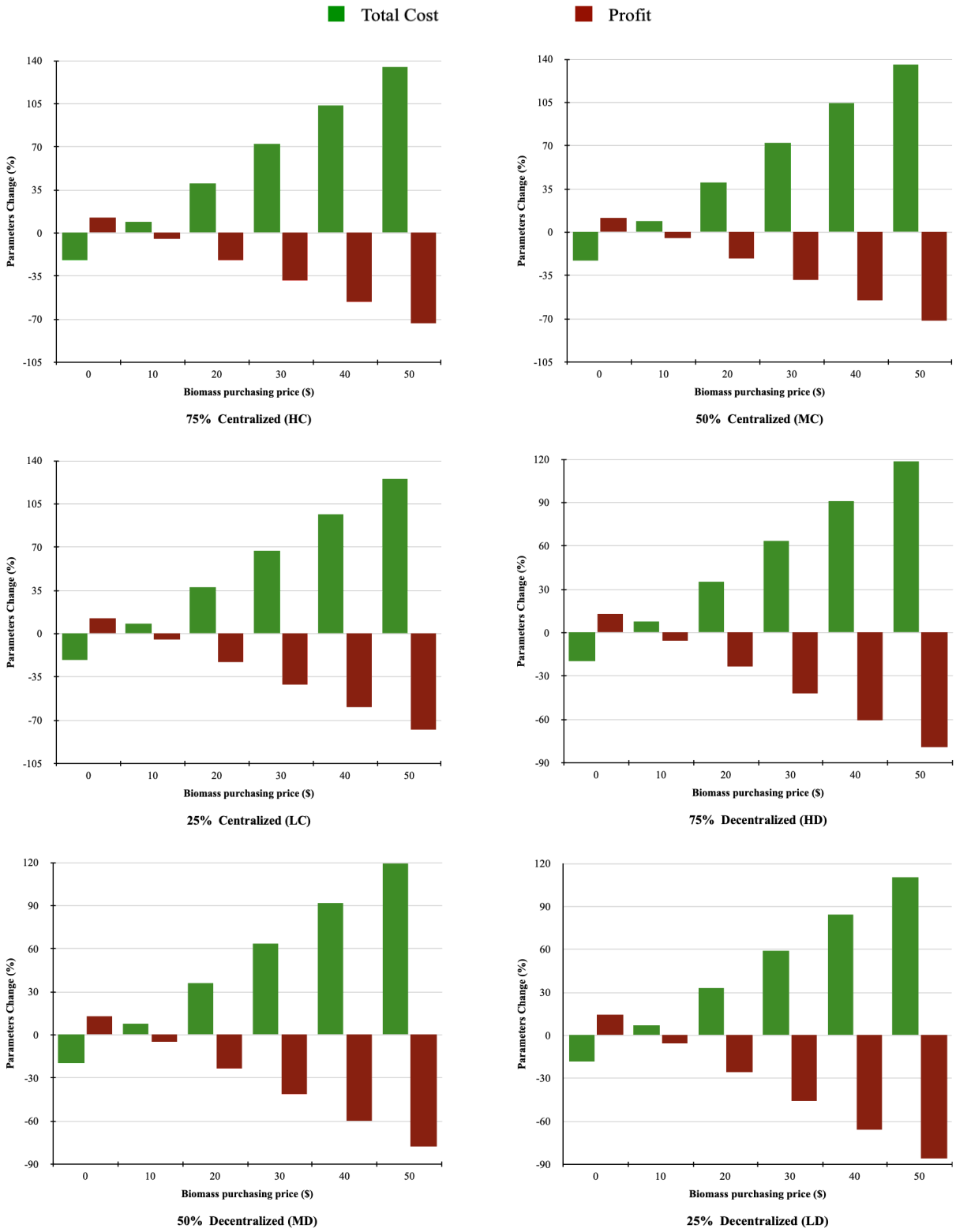
Figure VI-12 depicts the relationship between total cost and profit at various biomass purchasing prices ranging from US$0 to US$50 per tonne. The green bar graph indicates the total cost, which will significantly increase when the biomass purchasing cost is higher than the scenario. Indirectly, it has a slight negative impact on profit; thus, considering biomass purchasing is critical for deciding the amount and location of biomass procurement. When biomass procurement is free, the total cost is approximately 23 and 17% lower than the scenario analysis for centralized and decentralized models for all production capacities. As a result, all models' profits have increased by approximately 15%. When the cost of biomass purchase was $30 per tonne, the total cost was significantly higher, nearly 50% in the decentralized production scenario. Moreover, it can reach more than 70% in centralized distribution models, with the highest enhancement in HC and MC scenarios (73%) when the biomass price was US$30 per tonne. Furthermore, profit decreased significantly by 40% and 53% for centralized and decentralized models, respectively. The results explain why the profit sharply decreased by nearly 20% when the biomass price increased by US$10. It confirms that when the biomass purchasing cost is higher than US$20, the decision-making process should have re-evaluated the amount of biomass procurement and the distance from the biomass site to the treatment area to minimize the total cost. In the long term, the uncertainty of biomass availability, limited land, and the gradually high demand for bioenergy and other applications would contribute to the volatile biomass market price.


Total Cost
Profit
Parameters Change (%)
Biomass purchasing price ($)
75% Centralized (HC)
50% Centralized (MC)
25% Centralized (LC)
75% Decentralized (HD)
50% Decentralized (MD)
25% Decentralized (LD)

(a)


Total Cost
Profit
Parameters Change (%)
Biomass purchasing price ($)
75% Centralized (HC)
50% Centralized (MC)
25% Centralized (LC)
75% Decentralized (HD)
50% Decentralized (MD)
25% Decentralized (LD)

(b)

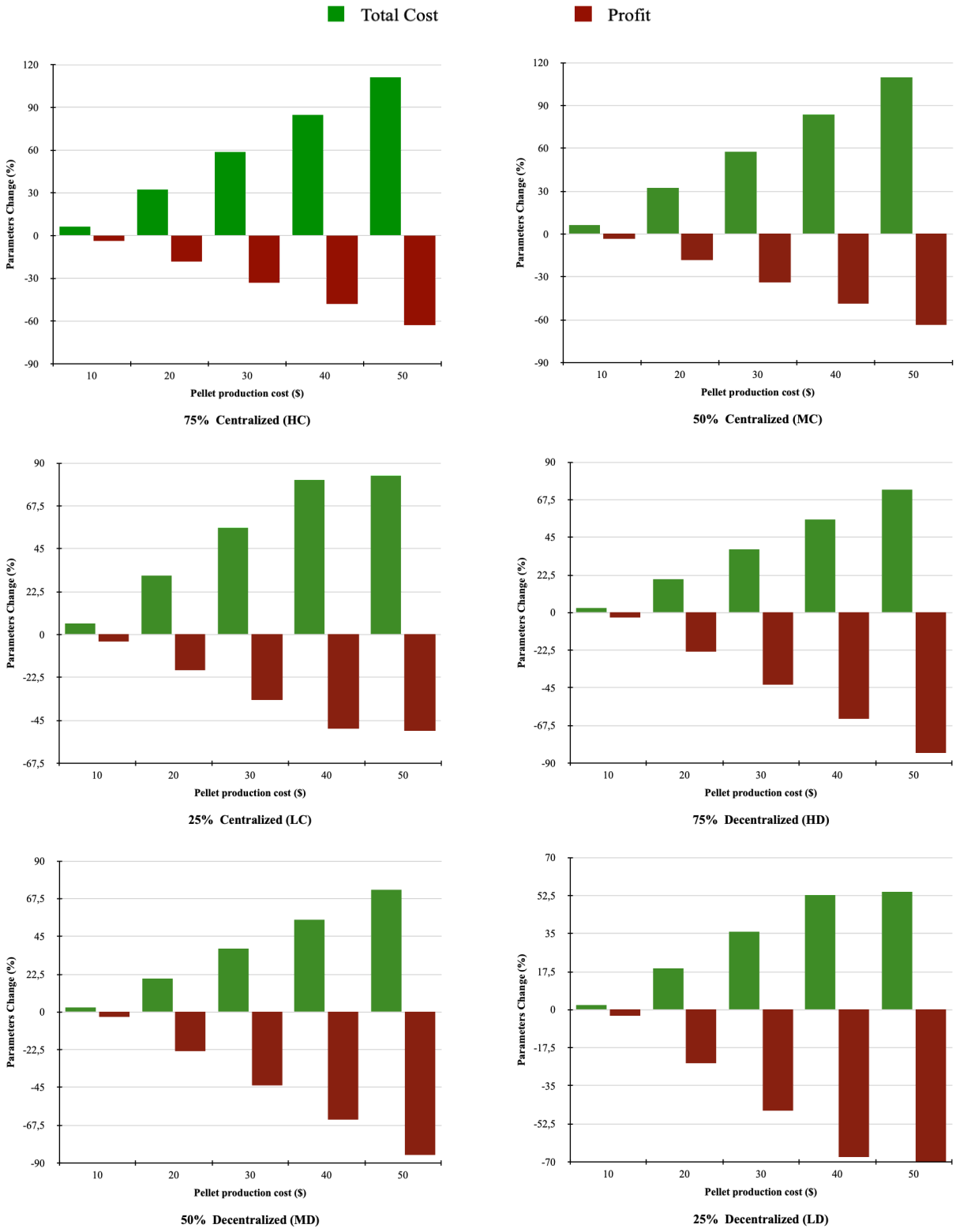


(c)

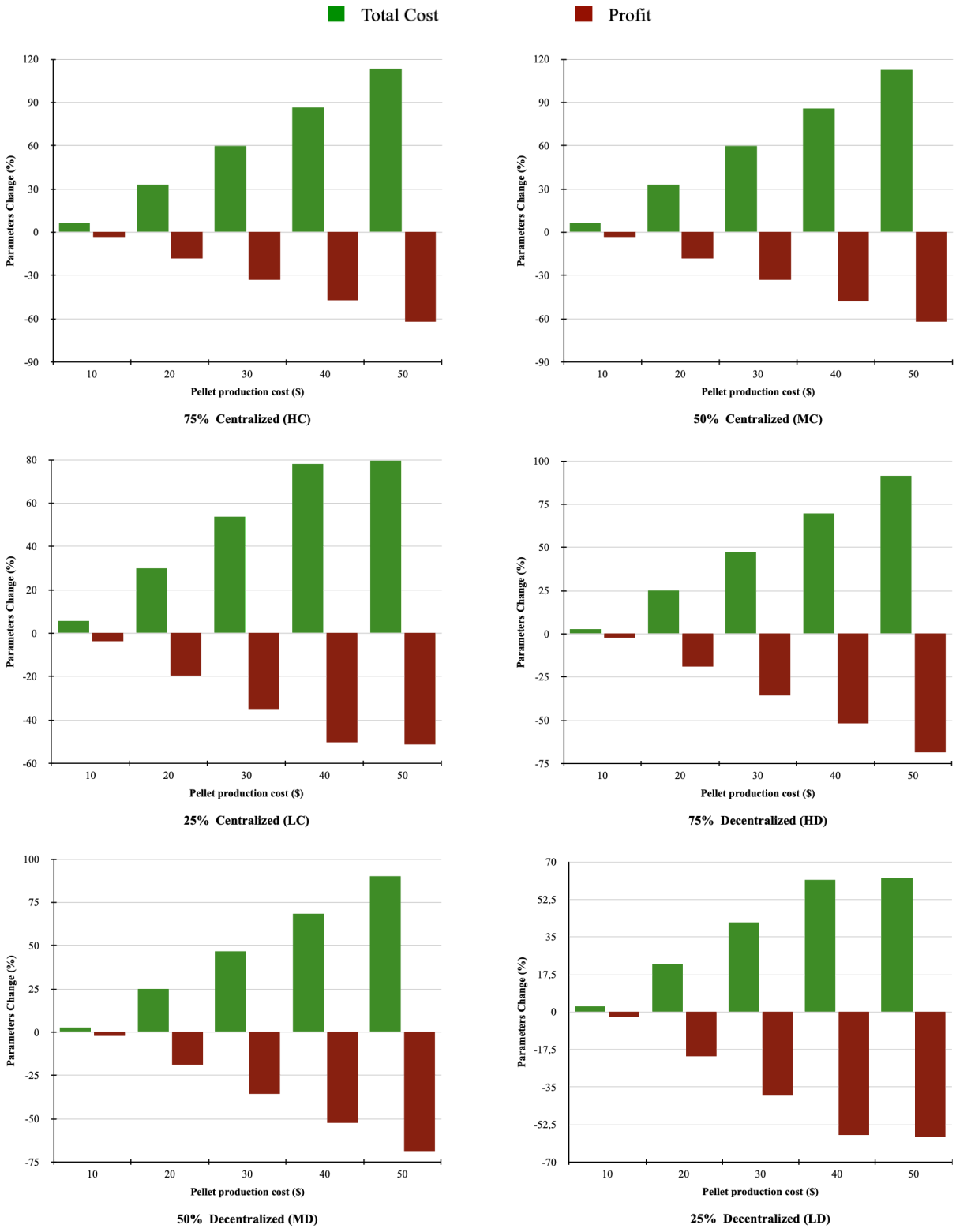
Figure VI-12. Effect of biomass purchasing price for economic feasibility based on the scenarios for the capacity production: (a) 10 tonnes per hour, (b) 20 tonnes per hour, and (c) 50 tonnes per hour

4.4.2. Sensitivity to pellet production cost

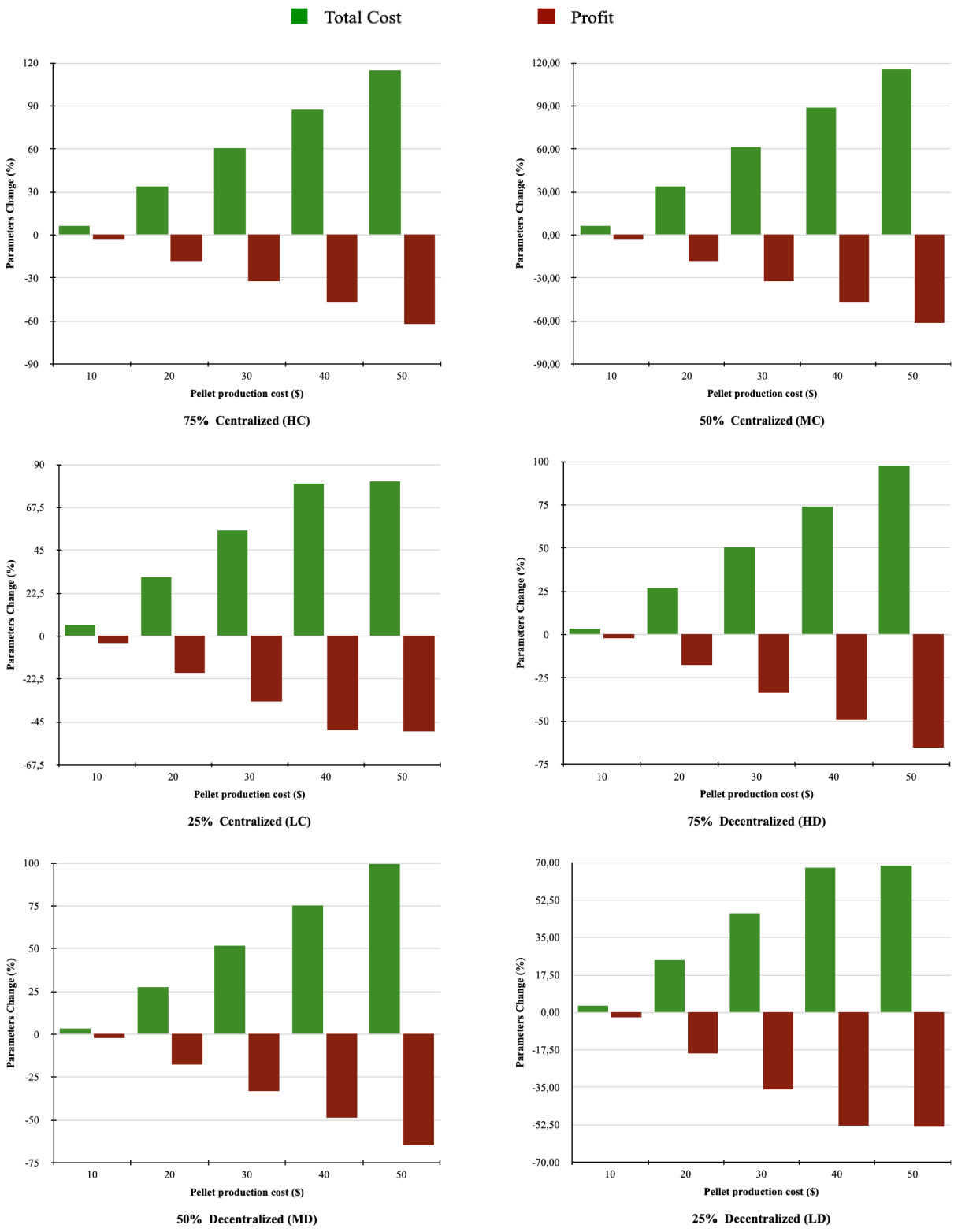
The supply chain design, i.e., feedstock type, production location, and pellet plant size, are partly variables contributing to estimating a pellet production cost. It describes our motivation to assess the effect of pellet production costs on the total cost and profit of the biomass supply chain. Figure VI-13 presents the varying production costs ranging from US$10 to US$50 compared to the base scenario. The results show that the centralized distribution model has a greater increase in total cost than the decentralized distribution model; for example, when the production cost was US$10 per tonne, the HC scenario had a 6% increase in total cost than the scenario analysis, while the HD scenario had a 3% increase. The centralized model has a twofold higher total cost than the decentralized model. Moreover, when the production cost was US$30 per tonne, the total cost was significantly higher by 50% and reached more than 100% when the production cost was US$50 per tonne. Furthermore, for every US$10 increase in production cost, the magnitude of the difference between increasing price and profit decline was nearly 60%. It also reveals that the maximum production cost could be at most US$20 per tonne to stabilize the total cost and profit; however, when the total cost is more than US$20 per tonne, the biomass supply chain is mainly not economically viable.


Total Cost
Profit
Parameters Change (%)
Pellet production cost ($)
75% Centralized (HC)
50% Centralized (MC)
25% Centralized (LC)
75% Decentralized (HD)
50% Decentralized (MD)
25% Decentralized (LD)

(a)


Total Cost
Profit
Parameters Change (%)
Pellet production cost ($)
75% Centralized (HC)
50% Centralized (MC)
25% Centralized (LC)
75% Decentralized (HD)
50% Decentralized (MD)
25% Decentralized (LD)

(b)



(c)

Figure VI-13. Effect of pellet production cost for economic feasibility based on the scenarios for the capacity production: (a) 10 tonnes per hour, (b) 20 tonnes per hour, and (c) 50 tonnes per hour

(c)

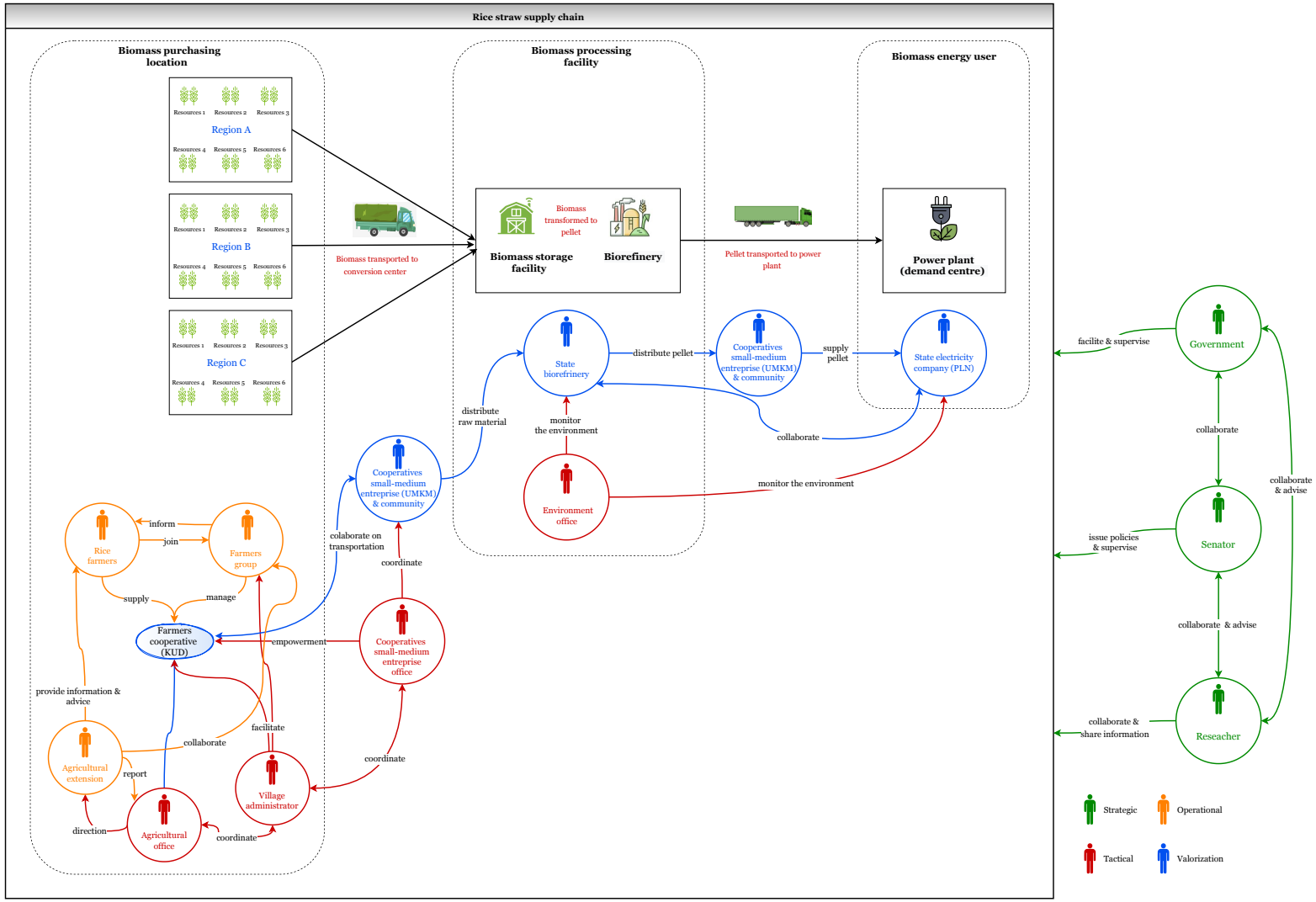
5. Conclusion and perspective

This chapter focuses on the middle term of the industrial development of biomass pellets from rice straw through sustainable supply chain design. An integrated classical and purposed approach was developed to identify a reliable economic model at the tactical decision-making level, based on a previous study at the strategic decision level regarding stakeholders' opinions and willingness. A rice straw supply chain was designed at a regional scale in East Java Province, Indonesia, by highlighting a centralized and decentralized distribution network. Furthermore, four regions were chosen (Tuban, Bojonegoro, Lamongan, and Ngawi) as the locations of biomass resources and processing by considering (i) annual rice production, (ii) productivity, (iii) policies and regulations issued regarding sustainable agriculture, and (iv) the support of stakeholders. Moreover, four types of rice straw storage (i.e., closed warehouse, open warehouse, semi-permanent covered by an outside with a trap on the gravel, and uncovered or unprotected ground) were analyzed to determine the optimum model to achieve a semi-permanent covered storage type using an outside with a trap on the gravel. Its application leads to high operational costs to reduce costs in a supply chain that can generate a monthly profit of US$0.7 million per month, which is nearly 15% and 35% than an open and closed warehouse and 10% lower than ground unprotected storage. From the inventory profile, the peak stock in October was approximately 25000 tonnes due to the next month's rainy season; therefore, feedstock sustainability should be guaranteed. Consequently, the operational cost increased significantly by 37% from the monthly average operational cost.

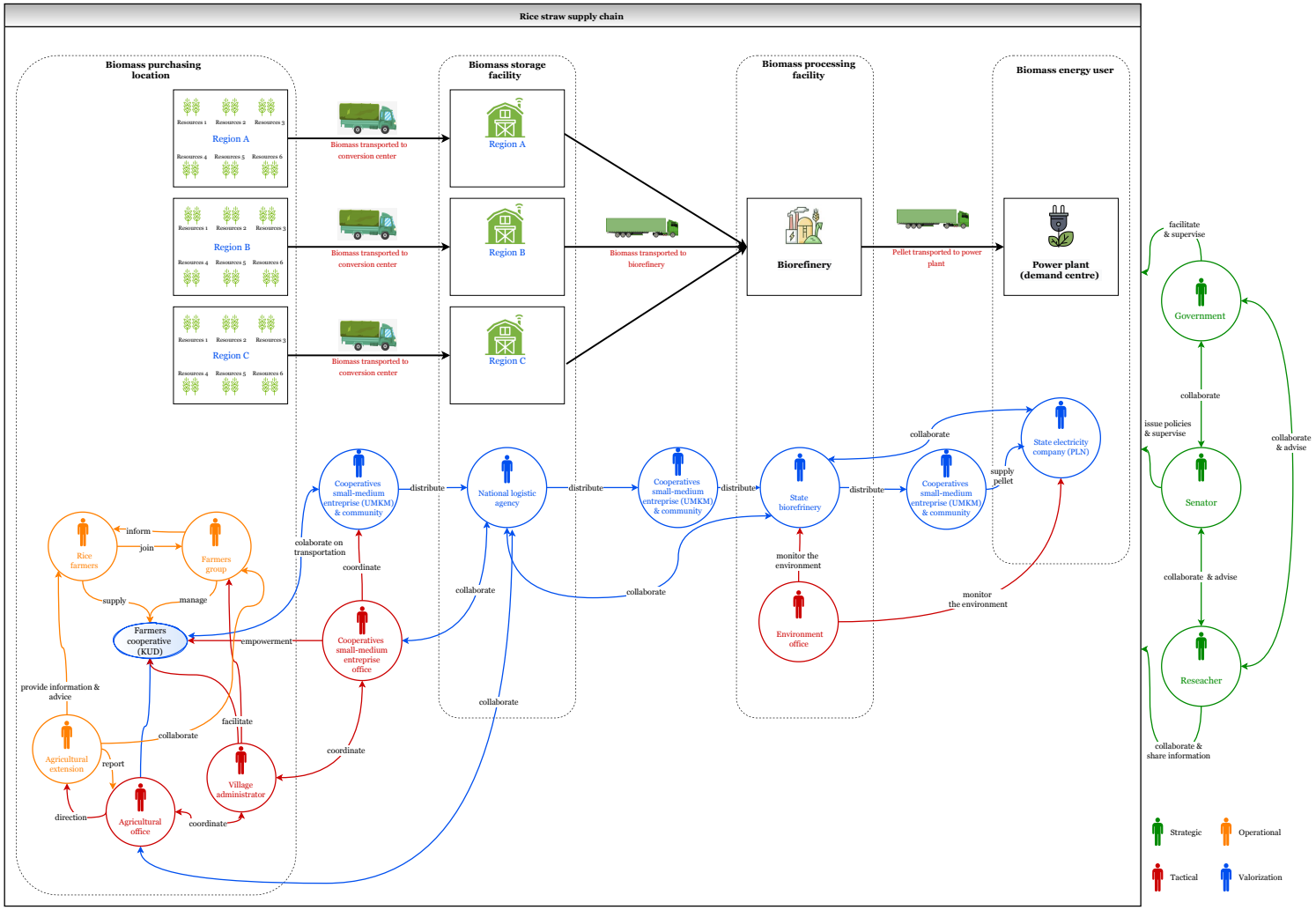
Moreover, scenario analysis was implemented to capture the different conditions between resource availability and the distribution model. Active and passive resources were chosen by combining centralized and decentralized models to investigate when resources were abundant or high (75% availability), moderate (50% availability), and low (25% availability). According to the sustainability pillars, the optimum result is 50% of the available resources when the production capacity is 20 tons per hour. This corresponded to the stakeholders' opinion that approximately 70% of rice straw was not utilized optimally, and 30% was used as animal feed and fertilizer. The MC scenario is more economically and environmentally friendly than the other scenarios. However, the MD scenario has higher social benefits, such as (i) creating new jobs in rural areas, (ii) improving communities' skills through new counseling, (iii) training and education in rice straw management, (iv) implementing empowerment programs, and (v) improving stakeholders' participation to realize food and energy security without reducing sustainability values. From the inventory profile, the peak biomass procurement and stock were similar to those in the control analysis in October. A sensitivity analysis was performed to determine the effect of the biomass purchasing price and pellet production cost on economic feasibility. The results showed that the maximum cost of biomass purchasing and pellet production should be at most US$25 per tonne to maintain profit stability. Therefore, it is crucial to have precise data on the parameters that

significantly impact the cost and revenue by considering the uncertainty factors, which would help develop a more optimal BSC system. Finally, the interaction diagram between stakeholders' role in each distribution network is shown in Figure VI-14.

In the future, the study will also focus on the transportation methodology, particularly vehicle routing, to discover specific costs related to the economic feasibility of the rice straw value chain. Furthermore, the environmental aspect should be investigated in the future to identify the correlation between each sustainability dimension in rice straw valorization programs without dismissing the influence of technological development and political assessment.


Rice straw supply chain
Biomass purchasing location
Biomass processing facility
Biomass energy user
Resources 1
Resources 2
Resources 3
Resources 4
Resources 5
Resources 6
Region A
Region B
Region C
Biomass transported to conversion center
Biomass transformed to pellet
Biomass storage facility
Biorefinery
Pellet transported to power plant
Power plant (demand centre)
State biorefinery
distribute pellet
Cooperatives small-medium entreprise (UMKM) & community
supply pellet
State electricity company (PLN)
distribute raw material
monitor the environment
collaborate
Environment office
monitor the environment
Cooperatives small-medium entreprise (UMKM) & community
colaborate on transportation
coordinate
Rice farmers
inform
join
Farmers group
supply
manage
Farmers cooperative (KUD)
empowerment
Cooperatives small-medium entreprise office
provide information & advice
facilitate
collaborate
Agricultural extension
report
Village administrator
coordinate
direction
Agricultural office
coordinate
facilite & supervise
Government
collaborate
collaborate & advise
issue policies & supervise
Senator
collaborate & advise
collaborate & share information
Reseacher
Strategic
Operational
Tactical
Valorization

(a)



(b)

Figure VI-14. Annual material flow when the availability of the resource is 50%, and the capacity production is 20 tonnes per hour: (a) Centralized and (b) Decentralized

Chapter VII. General conclusions and perspectives

7.1. General conclusion

Agricultural residues have emerged as promising bioenergy feedstocks to replace fossil fuels. A lack of optimal residue utilization can cause open burning during the postharvest period, which could result in environmental issues such as greenhouse gas emissions, soil degradation, water pollution, and biodiversity damage. However, biomass residue potential is abundant and available throughout the year. These two points are fundamental for describing the opportunities and barriers to realizing the goals of agricultural residue valorization. Therefore, a comprehensive solution that considers sustainable development and actual data is required to design and develop these programs.

The primary objective of this study is to take the fundamental design for developing agricultural residue application, specifically rice straw valorization according to production and harvesting areas, into account to achieve more effective management in the supply chain network. This objective was achieved by constructing a rice straw valorization design and planning at strategic and tactical decision-making levels, considering sustainability dimensions. The actual case study in Indonesia has enormous rice production and harvested areas annually, specifically in the East Java Province.

In Chapter II, the potential agricultural residue in Indonesia is evaluated to determine its actual amount and energy generation. To calculate the energy potential of the biomass residue, the minimum and maximum value parameters, such as the residue-to-product ratio, moisture content, and heating value, were derived from published studies. The power potential was obtained using three conversion factor efficiency scenarios: low, medium, and high. The results showed that Indonesia produces 155.27 million metric tons of dry biomass residue from agricultural waste each year. It had an energy potential of approximately 302 PJ. The yearly power generation potential from agricultural residue was predicted to be 2822.29 MW for fluidized bed combustion and generating turbines (C/GT) technology and 4181.17 MW for the combined gas and steam cycle (C/GC) technology. This accounts for approximately 28% of Indonesia's electricity supply in 2019. The highest resource used as a bioenergy feedstock is rice straw, with approximately 76 million tonnes produced per year, given that rice is the primary food source in Indonesia and has been cultivated in all regions. Furthermore, the results suggest that strategic components for promoting residue valorization (i.e., planning, organizing, and operating) should be created comprehensively, given the significant potential for optimizing agricultural residue supply and utilization by considering sustainability dimensions.

Furthermore, to implement agricultural residue valorization, the design and management of its resources must be defined and analyzed, which will be covered in Chapter III as a state-of-the-

art biomass supply chain (BSC). Descriptive analysis will be conducted through scientific database contexts over the last decade, 2013–2022, to discover the latest studies on the BSC. This chapter presents the gaps between strategic and tactical decision-making levels, and the significance of sustainability dimensions to assist in improving stakeholders' roles. According to the review, the strategic decision-making level is long-term in design and planning when viewed through the eyes of stakeholders, and the policy perspective on selecting feedstock resources and facilities should balance the influence between actors' relationships and their perceptions to improve BSC performance. On the other hand, at the tactical decision-making level, it minimizes the operational cost and balances the material flows in the inventory section are interesting to investigate. The results indicate that both decisions significantly correlate with the success level of rice straw value chain implementation by minimizing cost goals while retaining sustainability aspects.

The first step in developing rice straw valorization is to assess farmers' willingness to supply biomass feedstock, which is an important key to guaranteeing sustainable bioenergy production, as presented in Chapter IV, which is a part of the strategic decision-making level. Statistical data analysis and clustering methods using multiple correspondence analysis (MCA) were employed to visualize and extract information about farmers' willingness and participation. The survey results of 300 farmers in three regions of East Java (Magetan, Bojonegoro, and Lamongan) found that most farmers utilized rice straw depending on the weather for animal feed and planting purposes, such as mushroom media planting, fertilizer, and mulch, with an amount of no more than 25%, which means approximately 75% of rice straw can be used as bioenergy feedstock. Farmers will obtain economic benefits as an additional income of approximately US$394 when a ton of rice straw is valued at US$7.14 and their supply is 55 tons of materials. More than 60% of farmers have a significant perception that better rice straw management, when complemented by the government's role in supporting physical and non-physical facilities, will improve farmers' socioeconomic quality and mitigate greenhouse gas emissions. Therefore, it is necessary to identify stakeholders' roles (i.e., policymakers, the government, academics, and entrepreneurs) in providing technical and financial facilities, as well as the question of how to extend the plan and implementation of policies and regulations issued to support rice straw valorization programs, as discussed in Chapter V.

Similar to the last part of the discussion on farmers' willingness, in Chapter V, the discussion of stakeholder opinions and participation are essential components that can assist in providing information on the design and planning of rice straw valorization during the strategic decision-making process. A total of 150 stakeholders were selected for interviews to discover their opinions, motivations, perceptions, and participation in rice straw valorization programs. Furthermore, MCA was applied to map stakeholders' willingness; the results would be used to indicate their current role; and in the future when valorization has been implemented. The result was grouped into three categories of stakeholders' willingness level, i.e., 53% of stakeholders were "unwilling,"

26% of stakeholders were "willing-time," and 32% of stakeholders were "innovative-sustainable." However, 50% of stakeholders recognized that rice straw valorization could improve farmers' socioeconomic status, and 46% believed that this program could mitigate environmental issues, mainly by reducing open-burning activity. Furthermore, stakeholders' roles and relationships were investigated through mapping. In particular, before implementing valuing programs, the structure of the actors at each decision-making level is simplified. For example, at the tactical decision-making level, only the agricultural officer, environmental agency, village administrator, and feed industry are shown, whereas, when the program is implemented, the feed industry actor moves to the strategic decision-making level. Moreover, to increase the quality and quantity of cooperation to provide market share, establish a link between SME agencies and farmers through village cooperatives (KUD) to provide the necessary services to improve residue quality. It can integrate suitable empowerment programs for farmers and communities to optimally produce biomass, considering regional potential and environmental capacity. Consequently, stakeholder involvement has significantly impacted sustainable development and simultaneously realized food and energy security programs.

Finally, in Chapter VI, the study focuses on the tactical decision-making level, which aims to organize economic efficiency for optimal material flow, transportation, and storage, considering centralized and decentralized distribution networks to reduce the BSC challenge. Incorporate the classical approach by considering the amount of rice straw availability discovered from farmers' willingness and stakeholders' participation in Chapters 4 and 6. This study is a real case conducted in East Java Province, similar to a previous study. The scenario implementation highlights resource availability (i.e., high or 75%, moderate or 50%, and low or 25% resources) and the distribution network (i.e., centralized and decentralized models) to identify and maximize profit and minimize the cost and inventory profile. The results show that the 50% centralized scenario is more economically and environmentally friendly than other scenarios. However, the 50% decentralized scenario had higher social benefits because it created new jobs and improved empowerment in rural areas. To assess the impact of biomass purchasing and pellet production costs on economic feasibility, a sensitivity analysis was performed.

Overall, all the studies in this thesis are original, indicating the great potential of developing an agricultural residue valorization program to simultaneously achieve national energy goals and maintain food security. However, this conclusion should be complex and interpreted cautiously since the social aspect requires a more in-depth and volatile study due to a lack of understanding and awareness among stakeholders and a lack of historical data on the quantity and quality of residue, which is only estimated and limited. Integrated cooperation and mutual support between actors are essential for building better ways to communicate and improve the BSC performance.

The main contribution of this thesis, which is a real-life case study, is the fundamental issue of how to develop valorization programs for rice straw, which is a critical factor in the BSC. The

strength of this study lies in having access to accurate data and communicating with several stakeholders. Their perspectives and expectations help to depict (i) the potential of rice straw valorization when considering opportunities and challenges. (ii) What affects the feedstock supply? Furthermore, (iii) how to determine the long-term, medium-term, and short-term strategies that consider sustainability, as shown in Figure VII-1.

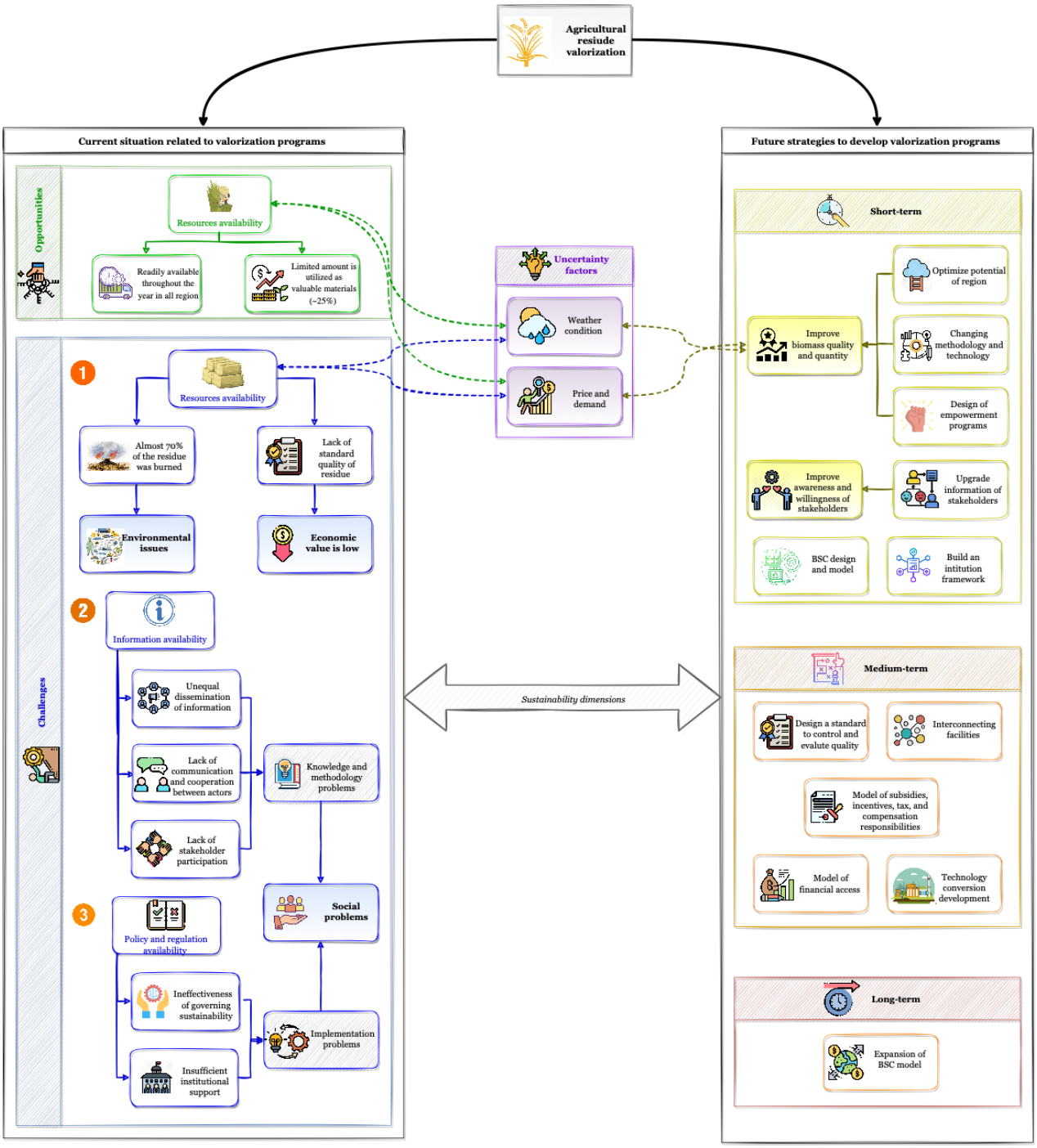


Figure VII-1. Results findings related to the potential valorization of agricultural residues

Considering that resource availability is abundant in all regions throughout the year, as discussed in previous chapters, it faces some challenges in terms of sustainability. The feedstock

cost is a significant variable cost component in bioenergy production, which should have a consistent quality to maximize the product yield and on-stream time. The lack of a BSC strategy can decrease feedstock quality; therefore, a standard for material handling, transportation, storage, and pre-processing is required as a medium-term solution to reduce the factors that lead to high feedstock costs through preservation and pre-conditioning during distribution and inventory activities. To improve the quantity of residue, changing the harvesting and collection methodology and technology is a primary method that should be conducted in the short term. However, it should be noted that weather conditions (i.e., rainfall, temperature, and humidity) are a source of uncertainty, which is permanently calculated due to the fact that they can highly fluctuate from one time to another and affect feedstock availability in a triangular distribution. This was also related to answering the question of how actors can optimize regional potential and how to design empowerment to ensure farmers' willingness to supply feedstock on a continuous basis. Therefore, updated information is required to improve farmers' willingness and awareness. Considering that the challenge of information availability is the unequal dissemination of information, the government regularly provides counseling and training to improve their participation. Furthermore, the need for greater communication and cooperation among stakeholders is a social problem that should be solved by building an institutional framework in the short term.

Moreover, sensitivity analysis was highlighted by focusing on price and demand to assess the economic feasibility of the BSC network. As a result, some of the uncertainty factors would significantly raise the cost as demand increases or supply decreases; at the same time, implementing policies and regulations can affect demand and supply. Indirectly, the question of how to improve the effectiveness of the governance of the materials and facilities to minimize the BSC problems and thereby the interconnection of facilities should be evaluated first, including how the optimum schedule of routine maintenance and another factor that can be predicted should be noted to maintain the sustainability of the supply chain. Furthermore, in the medium term, the design and model of subsidies, taxes, and compensation responsibilities are strategies to improve stakeholder participation that should be incorporated into a new design of policies and regulations through the optimization of institutions' roles to support residue valorization. Similarly, the design and model of financial access are still linked to the existence of policies and regulations, such as how to incorporate carbon costs and evaluate credit risk to aid the long-term expansion of value-added programs. By contrast, in the medium term, the design of financial access is a sensitive object for stakeholders, which is related to the political context for creating synergy in economic development. Therefore, developing renewable and advanced technology in medium- and long-term strategies should consider the sustainability aspects, local potential, and readiness of stakeholders to be involved and maintain the continuity of valorization programs.

7.2. Perspectives

According to previous study findings, the first potential of future research is to develop an operational aspect, which is focused on designing transportation routes that are more profitable and minimize the environmental impact and raw material flows in pellet production, starting with biomass collection, distribution, inventory, and pellet distribution. The proposal is based on a real case study designed using actual data from rice and other agricultural residues. A potential direction for future research is to extend the development of rice straw valorization to a multi-objective model to discover more details regarding the environmental impacts and social gains of bioenergy production. This requires environmental impact performance using life cycle assessment (LCA), which is associated with all stages of bioenergy production. Furthermore, a social life cycle assessment (S-LCA) was used to evaluate the social benefits of rice straw valorization programs, and technological and political aspects should be incorporated and analyzed to create a complex network and pathways for the BSC.

Stakeholder categories can be analyzed based on their power and legitimacy, which are divided into three categories: (i) key stakeholders, who have dominating power and legitimacy related to issuing policies and regulations (i.e., senators and government) and technology development (i.e., researchers); (ii) primary stakeholders, who have power but have a positive and negative impact on the valorization programs (i.e., farmers and entrepreneurs); and (iii) second stakeholders, who have marginal effects on valorization programs but have roles in disseminating the latest information (i.e., media). As previously stated, key stakeholders were classified into three groups: power actors who issued policies and regulations, willing-time actors who were concerned about how policy and regulation implementation could improve social welfare, and innovative-sustainable actors concerned about improving sustainability quality through technological development in these programs. Second, the primary actors consisted of unwilling actors, who were more concerned with improving the economic aspects, that is, how to improve their profits regularly. Moreover, farmers have been investigated based on the social and economic conditions that influence their concern for improving the quality of sustainability dimensions. Furthermore, the media, as a second stakeholder, should be incorporated into this program to discover its significant roles, which can be investigated in a future study. Finally, the findings of this study are fundamental for modeling the BSC optimization by considering the uncertainty, risk, and resilience parameters to achieve better and more precise results in the valorization program. The game theory approach can be applied to investigate a novel methodology using a mathematical optimization model, as shown in Figure VII-2.

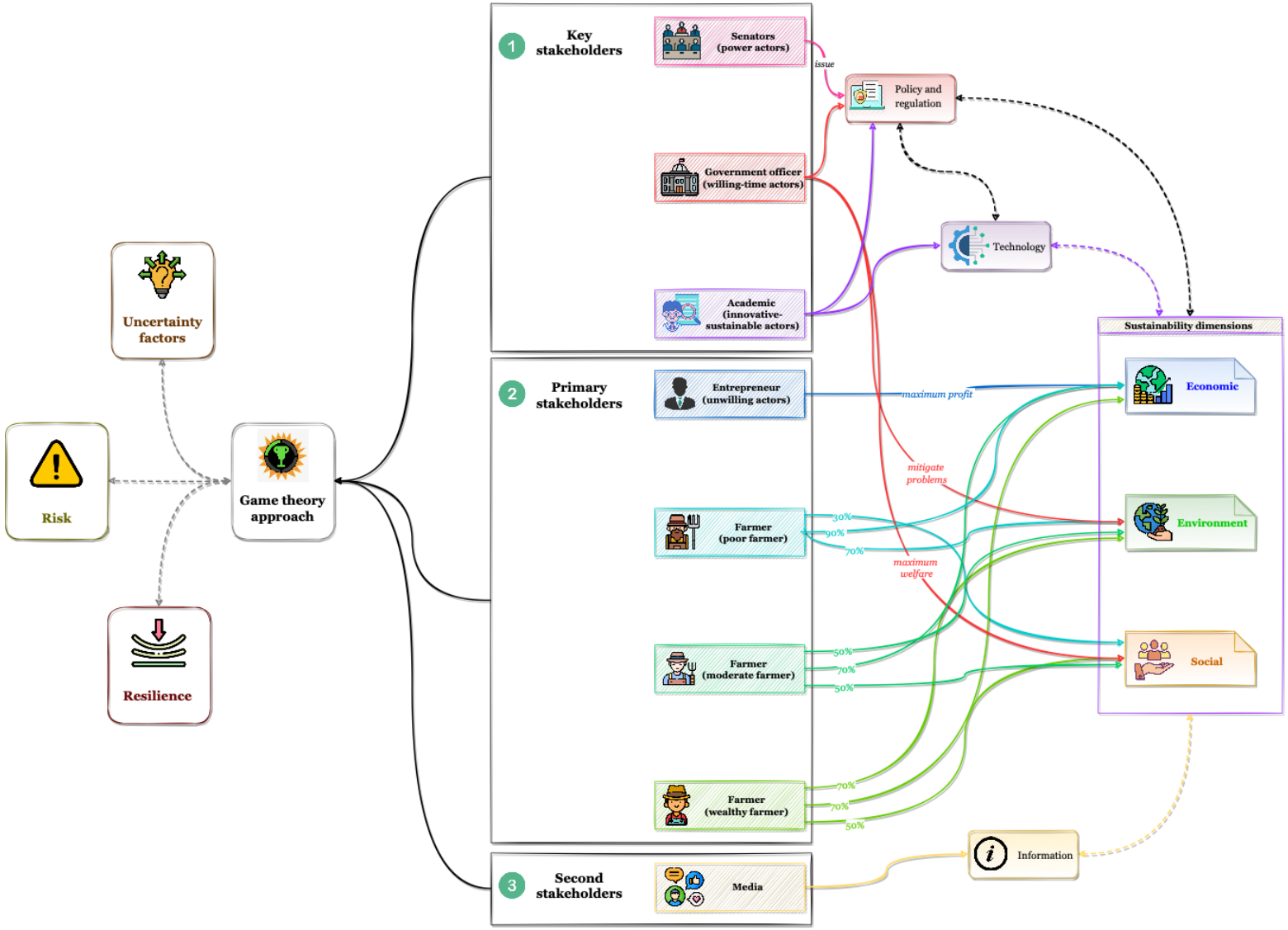


Figure VII-2. Future perspective to develop agricultural residue valorization

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Appendix

- Appendix A. Summary of the publications related to the strategic decision-making level of biomass supply chain for biofuel production
- Appendix B. Summary of the publications related to the tactical decision-making level of biomass supply chain for biofuel production
- Appendix C. Questionnaire of farmers
- Appendix D. Farmers' characteristics in the factor map
- Appendix E. Indonesia's regulation and policy related to biomass energy
- Appendix F. Questionnaire of stakeholders
- Appendix G. Stakeholder s' characteristics in the factor map
- Appendix H. Distance among biomass purchasing location and storage facilities
- Appendix I. An optimum material flows of various storage deterioration based on the scenarios centralized and decentralized
- Appendix J. Total operational cost for centralized and decentralized distribution model according to the various of production capacity

Appendix A. Summary of the publications related to the strategic decision-making level of biomass supply chain for biofuel production

No	Authors	Location	Biomass type	Product	Sustainability dimensions			Decision level			Main decisions
					Economic	Environment	Social	Strategic	Tactical	Operational	
1	(Giarola et al., 2013)	Italy	Corn, poplar, willow, miscanthus, stover, barley straw, wheat straw, and switchgrass	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Ethanol fuel facilities number, capacity and technology selection, biomass type and materials flow, technology upgrading
2	(Osmani and Zhang, 2013)	United State	Switchgrass	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Land allocation of biomass, capcity and location of biorefrinery
3	(Lin et al., 2013)	United State	Miscanthus	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Numbers, locations, and capacities of farms, centralized storage and pre-processing site, and biorefineries
4	(Ng et al., 2013)	Malaysia	Rubber seed	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of biomass resources, location and capacity of facilities, materials flow
5	(P. Sharma et al., 2013)	United State	Switchgrass, sugarcane	Heat, electricity, biofuel (bioethanol, biodiesel), biochemical products	✓	-	-	✓	-	-	Feedstock mix, product portfolio, conversion technology and process configuration, stakeholders value
6	(Lin et al., 2014b)	United State	Miscanthus	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of facilities, materials flow

7	(Yue et al., 2014a)	United State	Cellulosic biomass	Heat, electricity	✓	✓	✓	✓	✓	-	BSC network layout, facility location and sizing, technology selection, materials flow, job creation
8	(Osmani and Zhang, 2014)	United State	Lignocellulosic	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	-	-	Type and amount of biomass, size, location, type and capacity of biorefrinery, materials flow
9	(Santibañez-Aguilar et al., 2014)	Mexico	Wood chips, commercial wood, sugar cane, corn grain, sorghum grain, sweet sorghum, sunflower, African palm oil and jatropha	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	-	-	Location, type and amount of biomass, location, number, and capacity of facilities, type and capacityof technology conversion
10	(Li and Hu, 2014)	United State	Corn stover	Bio-oil	✓	-	✓	✓	-	-	Location and capacity of biorefrinery, farmers participation
11	(Tong et al., 2014a)	United State	Corn stover, switchgrass, forest residues	Hydrocarbon biofuel	✓	-	-	✓	✓	-	Location and capacity of biorefrinery, technology biorefrinery selection, integrated biofuel and petroleum supply chain design
12	(Tong et al., 2014b)	United State	Corn stover, switchgrass, forest residues	Hydrocarbon biofuel	✓	-	-	✓	✓	✓	Location and capacity of biorefrinery, technology biorefrinery

											selection, integrated biofuel and petroleum supply chain design
13	(Azadeh et al., 2014)	United State	Switchgrass, mill residues, urban wastes, corn stover, wheat straw, rice straw, cotton residues	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Selection of biomass type, location and capacity of facilities, technology conversion selection, materials flow
14	(Yılmaz Balaman and Selim, 2014)	Turkey	Animal manure and energy crops	Biogas	✓	✓	-	✓	✓	-	Location of biomass resources, location and capacity of facilities, BSC network design
15	(Kelloway and Daoutidis, 2014)	United State	Corn stover, wheat straw, barley straw, switch grass	Biochar, bio-oil	✓	-	-	✓	✓	-	Location of biomass site, location and capacity of biorefrinery, prosess and design of biorefrinery
16	(Marufuzzaman et al., 2014)	United State	Wastewater sludge	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location and capacity of facilities, materials flow, BSC network design and planning
17	(Duarte et al., 2014)	Colombia	Coffee cut stems	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of facilities, BSC network design and planning, materials flow

18	(Kostin et al., 2015)	Spain	Sugarcane residue	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	-	-	BSC network, materials flow, type and location of the technologies selected, the capacity of production plants and warehouses
19	(Gonela et al., 2015a)	United State	Corn	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location of biomass resources, location and capacity of biorefrinery, BSC network design, tranportation planning
20	(Gonela et al., 2015b)	United State	Corn	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Location of biomass resources, location and capacity of biorefrinery, BSC network design, tranportation planning
21	(Babazadeh et al., 2015)	Iran	Jatropha curcas L.	Biofuel (bioethanol, biodiesel)	-	✓	✓	✓	-	-	Location of biomass site
22	(Yılmaz Balaman and Selim, 2015)	Turkey	Animal manure and energy crops	Heat, electricity	✓	-	-	✓	✓	-	Number, location, and capacity of bioenergy plant, materials flow
23	(Wu et al., 2015)	United State	Forest residue, animal manure and grass	Solid fuel (pellet, briquette)	✓	-	-	✓	✓	✓	Location and capacity of biorefrinery, materials flow
24	(Paulo et al., 2015)	Portugal	Forest residue	Electricity	✓	-	-	✓	-	-	Location, number and size biomass resources, transportation mode, BSC

											network design and planning
25	(Ahn et al., 2015)	United State	Switchgrass	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	-	-	Allocated of biomass sources, location, capacity and size of facilities, conversion pathways
26	(Zhang et al., 2016)	United State	Woody biomass	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Number, capacity, and location of storage yards and biorefineries, and harvesting plans
27	(Guo et al., 2016)	United Kingdom	Livestock residue	Heat, electricity	✓	✓	-	✓	-	-	BSC network, land-use transition, understanding of bioenergy
28	(Azadeh and Vafa Arani, 2016)	Iran	N/A	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Location and capacity of biorefrinery, technology conversion development, BSC network, materials flow
29	(Bairamzadeh et al., 2016)	Iran	Corn stover and wheat straw	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location and capacity of biomass resources, size, location and capacity of facilities, technology conversion selection, BSC network design, materials flow
30	(Santibañez-Aguilar et al., 2016)	Mexico	Wood chips, commercial wood, sugar cane, corn grain, sorghum	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location and capacity of biomass resources, technology

			grain, sweet sorghum, sunflower, African palm oil and jatropha								conversion selection, location and capacity of facilities and market
31	(Mohseni and Pishvaee, 2016)	Iran	Microalgae	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Allocated of biomass sources, location, capacity and size of facilities, location of market, BSC network design and planning
32	(Mohseni et al., 2016)	Iran	Microalgae	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location of biomass resources, location and capacity of production facilities, materials flows, BSC network design and planning
33	(Caffrey et al., 2016)	United State	Switchgrass, sorghum, rapeseed, barley	N/A	✓	-	-	✓	✓	-	Location and capacity of facilities, harvesting planning
34	(Najmi et al., 2016)	Iran	N/A	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location and capacity of facilities, biorefrinery technology selection, technology upgrading, market player
35	(Hombach et al., 2016)	Germany	Sawmill residues, forest residues	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	-	-	Location and capacity of biomass resources, location and capacity of facilities

36	(d'Amore and Bezzo, 2016)	Italy	Corn stover	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	-	-	Location and capacity of biomass resources, location and capacity of facilities, materials flow
37	(Woo et al., 2016)	South Korea	Agricultural residues, industrial residues, forestry residues, and energy crops	Hydrogen fuel	✓	-	-	✓	-	✓	Location and capacity of facilities, materials flow
38	(Babazadeh et al., 2017)	Iran	Jatropha curcas L., waste cooking oil	Biofuel (bioethanol, biodiesel)	-	✓	✓	✓	✓	-	Number, location and capacity of biomass resources, location and capacity of biorefrinery, biofuel distribution network
39	(de Jong et al., 2017b)	Sweden	Forest residue	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of facilities, BSC network design and planning,materials flow, transportation mode
40	(Mutenure et al., 2018)	South Africa	Barley straw, maize straw, sorghum straw, sugarcane residue, wheat straw	Heat, electricity, biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Biomass location and size, location and capacity of facilities, materials flow
41	(Bairamzadeh et al., 2018)	Iran	Lignocellulosic	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location of biomass recources, location and capacity of facilities, technology

											upgrading, BSC network design and planning, materials flow
42	(Huang and Hu, 2018) Huang	United State	Corn, switchgrass	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	✓	Location of biomass resources, farmers' participation of biomass planting, BSC network design, harvesting schedule
43	(Mirhashemi et al., 2018)	Iran	Moringa oleifera	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location of biomass resources, location and capacity of facilities, materials flow
44	(Nodooshan et al., 2018)	United State	Algae	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location and capacity of facilities, technology conversion selection, materials flow
45	(Hombach et al., 2018)	Germany	Miscanthus	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	-	-	Capacity, technology, and number of production facilities
46	(Ascenso et al., 2018)	Italy	Corn, stover, Arundo donax, Miscanthus, poplar and wood residues	Bioelectricity, bioethanol	✓	✓	-	✓	-	-	Location and capacity of biomass resources, location, size, and capacity of facilities, transportation mode, financial performance, impact to the environment

47	(Abasian et al., 2019)	Canada	Forest residue	Heat, electricity, solid fuel (pellet, briquette)	✓	-	-	✓	✓	-	Location and capacity of facilities, technology conversion selection, materials flow, BSC network design and planning
48	(Razm et al., 2019)	Iran and Armenia	Forest residues, woodwork factory residues, agricultural residues	Biofuel (bioethanol, biodiesel), solid fuel (pellet, briquette)	✓	-	-	✓	✓	-	Type of biomass selection, location and capacity of facilities, materials flow, BSC network design and planning
49	(Akgül and Ulusam Seçkiner, 2019)	Turkey	Corn and cotton stalk	Heat, electricity, biochar	✓	-	-	✓	-	-	Location, size, and capacity of facilities, technology conversion upgrading, BSC network design, materials flow
50	(Martínez-Guido et al., 2019)	Mexico	Waste biomass	Solid fuel (pellet, briquette)	✓	✓	-	✓	-	-	Location and capacity of biomass resources selection, location and capacity of plant, materials flows
51	(Sarker et al., 2019)	United State	Crops, grass, wood residue, and livestock waste	Biogas	✓	-	-	✓	✓	-	Location and capacity of biomass resources, location and capacity of facilities, materials flow
52	(Gao et al., 2019)	China	Corn residue, rice residue	Biofuel (bioethanol, biodiesel)	✓	-	✓	✓	-	-	Location and capacity biomass resources, location and capacity of

											facilities, materials flow, job creation
53	(Cho and Kim, 2019)	South Korea	Microalgae	Biofuel (bioethanol, biodiesel)	✓	✓	-	✓	-	-	Location and amount of biomass resources, location, amount, and capacity of biorefrinery, materials flows, amount and location of biofuel demand
54	(Gital Durmaz and Bilgen, 2020)	Turkey	Poultry waste	Biogas	✓	-	-	✓	✓	✓	Number, location, and size of the biogas facilities
55	(Saghaei et al., 2020)	United State	Pulpwood or saw timber residue	Electricity	✓	-	-	✓	✓	-	Location and capacity of facilities
56	(Mohseni and Pishvaee, 2020)	Iran	Wastewater sludge	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of facilities, BSC network design and planning, materials flow
57	(Mousavi Ahranjani et al., 2020)	Iran	Rice straw, wheat straw, barley straw and corn stover	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of technology biorefrinery, technology biorefrinery selection, materials flow
58	(Van Holsbeeck and Srivastava, 2020)	Australia	Forest biomass	Heat, electricity	✓	-	-	✓	✓	-	Location and capacity of facilities, materials flow
59	(Abbas et al., 2021)	Pakistan	Cotton crop waste	Heat, electricity	✓	-	-	✓	✓	-	Location and capacity of plant, size and capacity technology conversion

60	(Peña González et al., 2021)	Colombia	Palm oil	Electricity, biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of facilities, materials flow
61	(Ge et al., 2021)	United State	Agricultural wastes, urban litters, corn stover,urban wood	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of biomass resources, location and capacity of facilities, materials flow
62	(Morales Chavez et al., 2021)	Columbia	Agriculture waste	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	✓	Location and capacity of biomass resources, location and capacity of facilities, materials flow
63	(Mohtashami et al., 2021)	Iran	Jatropha Curcas L.	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Location, number and capacity of facilities, materials flow
64	(Luo et al., 2021)	Australia	Forest residue	N/A	✓	-	-	✓	✓	-	Location, number, quantity, and type of biomass, materials flow
65	(Gutierrez-Franco et al., 2021)	Columbia	Forest waste lignocellulose	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	-	-	Location and capacity of facilities, materials flow
66	(Piedra-Jimenez et al., 2022)	Argentina	Forest residue	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of biomass resources, location, size, and capacity of facilities, transportation link, materials flow
67	(Singh et al., 2022)	India	Animal fat, waste cooking oil, and vegetable oil	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Location and capacity of biomass resources, location and capacity of facilities, materials

											flow, government regulations
68	(Guo et al., 2022)	China	Corn stover	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	-	-	Location and capacity of biomass resources, location and capacity of facilities, materials flow, farmers participation

Appendix B. Summary of the publications related to the tactical decision-making level of biomass supply chain for biofuel production

No	Authors	Location	Biomass type	Product	Sustainability dimensions			Decision level			Main decisions
					Economic	Environment	Social	Strategic	Tactical	Operational	
1	(Shabani and Sowlati, 2013)	British Columbia, Canada	Forest residue	Electricity	✓	✓	-	-	✓	-	Type of biomass and supply demand of biomass in power plant
2	(Osmani and Zhang, 2013)	Dakota, USA	Switchgarss	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of technology conversion, site selection and allocation of biomass,bioenergy demand,
3	(Shabani et al., 2014)	British Columbia, Canada	Forest residue	Electricity	✓	-	-	-	✓	-	Flow of material in storage and supply for electricity production
4	(Ebadian et al., 2014)	British Columbia, Canada	Agriculture residue	Biofuel (bioethanol, biodiesel)	✓	-	-	-	✓	✓	Daily biomass demand, schedule of material flow
5	A(Akhtari et al., 2014)	British Columbia, Canada	Forest-based biomass	Heat	✓	-	-	-	✓	-	Flow of material
6	(Lin et al., 2014a)	Illinois, USA	Miscanthus	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Numbers, locations, and capacities of facilities, product distribution, delivery, and operating schedules and inventory monitoring

7	(Azadeh et al., 2014)	Iran	Agriculture residue	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Location and capacity of facilities, type of technology, flow of materials
8	(De Meyer et al., 2015)	Belgium	Herb and grassland	Biogas	✓	-	-	✓	✓	-	Sourcing, procurement, and allocation of biomass, location and capcity of facilities, logistic planning
9	(Shabani and Sowlati, 2016)	British Columbia, Canada	Forest residue	Electricity	✓	-	-	-	✓	-	Biomass availability and quality, product revenue
10	(Yılmaz Balaman and Selim, 2016)	Izmir, Turkey	Animal manure and energy crops	Heat, electricity	✓	-	-	✓	✓	-	Location and capacity of facilities, transportation planning, inventory management and energy production
11	(Miret et al., 2016)	France	Corn stover and wood residue	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Network design, facilities location, process selection and inventory policy
12	(Pinho et al., 2017)	Portugal	Forest residue	N/A	✓	-	-	-	✓	-	Biomass demand, number and capacity of transportation
13	(Zamar et al., 2017)	British Columbia, Canada	Forest residue	Electricity	✓	-	-	-	✓	-	Flow of material

14	(Memari et al., 2018)	Malaysia	Oil-palm empty fruit bunches	Heat, electricity	-	✓	-	-	✓	-	Carbon tax and carbon trading
15	(Morakabatchiankar et al., 2017)	Spain	Sugar cane residue	Heat, electricity, biofuel (bioethanol, biodiesel)	✓	✓	-	✓	✓	-	Location of feedstock and facilities, bioenergy production, electricity demand
16	(Bouchard et al., 2017)	Canada	Forest residue	Heat, electricity	✓	-	-	✓	✓	-	Flow of material, transportation network
17	(Liu et al., 2017)	Taiwan	Forest residue	Electricity, biofuel (bioethanol, biodiesel)	✓	✓	-	-	✓	-	Quantity of biomass, quantity of storage, flow of materials, amount of product
18	(Babazadeh, 2017)	Iran	Jatropha seeds and waste cooking oil	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Numbers, locations, and capacities of facilities, flow of materials, transportation mode, type of conversion technology
19	(Zhang and Jiang, 2017)	Suzhou, China	Waste cooking oil	Biofuel (bioethanol, biodiesel)	✓	✓	✓	✓	✓	-	Number, sizes and locations of bio-refinery, site and amount of materials, transportation planning
20	(Akhtari et al., 2018)	British Columbia, Canada	Forest-based biomass	Heat, electricity, biofuel (bioethanol, biodiesel), solid fuel (pellet, briquette)	✓	-	-	✓	✓	-	Biomass supply and demand, number and capacity of technology conversion

21	(Zandi Atashbar et al., 2018b)	France	Agriculture residue	N/A	✓	-	-	-	✓	-	Number, size and locations of biorefineries, bioenergy demand
22	(Bairamzadeh et al., 2018)	Iran	Agriculture residue	Biofuel (bioethanol, biodiesel)	✓	-	-	✓	✓	-	Biomass supply, biofuel demand, location and capacity of biorefinery

Appendix C. Questionnaire of farmers

Questionnaire of Indonesian Farmer (1)

This questionnaire prepared of the research "Rice Cultivation Management". The survey aims to determine the perception and participation of Indonesian farmers in the management of rice residue. The results of this research can be used recommendations to determine the methods and technology that are suitable for the community needed in utilising of rice residue.

Indentity of Respondent

1. Name of Respondent: ……
2. Address of Respondent: ……
   RT: …… RW: ……
3. Age: …… year
4. Gender
   ☐ Male ☐ Female
5. Education
   ☐ Not well educated ☐ SD ☐ SMP ☐ SMA
   ☐ Diploma (D1/D2/D3)* ☐ S1 ☐ S2 ☐ S3
6. Job status as a farmer
   ☐ Rice field owner
   ☐ Rice field owner as a cultivator
   ☐ Permanent farm laborer
   ☐ Seasonal farm laborer
   ☐ Other …….
7. Rice field ownership status
   ☐ Private property ☐ Family owned land
   ☐ Rented rice field ☐ Government rice field
   ☐ Other ……
8. Farmer group membership status
   ☐ Join in the farmer group* ☐ Not joined in the farmer group
   ☐ Other ……
   **If you joined on the farmer group, what is your participation level in the farmer group?*
   ☐ *Administrator in the farmer group* ☐ *Active member in the farmer group*
   ☐ *Other* ……

Rice field characteristics

1. Rice field area: ……. m^2

2. Type of rice field

   ☐ Irrigated rice fields ☐ Rain-fed rice fields

   ☐ Tidal paddy fields ☐ Lebak rice field (swampy area)

   ☐ Dry rice fields

3. Rice field topography (Based on the land slope by the Ministry of Agriculture)

   ☐ Flat land (slope <3%) ☐ Wavy land (slope 3-14%)

   ☐ Hilly land (slope 15-30%) ☐ Mountainous land (slope >30%)

4. Types of irrigated rice field

   ☐ Irrigation water pump ☐ Drip Irrigation (vertical irrigation

   ☐ Surface irrigation which is water obtained from rivers

   ☐ Sprinkler irrigation

   ☐ Location irrigation based on gravity the higher areas will get water first

Rice cultivation activities and methods

1. Rice plantting patterns

   ☐ Rice - rice - rice (3 times a year) ☐ Rice - rice - palawija (2 times a year)

   ☐ Rice - palawija - palawija (once a year) ☐ Other ……

2. Rice cultivation system

   ☐ Direct sowing the seed (Tabela) system

   ☐ Moving plant (Tapin) system

   ☐ System of rice intensification (SRI)

   ☐ Salibu system (Once planted, harvest many times)

   ☐ New tiller crop after harvest (Ratun) system

   ☐ Other …….

Rice planting schedule (a year)

*put a checklist √

	January	February	March	April	May	June	July	August	September	October	November	December
Planning												
Ploughing												
Sowing												
Fertilization												
Weed control												
Harvesting												
Other												
…….												

3. Rice planting method

   ☐ Jajar legowo 2:1 ☐ Jajar legowo 4:1

   ☐ Jajar legowo super ☐ Other ……..

4. Rice planting equipment and machinery

   ☐ Traditional (manual methods)

   ☐ Modern equipment (transplanter, seed drill, etc) *

   ☐ Other …….

   **If you use the modern equipment in rice planting activity, what is the equipment and machine ownership status?*

   ☐ *Private property* ☐ *Rent***

   ☐ *Government assistance* ☐ *Other* ……..

   ***If you rent the modern equipment in rice planting activity, how much the rental fee? (per day or per activity)* IDR. …… *per day or per activity*

   **If you use the modern equipment or machinery, how much the fuel consumption per day or per activity in rice planting? ..…… liters per day or per activity*

5. How long time does it take to plant of rice field per cultivation period …… day

6. How many farm laborer are working on rice planting activity

   ☐ > 3 farm laborers ☐ 4 farm laborers ☐ 5 farm laborers

   ☐ 6 farm laborers ☐ > 6 farm laborers ☐ Other ……..

7. How much farm labour salary per day that you give in rice planting activity

   ☐ IDR < 50,000 ☐ IDR 50,001 – Rp. 75,000

   ☐ IDR 75,001 – Rp. 100,000 ☐ IDR 100,001 – Rp. 125,000

   ☐ IDR 125,001 – Rp. 150.000 ☐ IDR >150,000

   ☐ Other ……..

8. Rice field tillage method

   ☐ Perfect tillage ☐ Minimal tillage (partial tillage)

   ☐ Without tillage ☐ Other ……..

9. Rice plowing equipment and machinery

   ☐ Traditional equipment (uga and cow or others)

   ☐ Modern equipment (tractors, rotavator, cultivator etc)*

   **If you use the modern equipment in rice plowing activity, what is the equipment and machine ownership status?*

   ☐ Private property ☐ Rent**

   ☐ Government assistance ☐ Other ……

   ***If you rent the modern equipment in rice plowing activity, how much the rental fee? (per day or per activity)* IDR. …… *per day or per activity*

**If you use the modern equipment or machinery, how much the fuel consumption per day or per activity in rice plowing? ..…… liters per day or per activity*

10. How long time does it take to plow of rice field per cultivation period …… day
11. How many farm laborer are working on rice plowing activity

    ☐ > 3 farm laborers ☐ 4 farm laborers ☐ 5 farm laborers

    ☐ 6 farm laborers ☐ > 6 farm laborers ☐ Other ……
12. How much farm labour salary per day that you give in rice plowing activity

    ☐ IDR < 50.000 ☐ IDR 50.001 – Rp. 75.000

    ☐ IDR 75.001 – Rp. 100.000 ☐ IDR 100.001 – Rp. 125.000

    ☐ IDR 125.001 – Rp. 150.000 ☐ IDR >150.000

    ☐ Other ……
13. During rice cultivation per period, how much fertilization has been done?

    ☐ Once during the planting period ☐ Two times during the planting period

    ☐ Three times during the planting period ☐ Other …….
14. Type of fertilizer that is used for rice cultivation

    ☐ Inorganic fertilizer (N-P-K, urea fertilizer)

    ☐ Organic fertilizer (compost)

    ☐ Inorganic and organic fertilizer (cobination)

    ☐ Other …….
15. Total fertilizer consumption that is used for rice cultivation

    Nitrogen (N) fertilizer : …….. kg

    Phospor (P) fertilizer : …….. kg

    Kalium fertilizer : …….. kg

    Urea fertilizer : …….. kg

    Compost fertilizer : …….. kg

    Other fertilizer (type of fertilizer …….) : …….. kg
16. What is the fertilizer price that is used to fertilize your rice fields per cultivation period (per kg)

    Nitrogen (N) fertilizer : Rp. …… per kg

    Phospor (P) fertilizer : Rp. …… per kg

    Kalium fertilizer : Rp. …… per kg

    Urea fertilizer : Rp. …… per kg

    Compost fertilizer : Rp. …… per kg

    Other fertilizer (type of fertilizer …….) : Rp. …… per kg
17. How long time does it take to fertize of rice field per cultivation period …… day
18. How many farm laborer are working on rice field fertilizing activity

    ☐ > 3 farm laborers ☐ 4 farm laborers ☐ 5 farm laborers

☐ 6 farm laborers ☐ > 6 farm laborers ☐ Other …….

19. How much farm labour salary per day that you give on rice field fertilizing activity

☐ IDR < 50,000 ☐ IDR 50,001 – IDR 75,000

☐ IDR 75,001 – Rp. 100,000 ☐ IDR 100,001 – IDR 125,000

☐ IDR 125,001 – Rp. 150,000 ☐ IDR >150,000

☐ Other ……

20. During rice cultivation per period, weeding control method

☐ Traditional method (it used resistant variety that is adapted to environmental condition or natural weeding control)

☐ Modern method (by pesticide)

☐ Other …….

21. Type of weeding control (pesticide) that is used for rice cultivation

☐ Inorganic pesticide (manufacture products)

☐ Organic pesticide (natural products)

☐ Inorganic and organic pesticide (cobination)

☐ Other …….

22. Rice weeding control equipment and machinery

☐ Traditional equipment (manual sprayer)

☐ Modern equipment (automatic sprayer)*

☐ Other …….

**If you use the modern equipment in rice weeding control activity, what is the equipment and machine ownership status?*

☐ *Private property* ☐ *Rent***

☐ *Government assistance* ☐ *Other* ……

***If you rent the modern equipment in rice weeding control activity, how much the rental fee? (per day or per activity) Rp. …… per day or per activity*

**If you use the modern equipment or machinery, how much the fuel consumption per day or per activity in rice weeding control? ..…… liters per day or per activity*

23. Total pesticide consumption that is used for rice cultivation ……liters/kilogram*
24. What is the pesticide price that is used to weeding control your rice fields per cultivation period (per kg) Rp. ……. per liter/bottle/pack*
25. How long time does it take to weeding of rice field per cultivation period …… day
26. How many farm laborer are working on rice field weeding activity

☐ > 3 farm laborers ☐ 4 farm laborers ☐ 5 farm laborers

☐ 6 farm laborers ☐ > 6 farm laborers ☐ Other …….

27. How much farm labour salary per day that you give on rice field weeding activity

☐ IDR < 50,000 ☐ IDR 50,001 – IDR 75,000

☐ IDR 75,001 – Rp. 100,000 ☐ IDR 100,001 – IDR 125,000

☐ IDR 125,001 – Rp. 150,000 ☐ IDR >150,000

☐ Other ……

Rice grain production

1. Rice plant variety

   ☐ Ciherang ☐ Inpari ☐ IR 64. ☐ Other …….

2. Rice grain after harvest production per cultivation period per rice field area (*gabah kering panen*)

   ☐ < 2 tonnes ☐ 2-4 tonnes ☐ 5-6 tonnes

   ☐ 7-8 tonnes ☐ 8-9 tonnes ☐ > 9 tonnes

3. The grain rice price per kg that you sell

   ☐ < IDR 1,000 ☐ IDR 1,001-Rp. 2,000 ☐ IDR 2,001-Rp.3,000.

   ☐ IDR 3,001-Rp. 4,000 ☐ IDR 4,001-Rp. 5,000 ☐ > IDR 5,000

4. Do you sell the rice grain directly after harvesting?

   ☐ Yes, I do*

   ☐ No, I don't**

   **If you sell the rice grain directly after harvesting, where do you sell it?*

   ☐ *Government (KUD or BumDes)* ☐ *Agricultural broker*

   ☐ *Directly to consumer* ☐ *Other …….*

   ***If you did not sell the grain, what is the process that you doing?*

   ☐ *Drying the rice grain* ☐ *Storage the rice grain*

   ☐ *Milling the rice grain*** ☐ *All the processes*

   ☐ *Other …….*

   ****If you are milling the rice grain, where do you mill the rice grain?^*

   ☐ *In the rice fields by bringing a mobile rice milling machine*

   ☐ *In the rice milling factory^^*

   ☐ *Other …….*

   ^If you are milling the rice grain, how much the operational cost? (per day or per activity)

   IDR …… *per day or per activity*

   ^^If you are milling the rice grain in the rice milling factory, what is the distance between the rice fields and the rice milling factory?

   ☐ *< 1 km* ☐ *2 km* ☐ *3 km*

   ☐ *4 km* ☐ *> 4 km* ☐ *Other …….*

   ^^If you are milling the rice grain in the rice milling factory, what the vechiles that you use to transpot the rice grain from the rice field to the rice milling factory?

   ☐ *Truck* ☐ *Motocycle* ☐ *Bicycle*

☐ *Car or pick up car* ☐ *Pedicab or cart* ☐ *Other …….*

5. Where is the place that you store the rice grain?

   ☐ House ☐ Private warehouse*

   ☐ Public warehouse* ☐ *Other …….*

   **If you store the rice grain in the warehouse, what is the distance between the rice fields and the warehouse?*

   ☐ < *1 km* ☐ *2 km* ☐ *3 km*

   ☐ *4 km* ☐ > *4 km* ☐ *Other …….*

6. Do you sell the rice (beras) after milling?

   ☐ Yes, I do*

   ☐ No, I don't

   **If you sell the rice (beras), where do you sell it?*

   ☐ *Government (KUD or BumDes)* ☐ *Agricultural broker*

   ☐ *Directly to consumer* ☐ *Other …….*

7. The rice (beras) price per kg that you sell

   ☐ < IDR 5,000 ☐ IDR 5,001-Rp. 7,001 ☐ IDR 7,001-Rp. 9,000.

   ☐ IDR 9,001-Rp. 11,000 ☐ IDR > 11,001 ☐ Other .....

   **If you sell rice/beras, how much rice you can produce per cultivation period per rice field area*

   ☐ < 2 tonnes ☐ 2-4 tonnes ☐ 5-6 tonnes

   ☐ 7-8 tonnes ☐ 8-9 tonnes ☐ > 9 tonnes

8. What is the transportation mode that you use during the rice cultivation activities?

   ☐ *Truck* ☐ *Motocycle* ☐ *Bicycle*

   ☐ *Car or pick up car* ☐ *Pedicab or cart* ☐ *Other …….*

Rice harvesting activities

1. Rice harvesting equipment and machinery

   ☐ Traditional equipment (sicke, ani-ani etc)

   ☐ Modern equipment (harvester machine)*

   ☐ Other …….

   **If you use the modern equipment in rice harvesting activity, what is the equipment and machine ownership status?*

   ☐ *Private property* ☐ *Rent***

   ☐ *Government assistance* ☐ *Other ……*

   ***If you rent the modern equipment, how much the rental fee? (per day or per activity)*

   IDR…… *per day or per activity*

   **If you use the modern equipment or machinery, how much the fuel consumption per day or per activity? ..…… liters per day or per activity*

2. How long time does it take to harvesting of rice field per cultivation period …… day

3. How many farm laborer are working on rice harvesting activities

   ☐ > 3 farm laborers ☐ 4 farm laborers ☐ 5 farm laborers

   ☐ 6 farm laborers ☐ > 6 farm laborers ☐ Others …….

4. How much farm labour salary per day that you give on rice harvesting activity

   ☐ IDR < 50,000 ☐ IDR 50,001 – IDR 75,000

   ☐ IDR 75,001 – Rp. 100,000 ☐ IDR 100,001 – IDR 125,000

   ☐ IDR 125,001 – Rp. 150,000 ☐ IDR >150,000

   ☐ Other ……

5. How is the method to cut the rice plant (rice straw)

   ☐ Cut at the top* ☐ Cut on the bottom

   * *If you cut of rice at the top, what do you do with the rice straw that is leave on the rice field?*

   ☐ *Leave of the rice straw in the soil* ☐ Burn it on the rice field

   ☐ *Other* ……

6. Do you utilize the rice straw in post-harvest time

   ☐ Yes, I always utilize*☐ Sometimes, I utilize*

   ☐ No, I didn't utilize ☐ Other …….

   * *If you utilize the rice straw, what for you utilize it?*

   ☐ *Animal feed* ☐ *Fertilizer*

   ☐ *Mulch when I remant in the rice field* ☐ *Raw material of craft*

   ☐ *Raw material of biofuel* ☐ *Other* …….

7. In the future, are you interested to more and valorized utilize the rice straw for additional income?

   ☐ Yes, a lot ☐ Yes, a little bit

   ☐ Not really ☐ Other …….

Questionnaire of Indonesian Farmer (2)

This questionnaire prepared for the research "**Agricultural Residue Valorization**". The survey aims to determine the Indonesian farmers perception and expectation in the rice straw valorization. This research can be used as recommendations to assess the methods and technology suitable for the community needed in utilizing crop residue.

Respondents' profile

1. Age of respondent _____ years
2. Gender ☐ Male ☐ Female
3. Education
   ☐ Primary school ☐ Middle school
   ☐ High school ☐ Bachelor degree and above
4. Duration on field working
   ☐ < 10 years ☐ 11 – 15 years ☐ 16 – 20 years
   ☐ 21 – 25 years ☐ > 25 years

Present rice straw utilization

1. What is percentage of rice straw utilization for valuable materials (i.e., animal feed, fertilizer, mulch, or handicrafts raw materials) during each planting period?

Estimation of rice straw utilization (%)									
10	20	30	40	50	60	70	80	90	100

2. Are you use rice straw for animal feed and bedding?
   ☐ Never ☐ Rarely ☐ Sometimes
   ☐ Often ☐ Always
3. Are you use rice straw for planting purposes, such as compost, mulch, or mushroom planting media?
   ☐ Never ☐ Rarely ☐ Sometimes
   ☐ Often ☐ Always

Availability of facilities to support rice straw valorization program

1. What is your opinion about the availability of accessing the latest information on rice cultivation methods to support rice straw management in the post-harvest period?
   ☐ Strongly not available ☐ Not available ☐ Possibly
   ☐ Available ☐ Strongly available
2. What is your opinion about the availability of accessing the weather information to support rice cultivation and straw management in the post-harvest period?
   ☐ Strongly not available ☐ Not available ☐ Possibly
   ☐ Available ☐ Strongly available

3. What is your opinion about the availability of accessing the facilities, such as public warehouses, agricultural equipment and machinery, distribution networking, and market share of rice residue to support rice planting activities?

☐ Strongly not available ☐ Not available ☐ Possibly
☐ Available ☐ Strongly available

Governments' role to support rice straw valorization program

1. What is your opinion about the government's role in regularly providing up-to-date rice cultivation methods and weather information through agricultural extension and training?

☐ Not at all role ☐ Slightly role ☐ Somewhat role
☐ Very role ☐ Extremely role

2. What is your opinion about the government's role in providing supporting facilities, such as public warehouses, agricultural equipment and machinery, distribution networking, and market share of rice residue to support rice planting activities?

☐ Not at all role ☐ Slightly role ☐ Somewhat role
☐ Very role ☐ Extremely role

Farmers' motivation to utilize and manage the rice straw for valorization program

1. How much does your motivation level when you are using and managing rice straw as a valuable material that can improve the quality of the environment because it is a way to reduce open burning activities that cause air pollution, water contamination, and soil erosion?

☐ Very poor ☐ Below average ☐ Average
☐ High ☐ Very high

2. How much does your motivation level when you are using and managing rice straw as a valuable material that can improve the quality of the economy because it is a way to earn additional income from rice cultivation activities?

☐ Very poor ☐ Below average ☐ Average
☐ High ☐ Very high

3. How much motivation do you gain when you use and manage rice straw as a valuable material with benefits for improving social community quality through empowerment programs?

☐ Very poor ☐ Below average ☐ Average
☐ High ☐ Very high

Perception of rice straw utilization and management

1. What is your perception level when you use and manage rice straw as a valuable material that can reduce open burning activities during the post-harvesting period, so the air pollution that causes greenhouse gas emissions and human respiration problems can be mitigated?

☐ Strongly disagree ☐ Disagree ☐ Neutral
☐ Agree ☐ Strongly agree

2. What is your perception level when you use and manage rice straw as a valuable material that can earn additional income from rice cultivation activities?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

3. What is your perception level when you use and manage rice straw as a valuable material that can reduce soil erosion because the traditional methods assume that the open burning is a method of returning the nutrient into the soil?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

Expectation of rice straw utilization and management

1. What is your expectation of the government's ability to provide training and education to improve farmers' knowledge and awareness?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

2. What is your expectation of the government's ability to provide supporting facilities?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

3. What is your expectation of the government's ability to provide funding assistance?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

4. What is your expectation of the government's ability to provide market share?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

5. What is your expectation of the government's ability to provide integrated cooperation?

   ☐ Strongly disagree ☐ Disagree ☐ Neutral
   ☐ Agree ☐ Strongly agree

Appendix D. Farmers' characteristics in the factor map

1. Internal factors

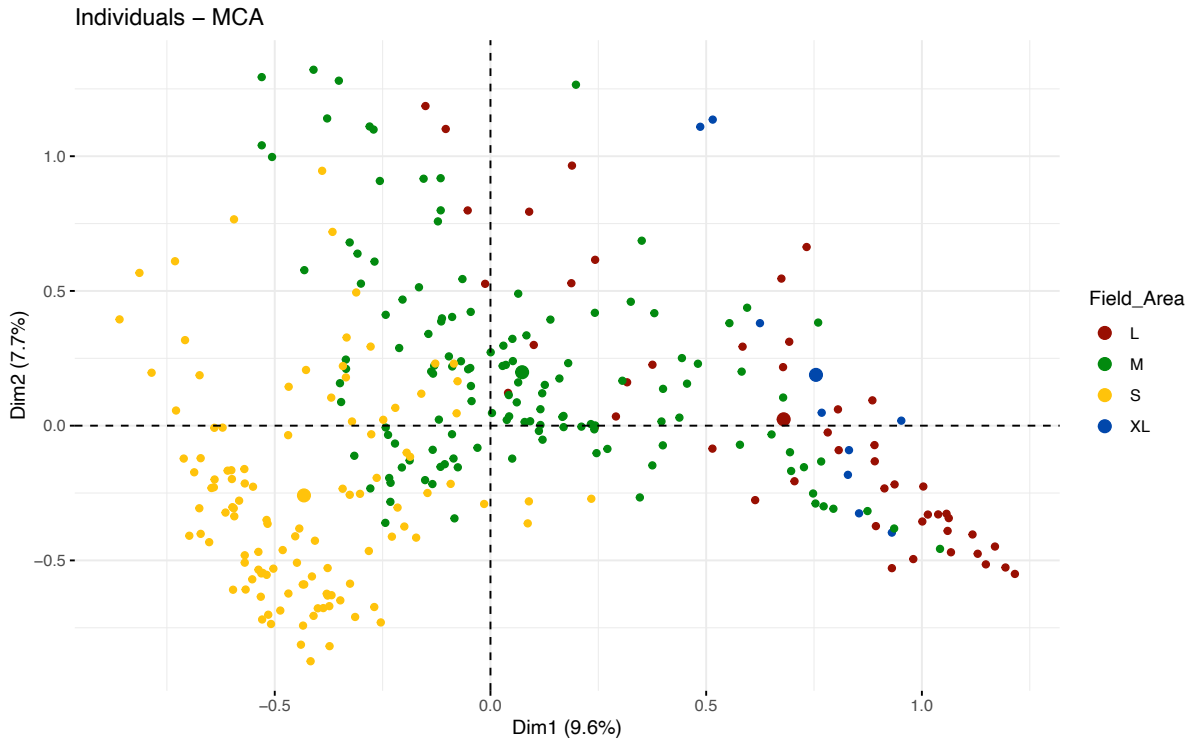


Figure D-1. Factorial map – rice field area

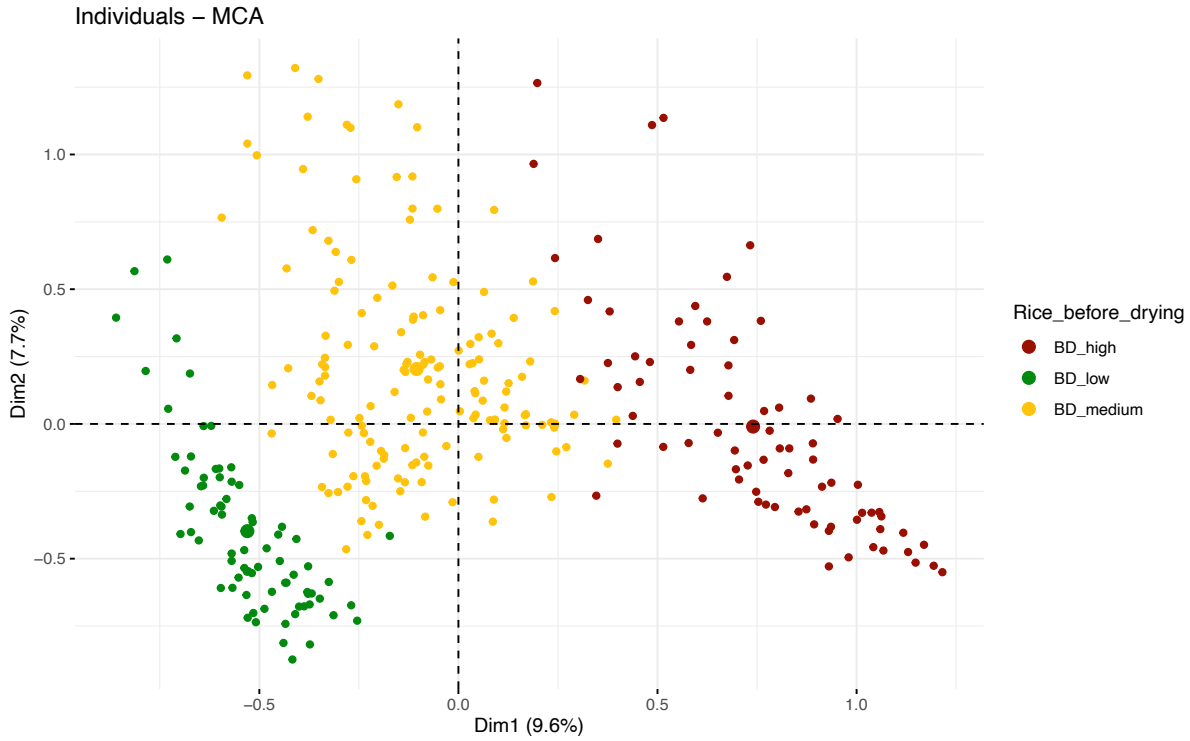


Figure D-2. Factorial map – rice production before drying

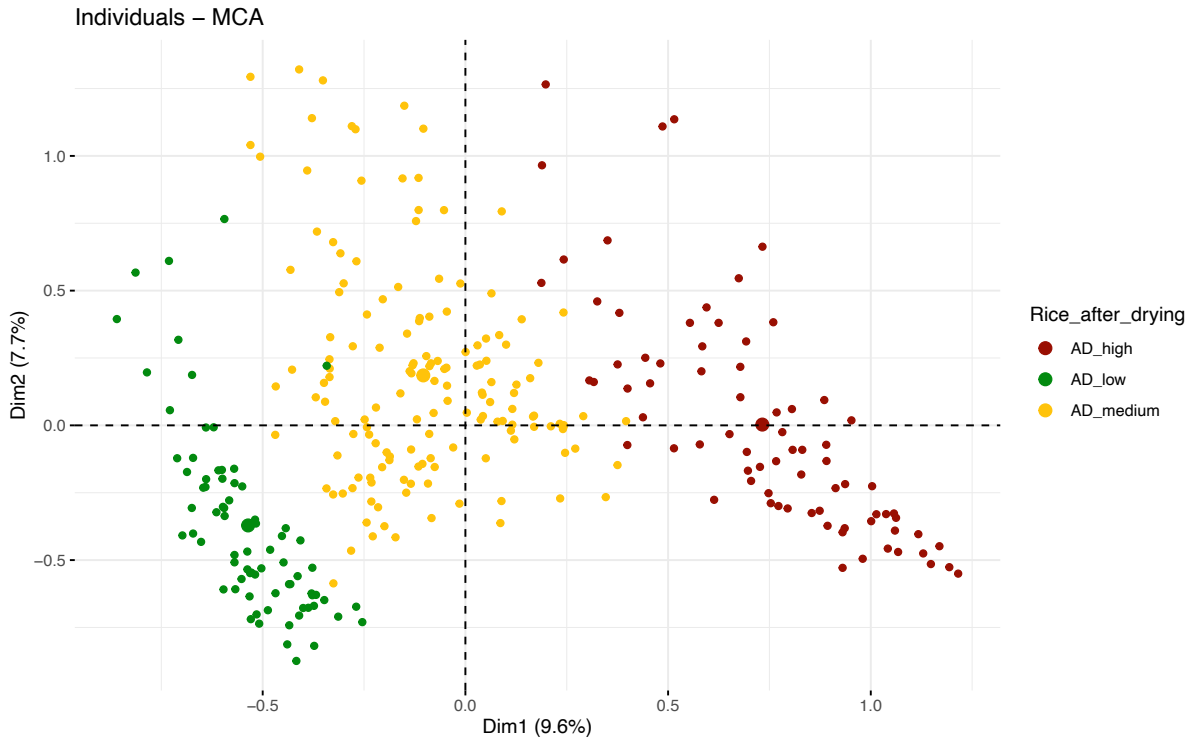


Figure D-3. Factorial map – rice production after drying

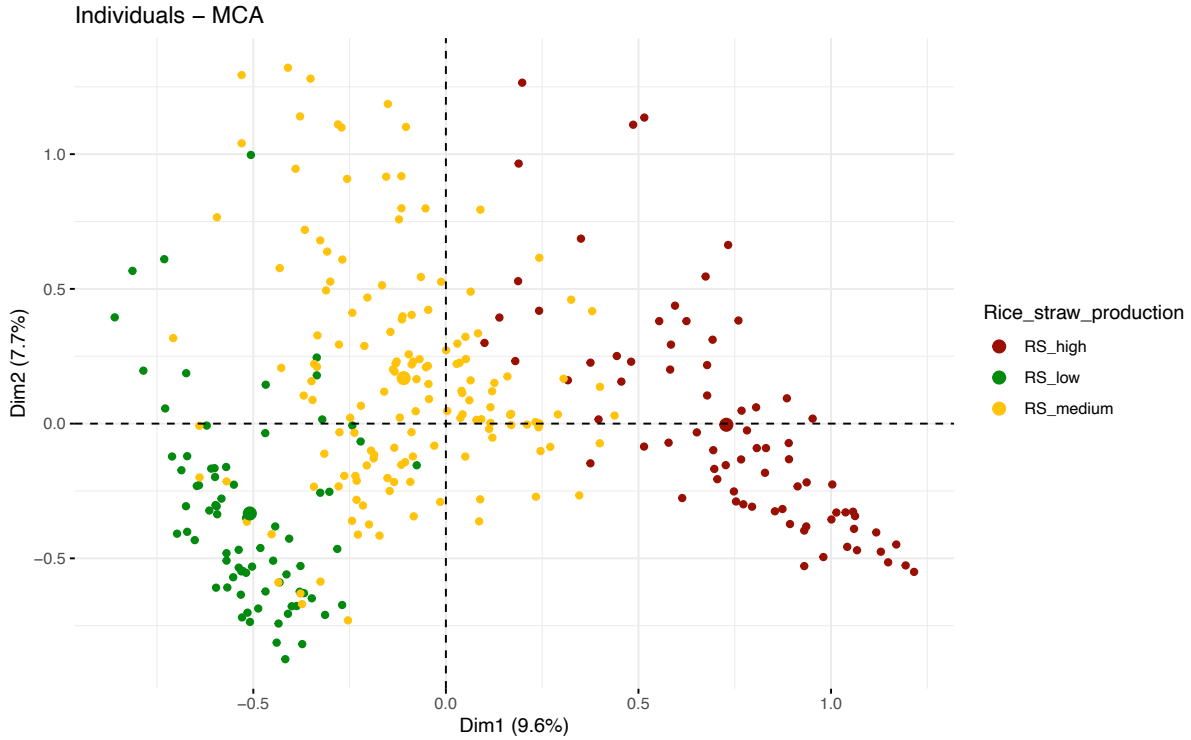


Figure D-4. Factorial map – rice straw production

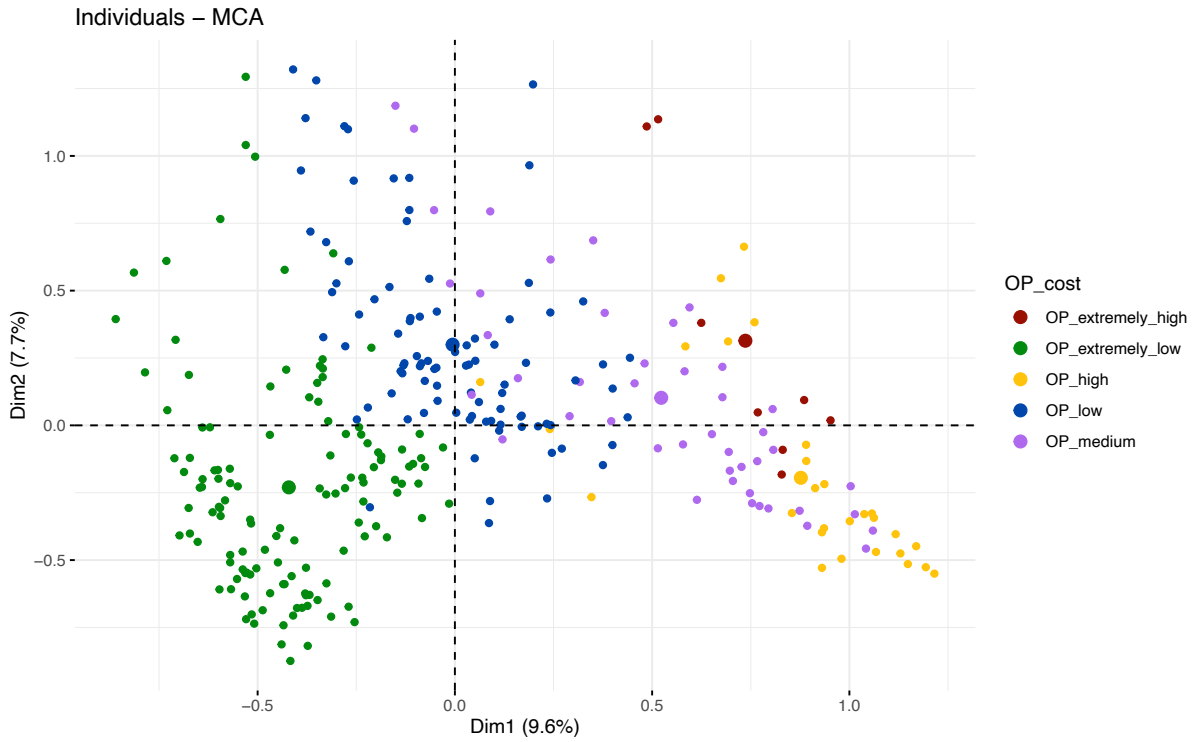


Figure D-5. Factorial map – operational cost

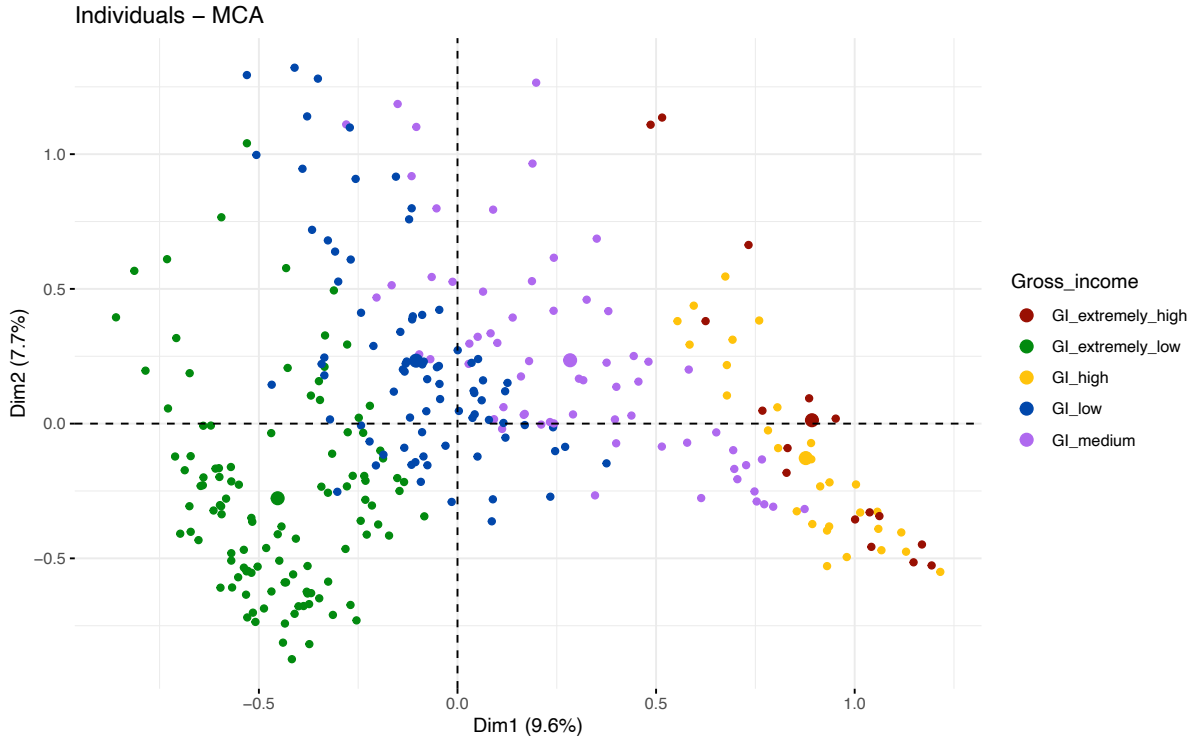


Figure D-6. Factorial map – gross income

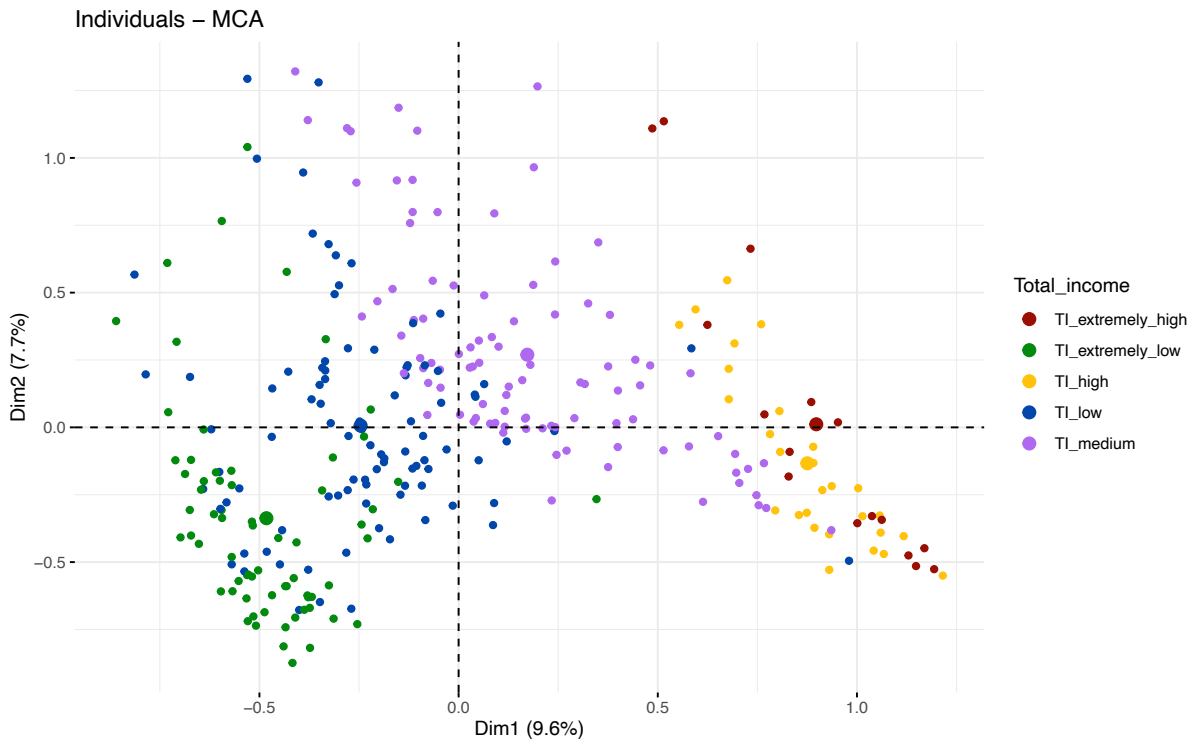


Figure D-7. Factorial map – total income

2. External factors

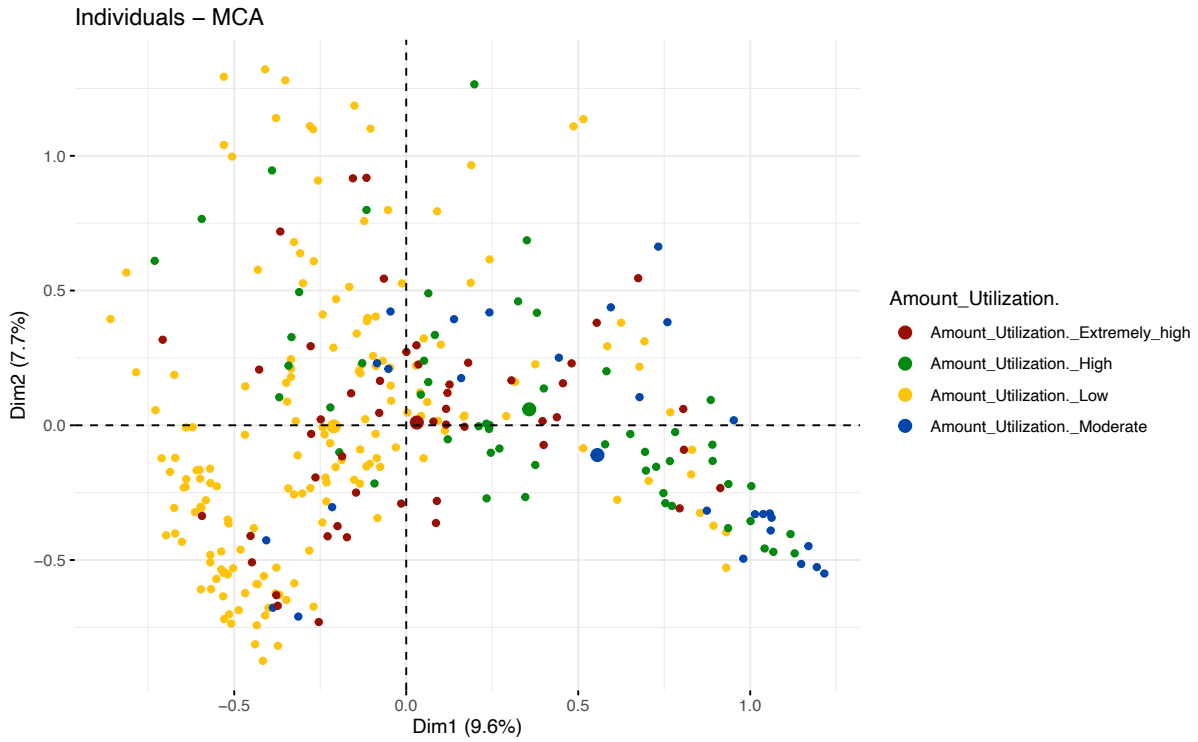


Figure D-8. Factorial map – current utilization of rice straw

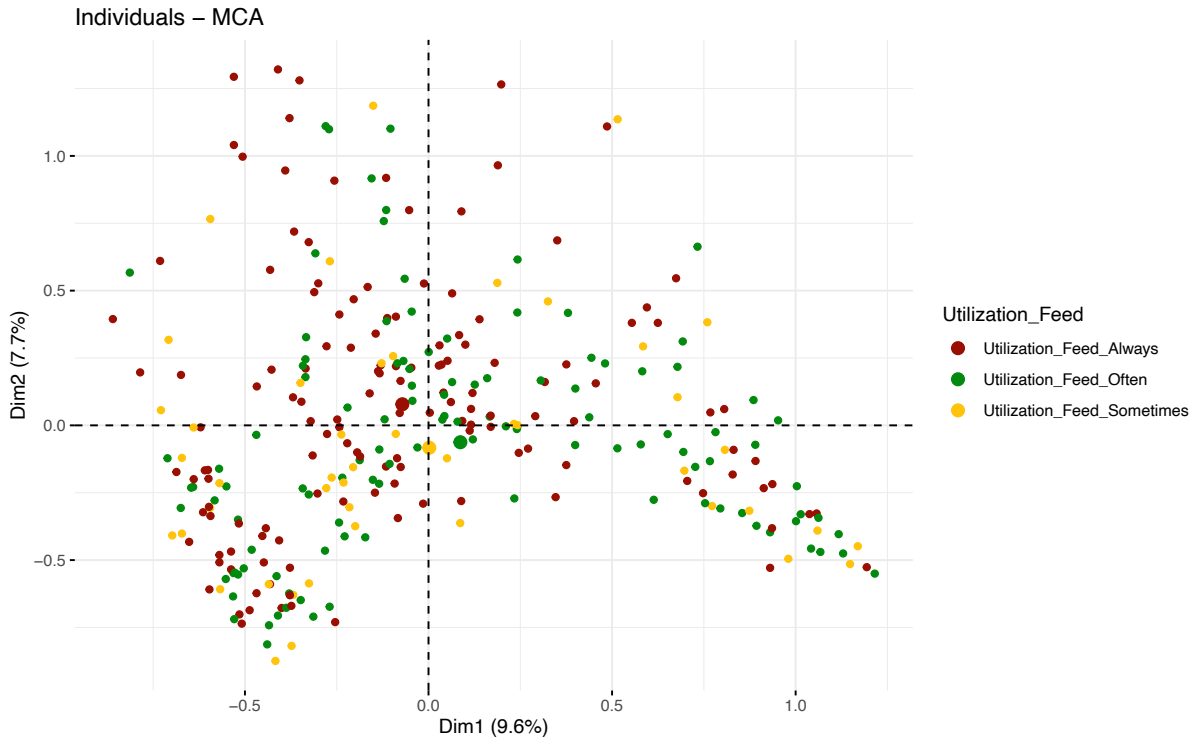


Figure D-9. Factorial map – rice straw utilization as animal feeding

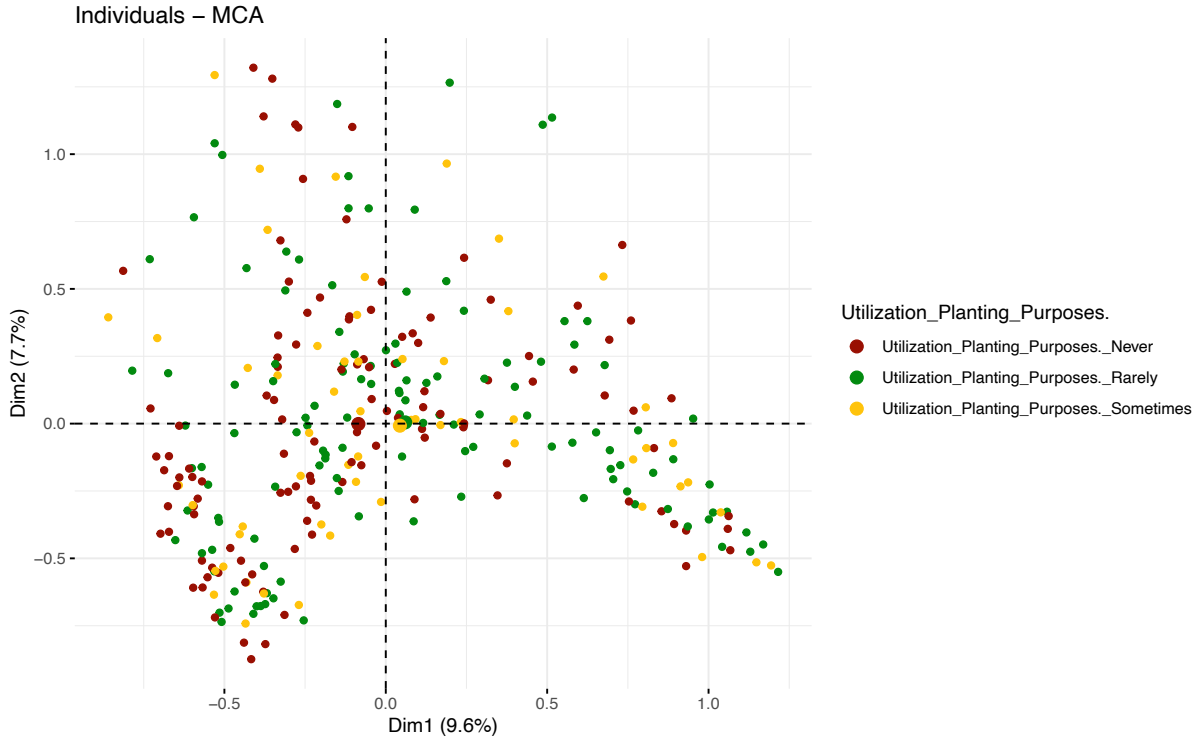


Figure D-10. Factorial map – rice straw utilization as planting purposes

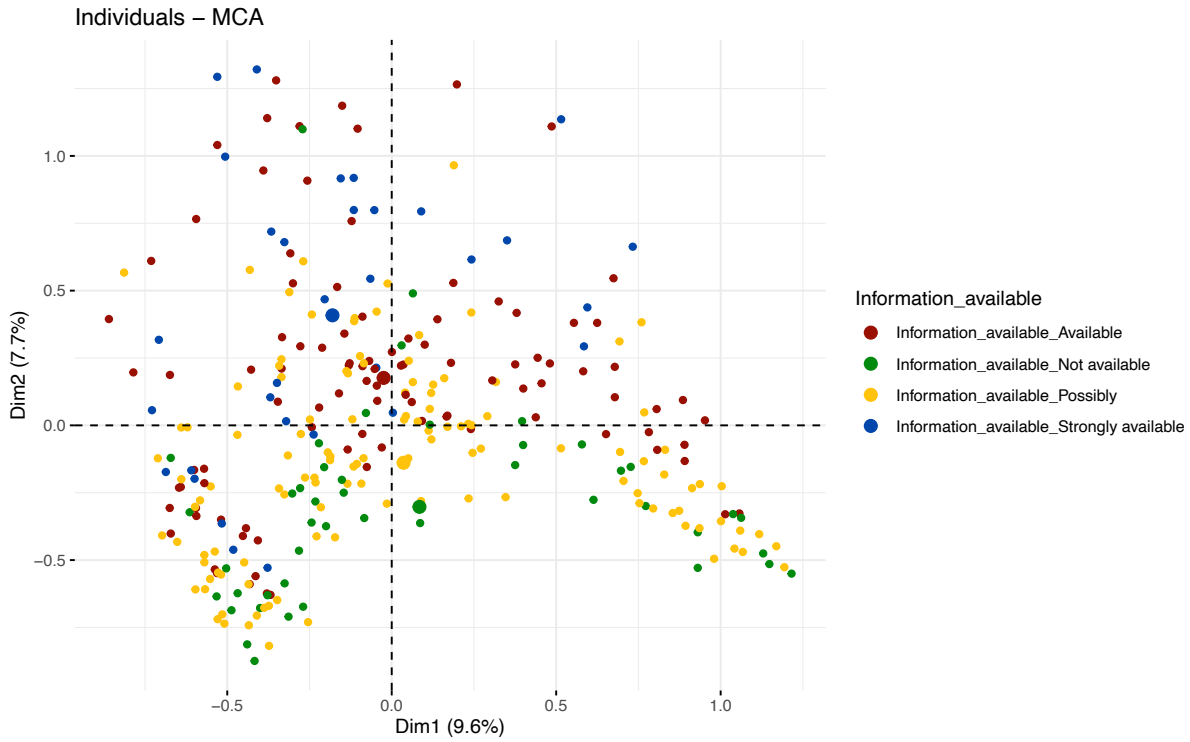


Figure D-11. Factorial map – information availability

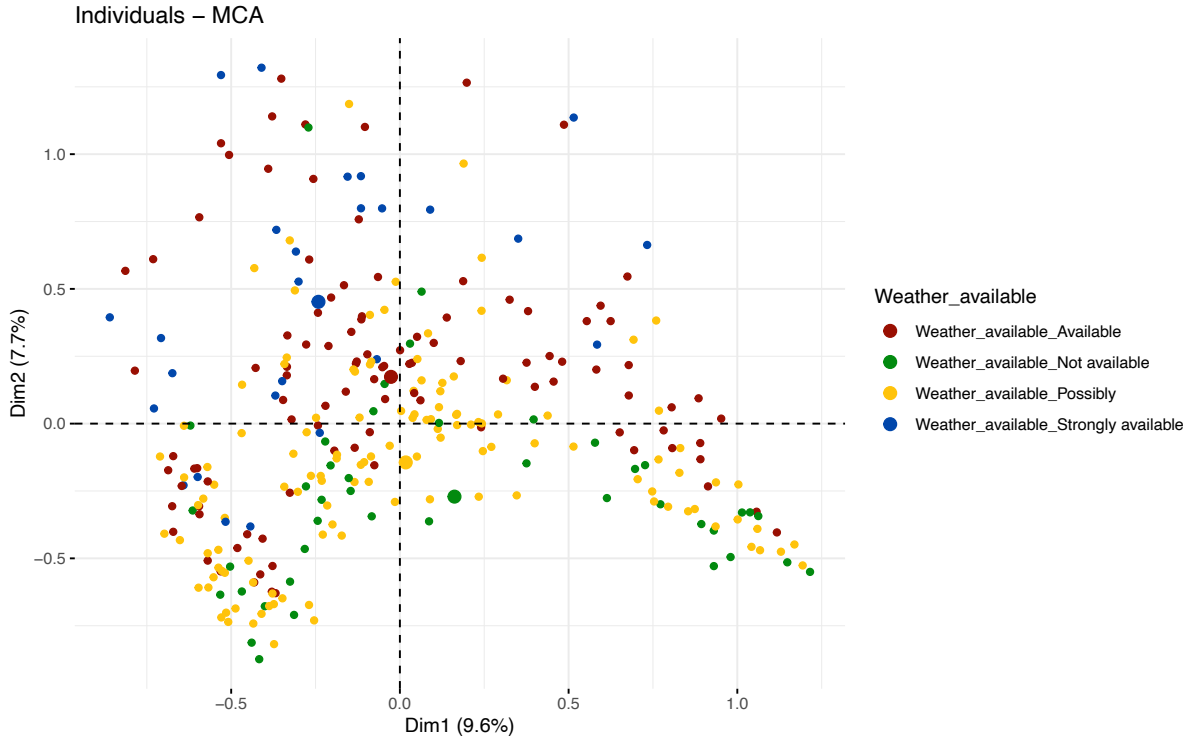


Figure D-12. Factorial map – weather availability

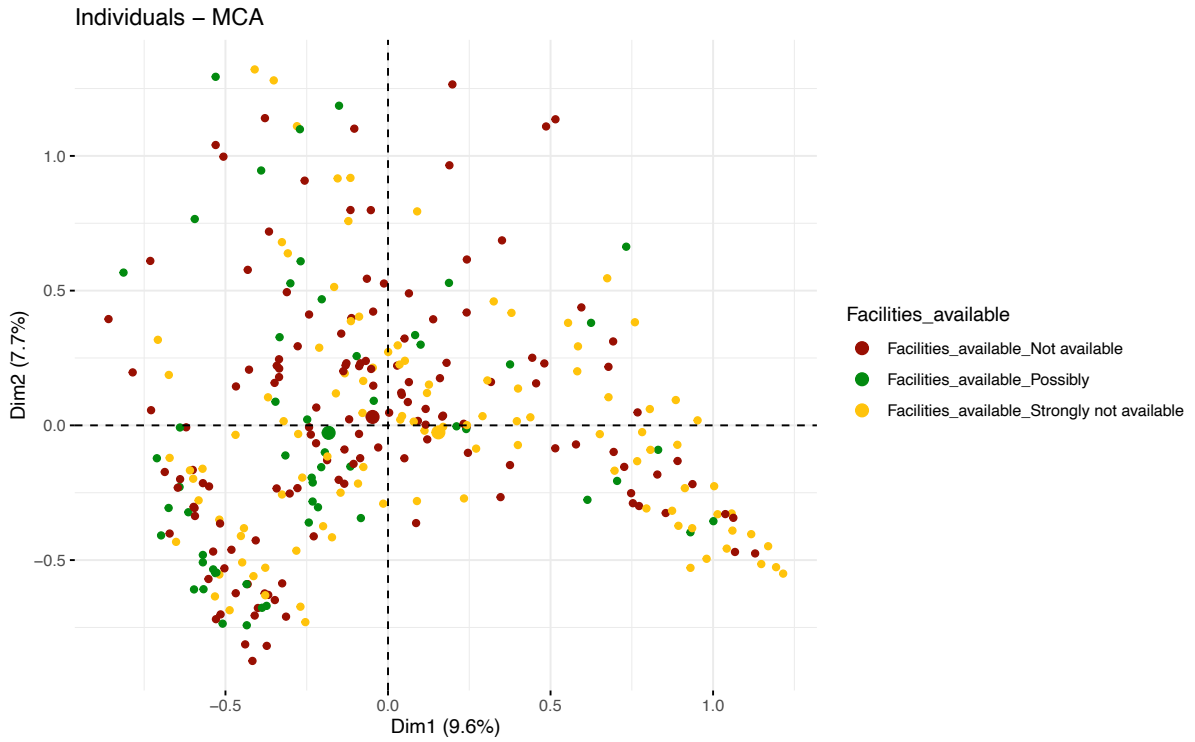


Figure D-13. Factorial map – facilities availability

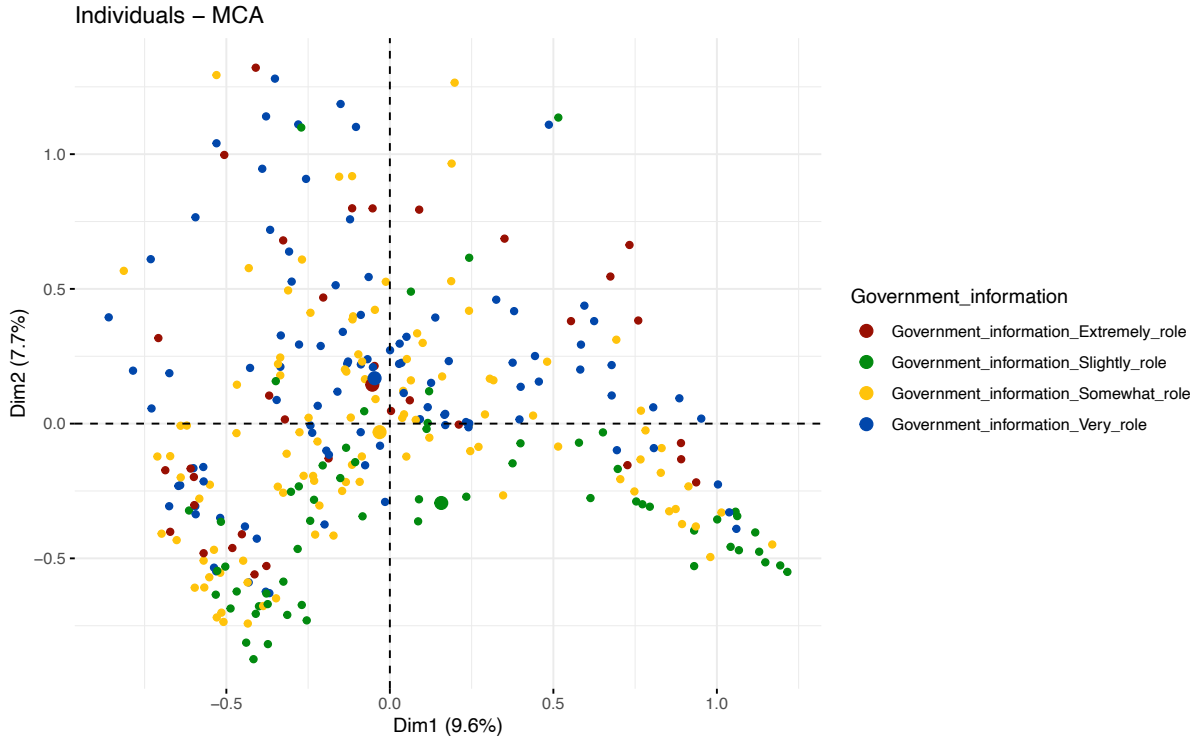


Figure D-14. Factorial map – government's role provides information

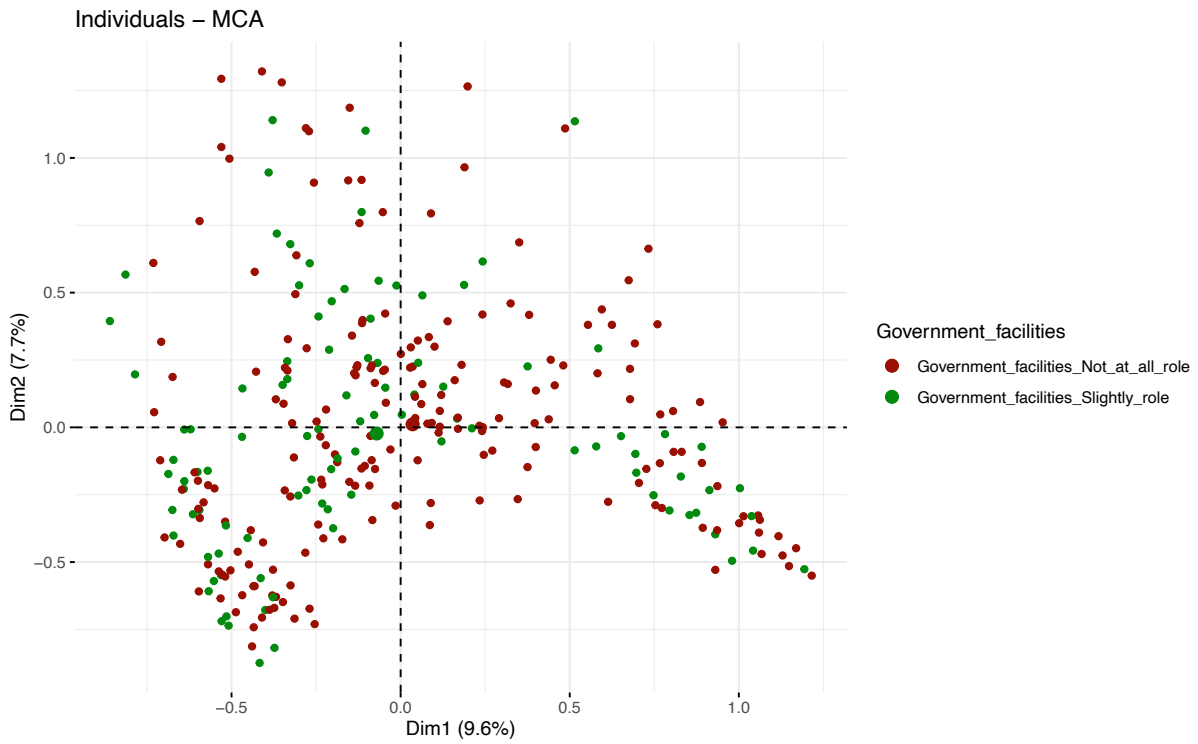


Figure D-15. Factorial map – government's role provides facilities

3. Farmers' motivation

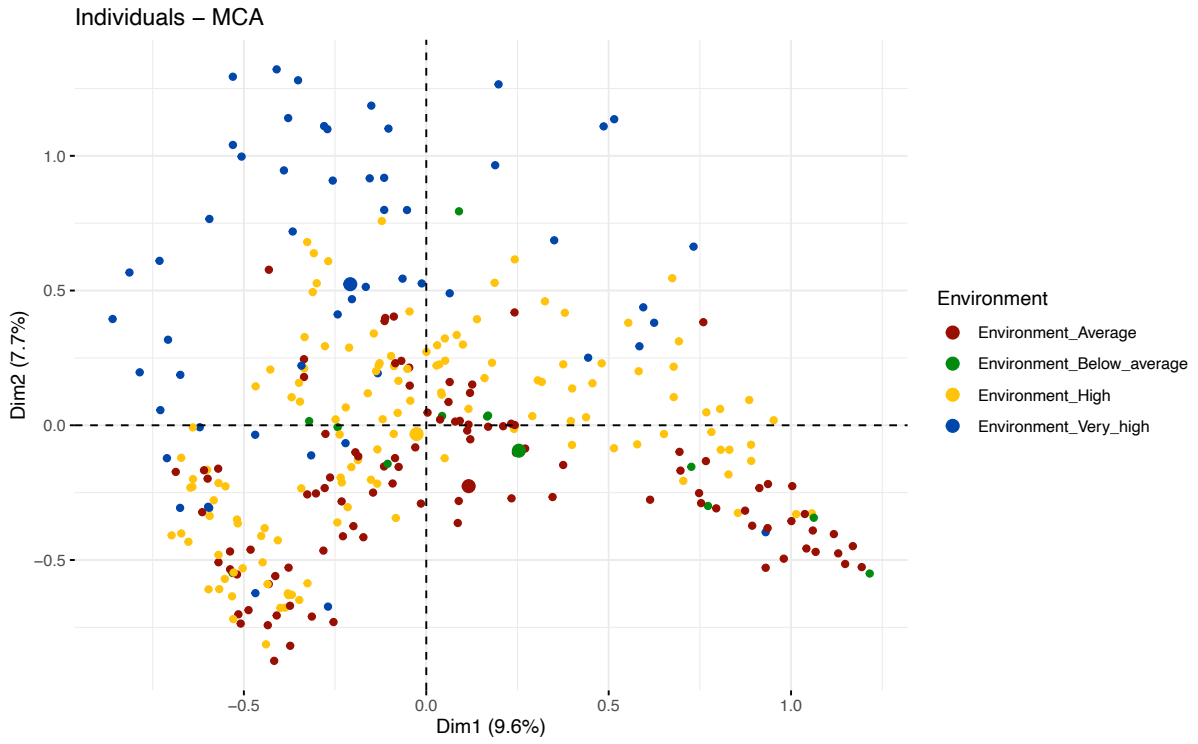


Figure D-16. Factorial map – environment motivation

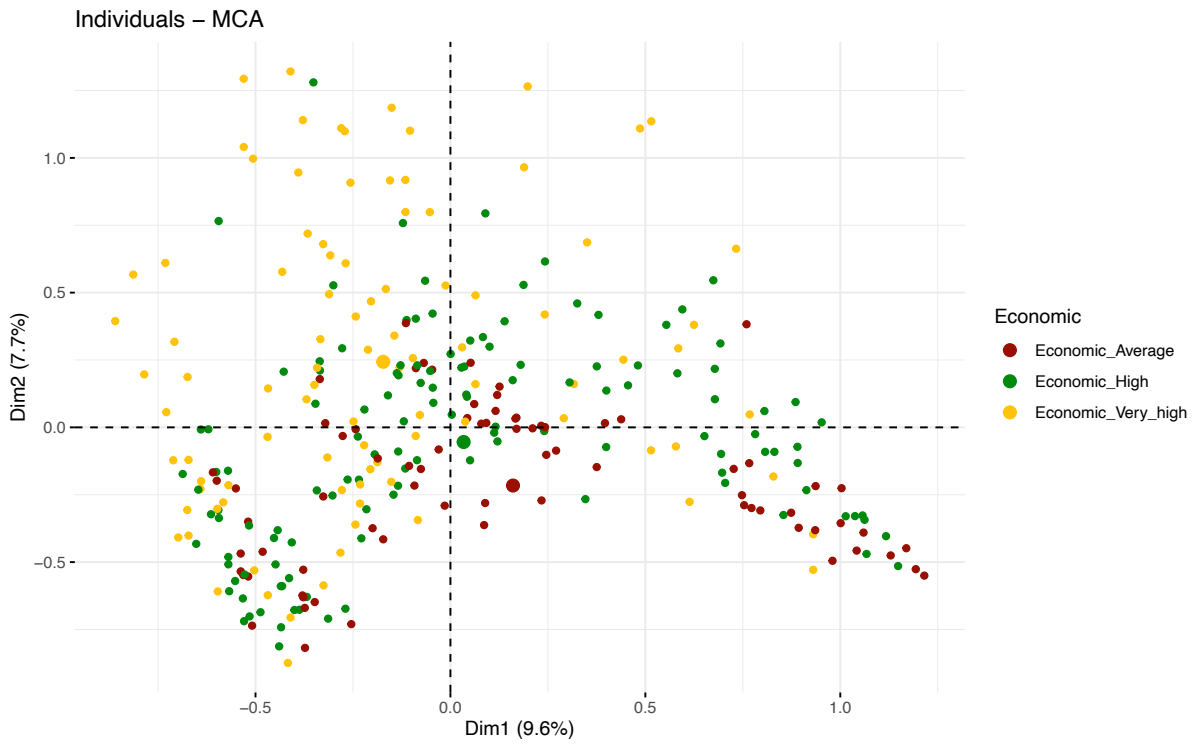


Figure D-17. Factorial map – economic motivation

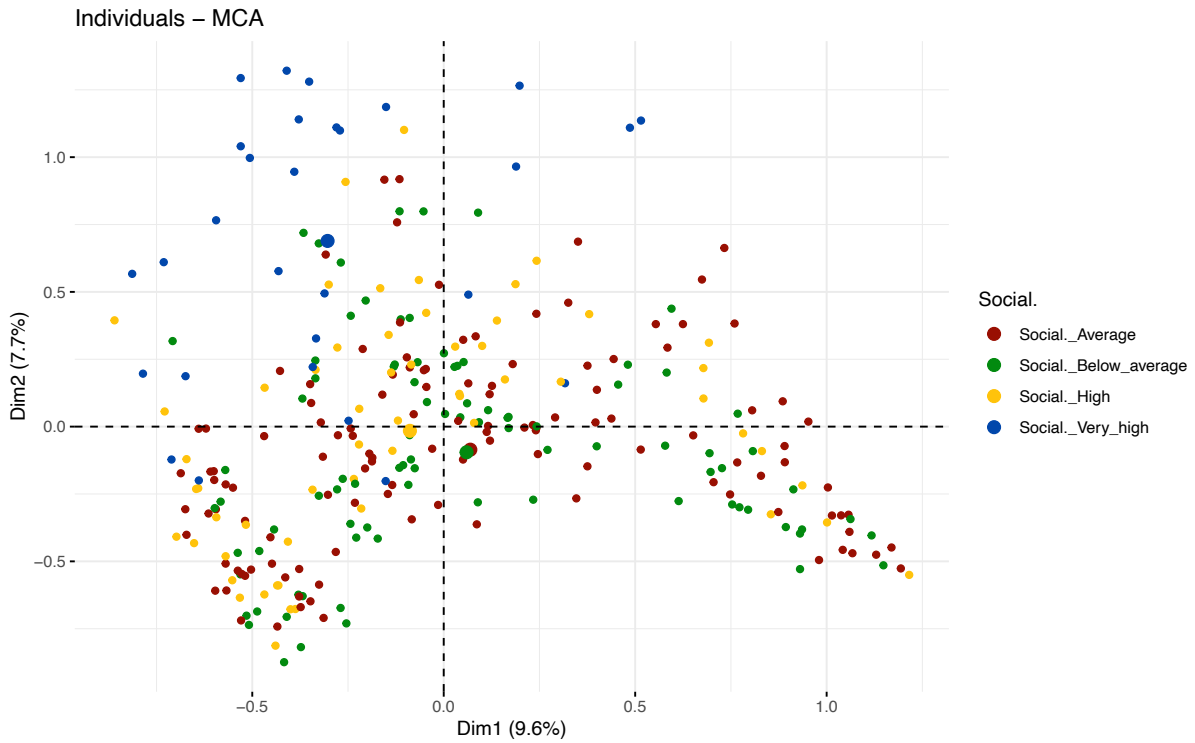


Figure D-18. Factorial map – social motivation

4. Farmers' perception

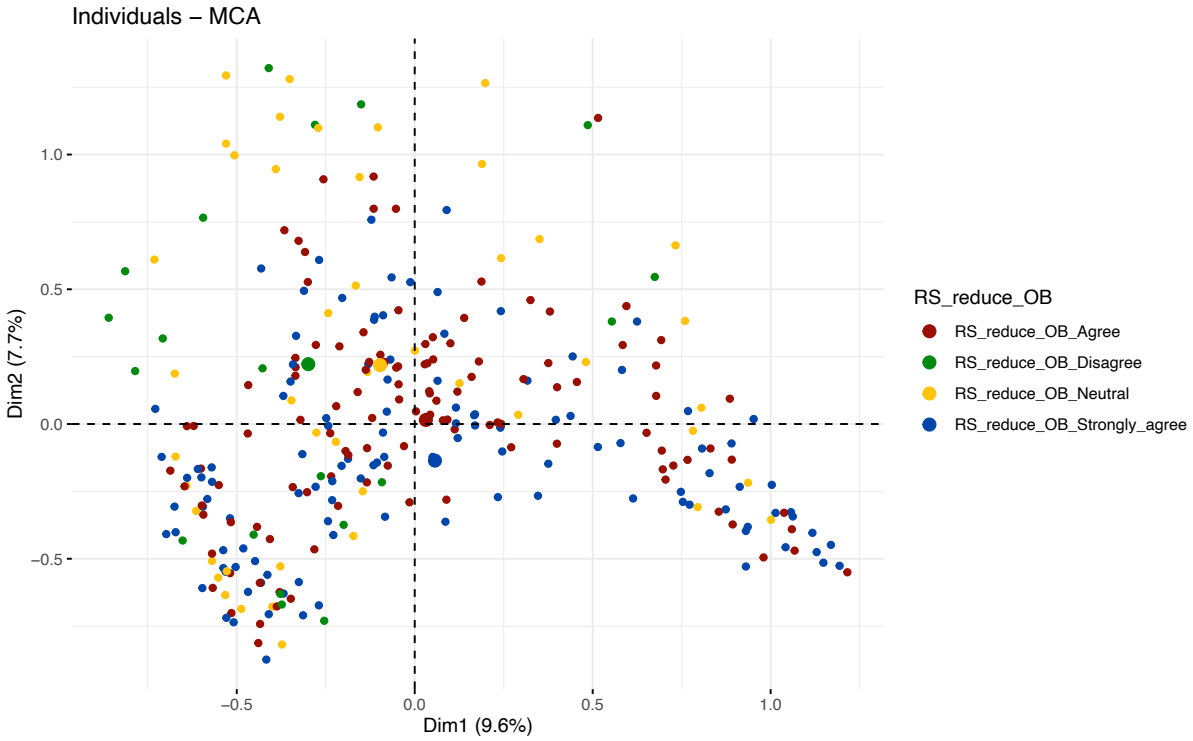


Figure D-19. Factorial map – perception of rice straw can reduce open burning

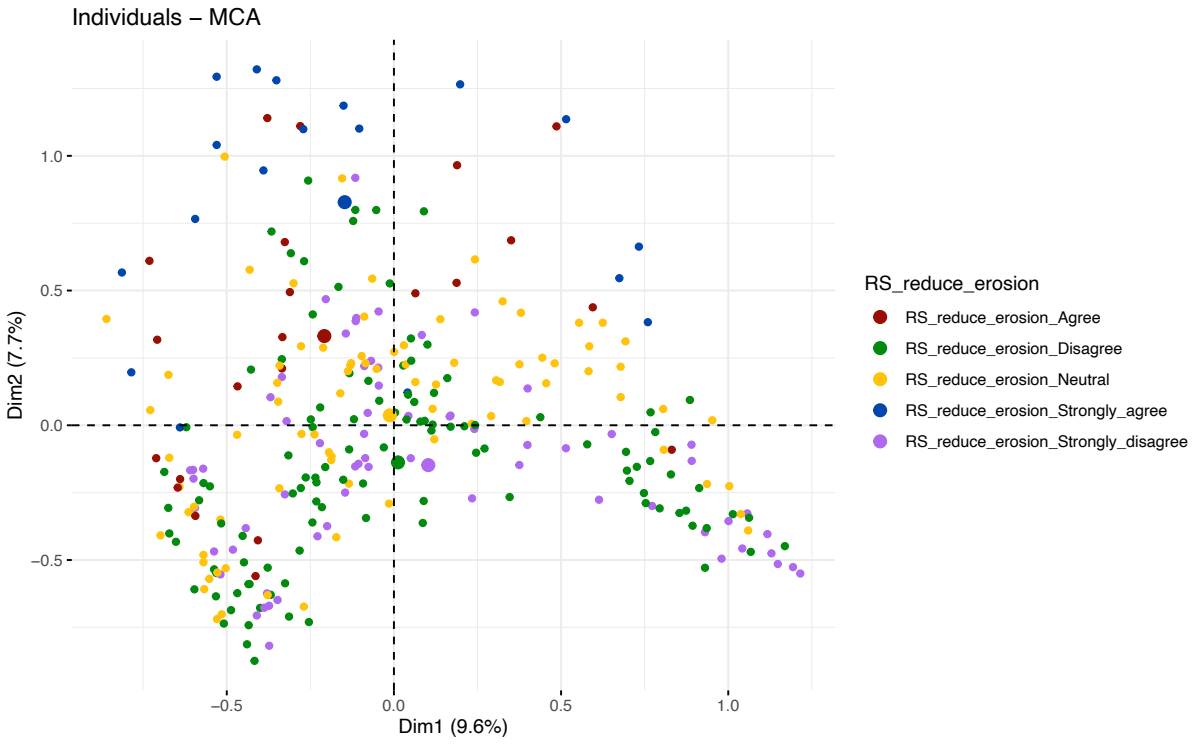


Figure D-20. Factorial map – perception of rice straw can reduce erosion

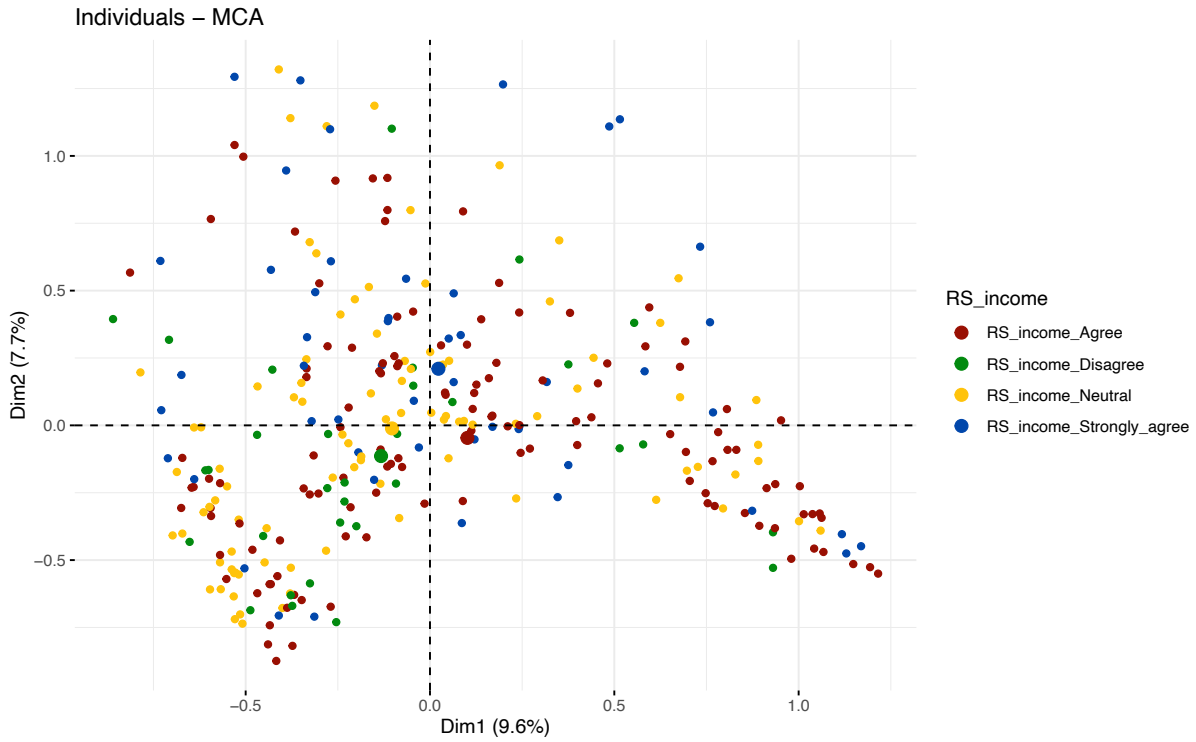


Figure D-21. Factorial map – perception of rice straw can add revenue

5. Farmers' expectation

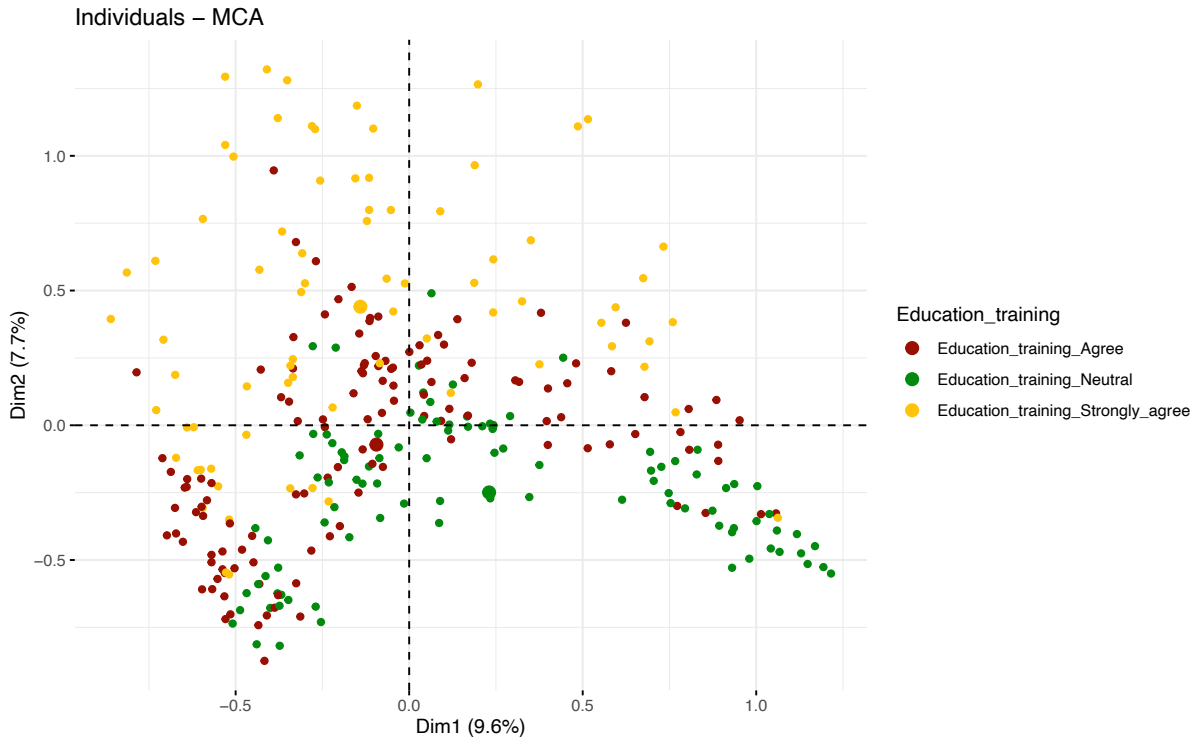


Figure D-22. Factorial map – expectation of education and training

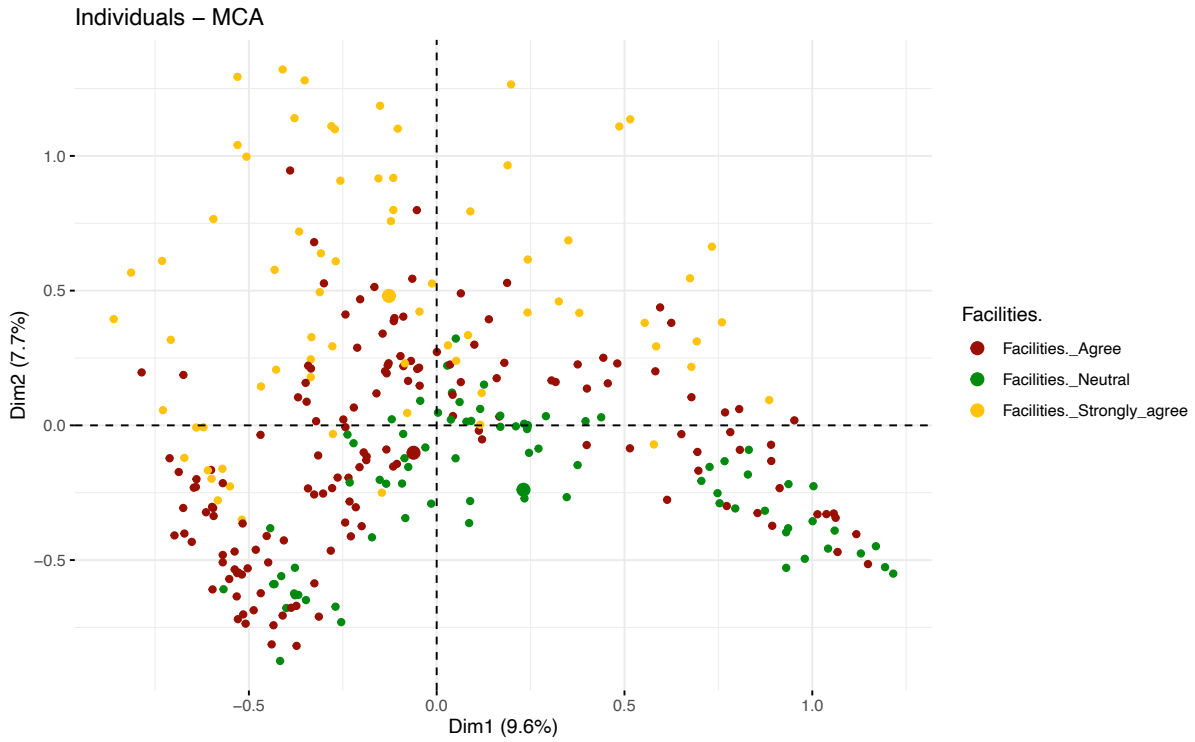


Figure D-23. Factorial map – expectation of facilities

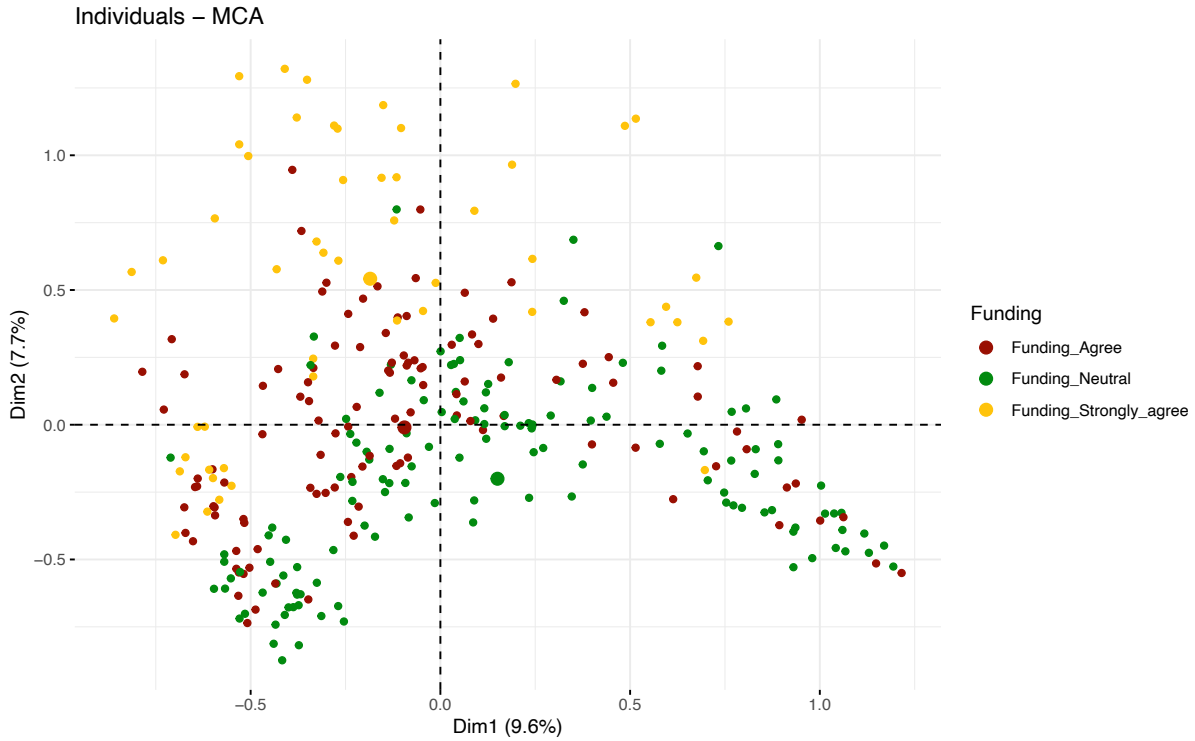


Figure D-24. Factorial map – expectation of funding assistance

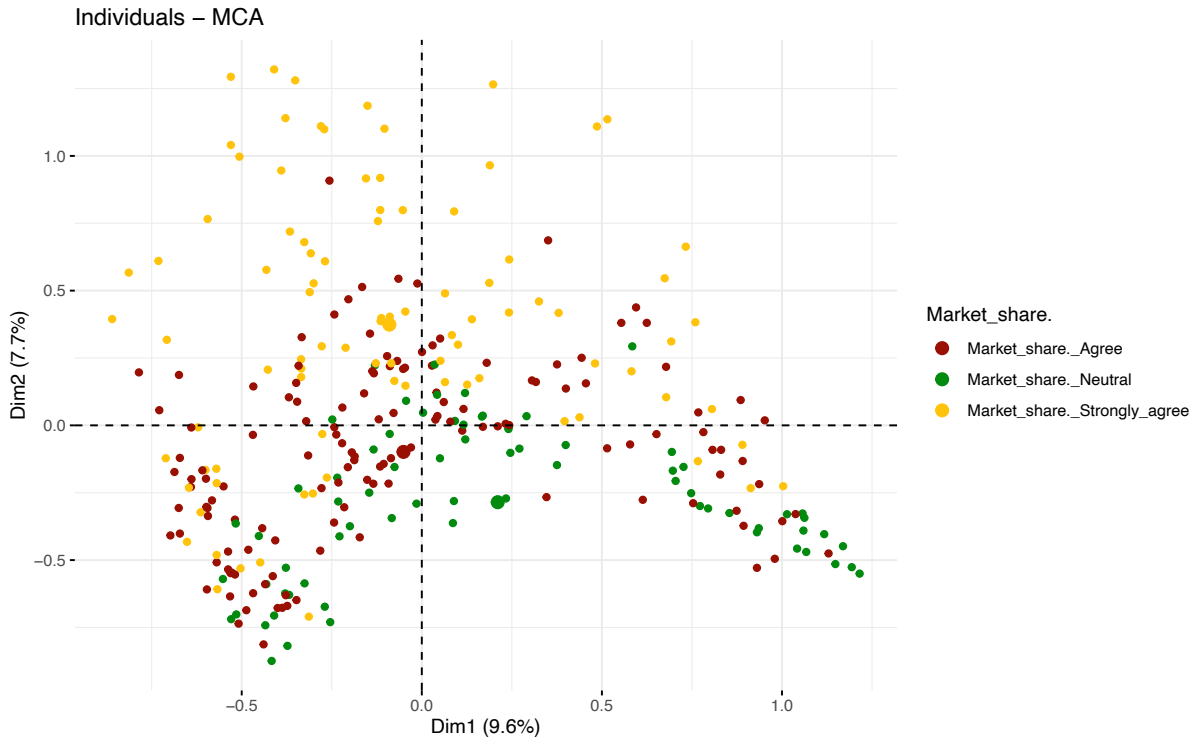


Figure D-25. Factorial map – expectation of market share

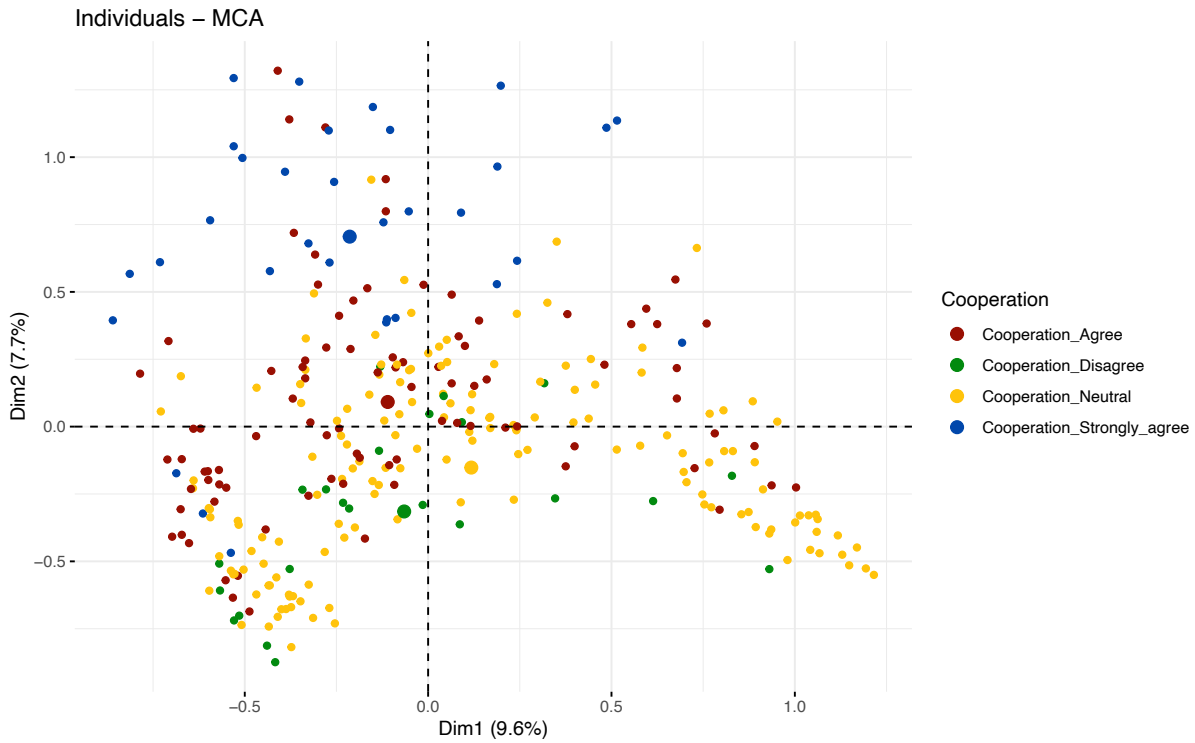


Figure D-26. Factorial map – expectation of cooperation

Appendix E. Indonesia's regulation and policy related to biomass energy

Title of regulations	Purpose
Presidential decree No 5, the year 2006 on National Energy Policy	Energy diversification and conservation in 2025
Presidential Instruction No 1, the year 2006 on Biofuel Development	The guidance development of biofuel as an energy substitution in Indonesia
Presidential Decree No 10, the year 2006 on National Team for Biofuel Development and Biofuel Roadmap	The National Biofuel Roadmap 2006-2025 to replace fossil fuel
Law No 30, the year 2007 on Energy	The national renewable energy development and efficiency
Law No 30, the year 2009 on Electricity Law	The application of biomass as electricity generation
Government Rule No, 79 the year 2014 on National Energy Policy	The guidance Indonesia's energy supply
Ministry of Energy and Mineral Resources Regulation No 39, the year 2017 on Implementation of the Physical Activities that Utilising Renewable Energy	The procedure and framework of physical activities of power plant facilities construction and development
Ministry of Energy and Mineral Resources Regulation No 53, the year 2018 on Utilisation of Renewable Energy as a Power Supply	The mechanism for purchasing electricity from the bioenergy power plant
Presidential Regulation No 112, the year 2022 on Acceleration on renewable energy development for electricity	Prioritize electricity purchases from biomass as a renewable energy source and develop biomass power plants.

Appendix F. Questionnaire of stakeholders

This questionnaire was prepared for the research "**A Short Logistic Chain Development of Indonesian Biomass for Sustainable Densifications**". The survey aims to determine the Indonesian government and stakeholder's perception and participation in biomass residue valorization program. This research can be used as recommendations to assess the methods and techniques suitable for the community needed in utilizing crop residue.

Thank you for your willingness to participate in providing information by completing this questionnaire

Identity of Respondent

Name of Respondent

_____

Age

_____ Year

Gender

☐ Male ☐ Female

Education

☐ Bachelor degree ☐ Master degree ☐ Doctoral degree

Occupation

☐ Government employees ☐ Agricultural entrepreneurs

☐ Agricultural researchers ☐ Senator

How long time have you worked in that institution?

☐ < 5 years ☐ 6 – 10 years ☐ 11 – 15 years

☐ 16 – 20 years ☐ 21 – 25 years ☐ > 25 years

Present rice straw Utilization

Instructions

This section asks things related to present agricultural residue utilization in your area. Answer as objectively as possible by crossing (X) on one of the available column numbers. There are five alternative answers, such as:
3 = Always or High
2 = Sometimes or Moderate
1 = Never or Low

No	Questions	Alternative answer		
		1	2	3
1	In my area, the farmers always burn agricultural residues such as rice straw, corn cob, or sugarcane bagasse in the field after harvesting activities	1	2	3

2	In my area, the agricultural residue burning activity after harvesting can be used to save operational cost	1	2	3
3	In my area, agricultural residue burning can be used to save management time for the next planting	1	2	3
4	In my area, agricultural residue burning contributes to environmental problems such as global warming and climate change	1	2	3
5	In my area, agricultural waste (such as rice straw, corn cob, or sugarcane bagasse) have been utilized as raw material for compost, animal feed and planting mulch	1	2	3

Motivation to support rice straw valorization

Instructions

This section asks things related to your motivation to utilize agricultural residue. Answer as objectively as possible by crossing (X) on one of the available column numbers. There are five alternative answers, such as:
3 = Always or High
2 = Sometimes or Moderate
1 = Never or Low

No	Questions	Alternative answer		
		1	**2**	**3**
1	Agricultural residue management as a bioenergy source can reduce environmental problems such as climate change and greenhouse gasses emissions	1	2	3
2	The realization of renewable energy diversification is one of Presidential Regulation No. 22 in 2017 of the National Energy General Plan (RUEN) manifestation	1	2	3
3	Agricultural residue utilization as renewable energy raw material can improve the socio-economic quality	1	2	3

Understanding level to utilize of agricultural residue

Instructions

This section asks things related to your participation in understanding level to utilize of agriculture residue. Answer as objectively as possible by crossing (X) on one of the available column numbers. There are five alternative answers, such as:
3 = Always or High
2 = Sometimes or Moderate
1 = Never or Low

No	Questions	Alternative answer		
		1	**2**	**3**
1	I comprehend that Presidential Regulation No 5, the year 2006, requires agriculture residue utilization as a renewable energy feedstock	1	2	3
2	I comprehend that agriculture residue utilization as bioenergy is a diversification energy model	1	2	3
3	I comprehend that agriculture residue utilization as bioenergy can benefit the community's socio-economic capacity	1	2	3

4	I comprehend that agricultural residue utilization as bioenergy can reduce environmental problems such as greenhouse gasses emission and global warming	1	2	3
5	I comprehend that the latest information related to science and technology methods is essential to support bioenergy development	1	2	3
6	I comprehend that research and development must continue to be done to improve the bioenergy quality	1	2	3
7	I comprehend that improving the cooperation quality between government, industry and academics sectors is necessary to accelerate the bioenergy development	1	2	3
8	I comprehend that the agricultural residue utilization as bioenergy requires infrastructure to access such as agricultural machinery, irrigation and drainage system, warehouse and connecting roads	1	2	3

Perception of agricultural residue valorization

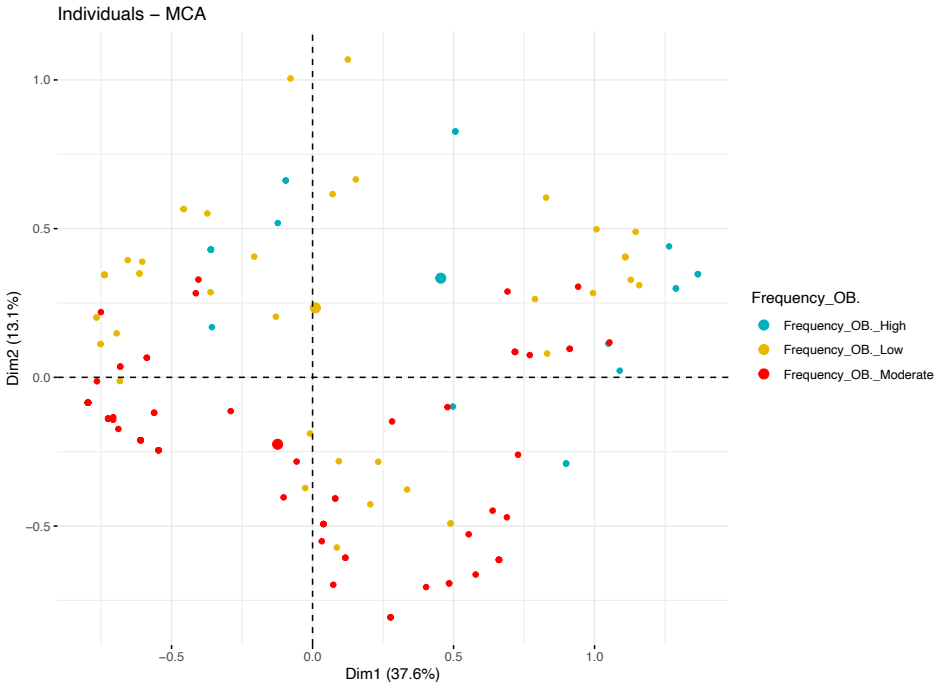
Instructions

This section asks things related to your perception of agricultural residue utilization in Indonesia. Answer as objectively as possible by crossing (X) on one of the available column numbers. There are five alternative answers, such as:
3 = Always or High
2 = Sometimes or Moderate
1 = Never or Low

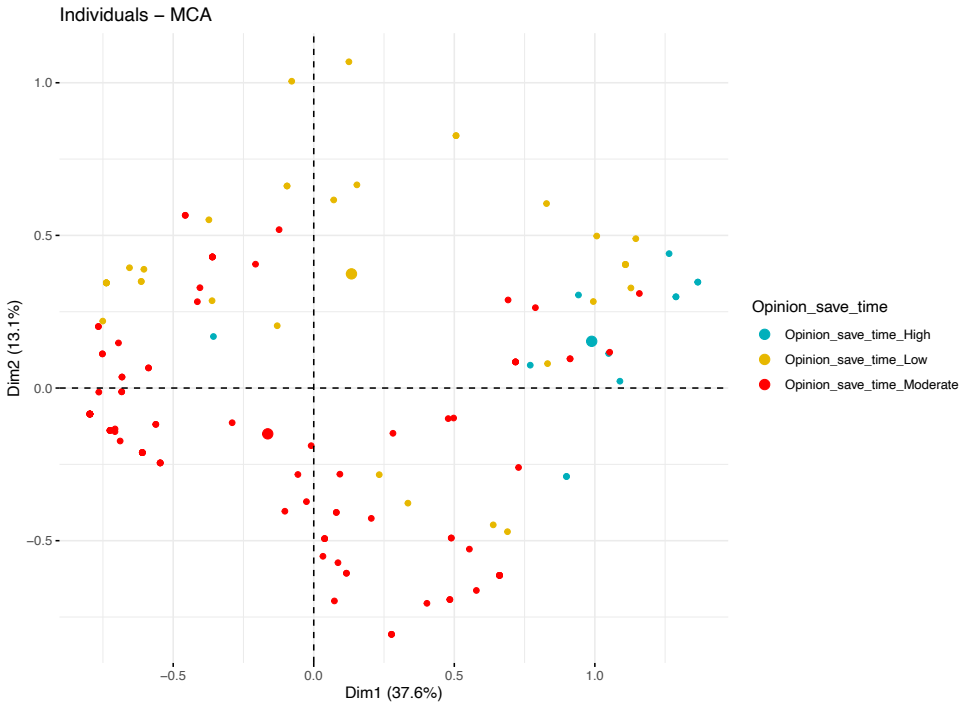
No	Questions	Alternative answer		
		1	**2**	**3**
1	As one of the policymakers, I am committed to reducing open burning in the field after harvesting activities after post-harvested	1	2	3
2	As one of the policymakers, I try to design the regulation and policies to reduce the agricultural waste burning after post-harvested	1	2	3
3	As one of the policymakers, I will disseminate the regulation and policies to the farmers to reducing the agricultural waste burning after post-harvested	1	2	3
4	As one of the policymakers, I will monitor and evaluate the regulation and policies to the farmers to reducing the agricultural waste burning after post-harvested	1	2	3
5	As one of the policymakers, I develop the infrastructure to support the agricultural residue utilization	1	2	3
6	As one of the policymakers, I will monitor and evaluate the infrastructure that has been constructed to support agricultural residue utilization	1	2	3
7	As one of the policymakers, I will improve collaboration quality to support agricultural residue utilization	1	2	3

Appendix G. Stakeholder s' characteristics in the factor map

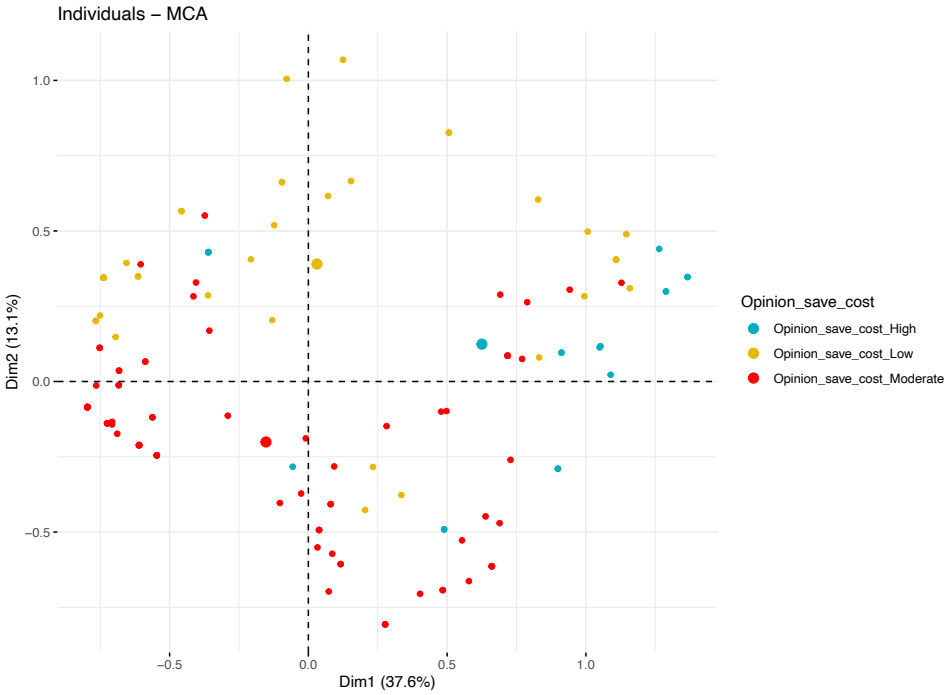
1. **Stakeholders' motivation to support rice straw utilization: (a) frequency of open burning, (b) open burning can save cost, (c) open burning can save time, (d) open burning contribute pollution, and (e) rice straw application purposes.**



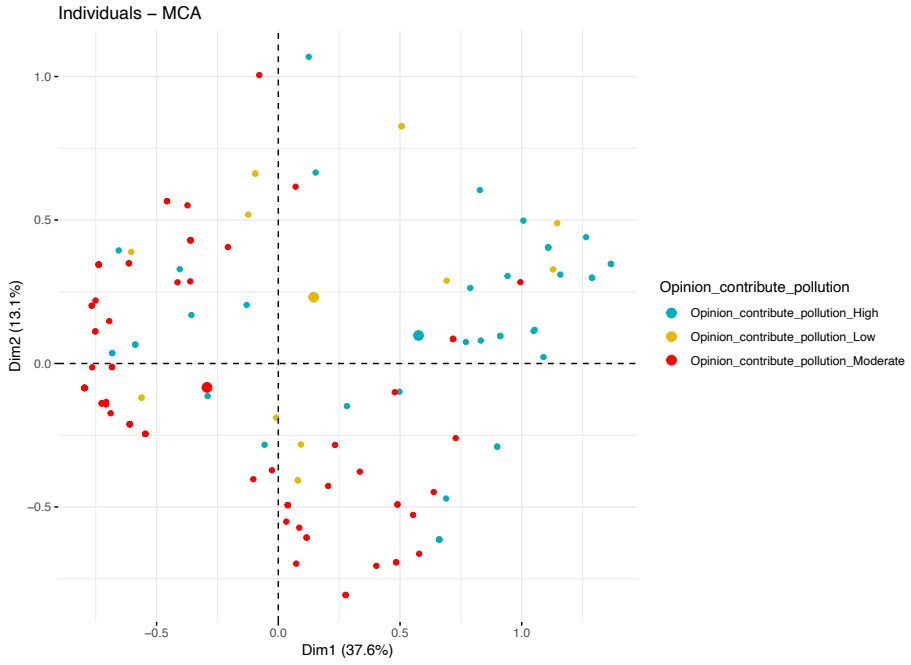
(a)



(b)


Individuals – MCA
Dim2 (13.1%)
Dim1 (37.6%)
1.0
0.5
0.0
−0.5
−0.5
0.0
0.5
1.0
Opinion_save_cost
Opinion_save_cost_High
Opinion_save_cost_Low
Opinion_save_cost_Moderate

(c)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Dim1 (37.6%)
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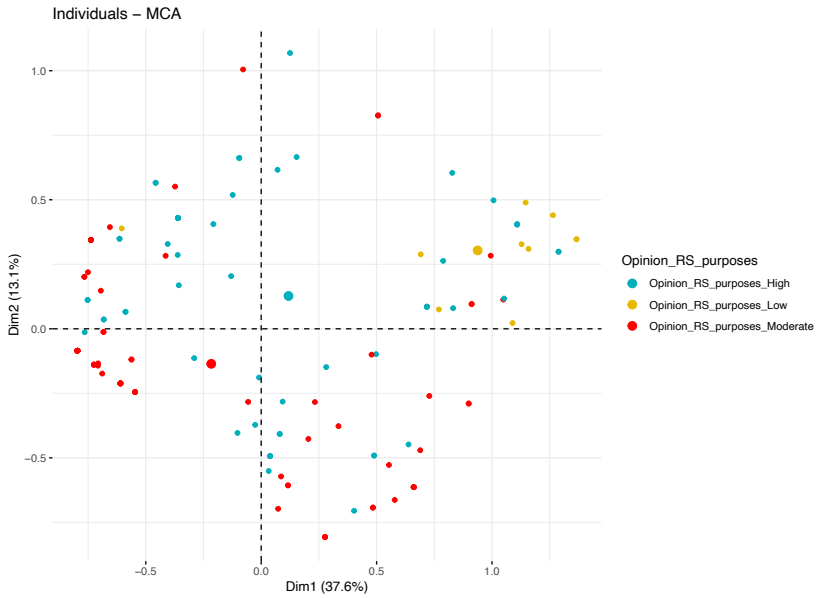
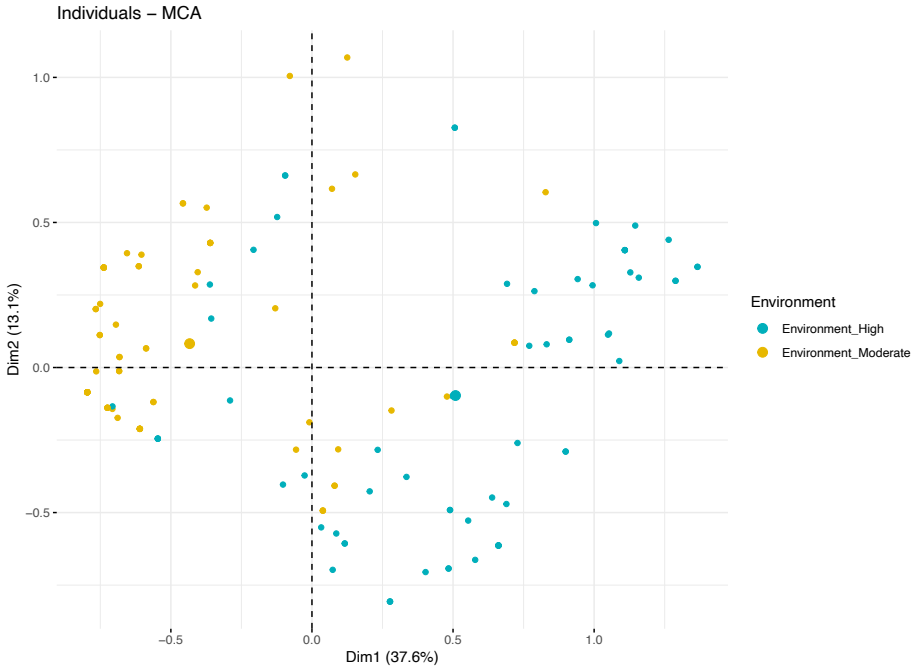
Opinion_contribute_pollution_High
Opinion_contribute_pollution_Low
Opinion_contribute_pollution_Moderate

(d)

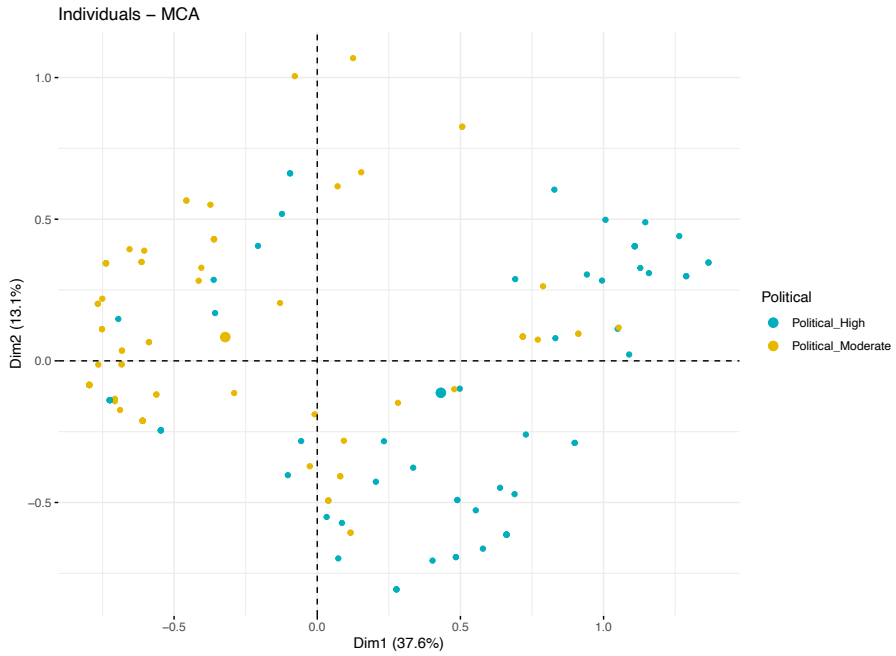


(e)

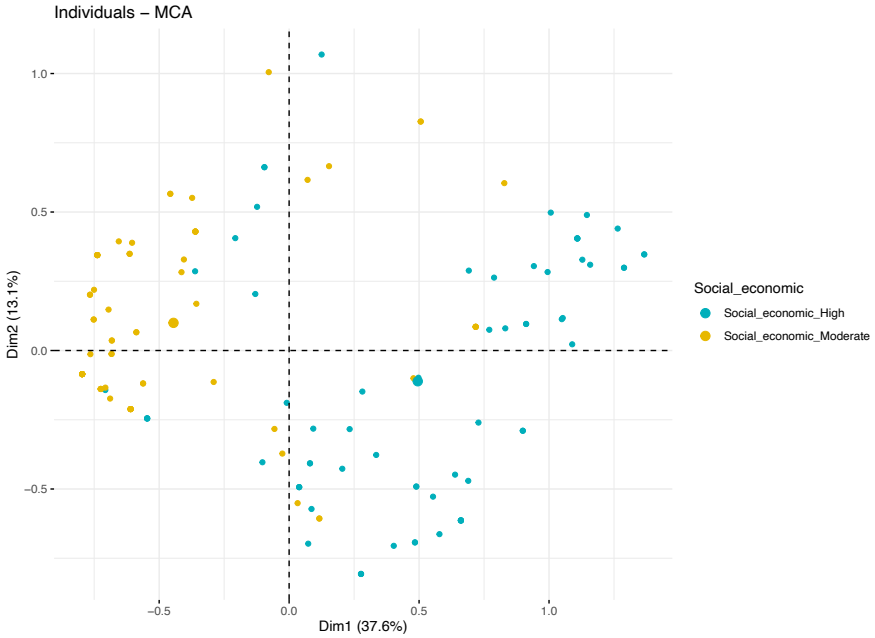
2. **Stakeholders' opinion on the rice straw utilization: (a) environment, (b) politic, (c) socio-economic.**



(a)

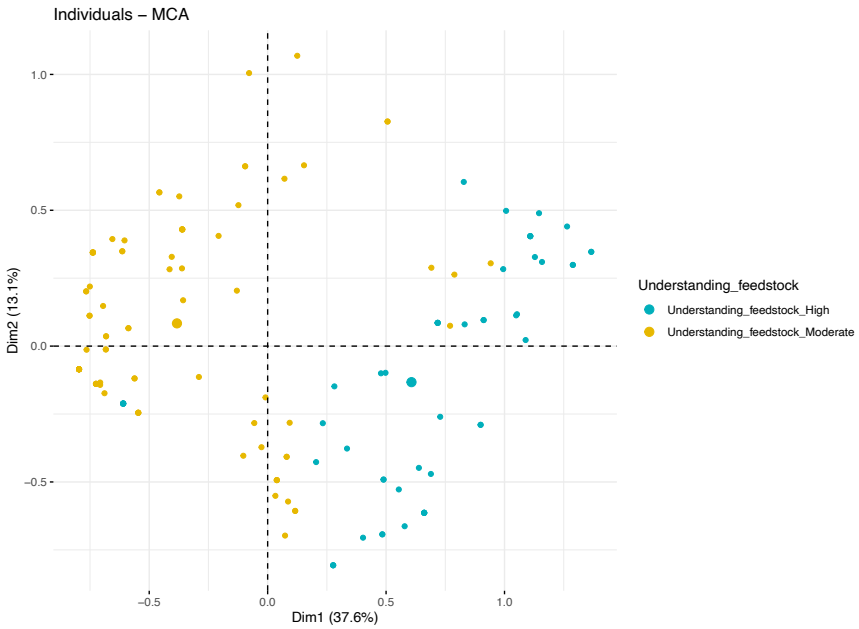


(b)



(c)

3. **Stakeholders' understanding to support agricultural residue valorization: (a) understanding of feedstock, (b) understanding of good governance, (c) understanding of improve social-economy quality, (d) understanding of reduce air pollution, (e) understanding of technology improvement, (f) understanding of research and development, (g) understanding of integrated cooperation, and (h) understanding of infrastructure improvement**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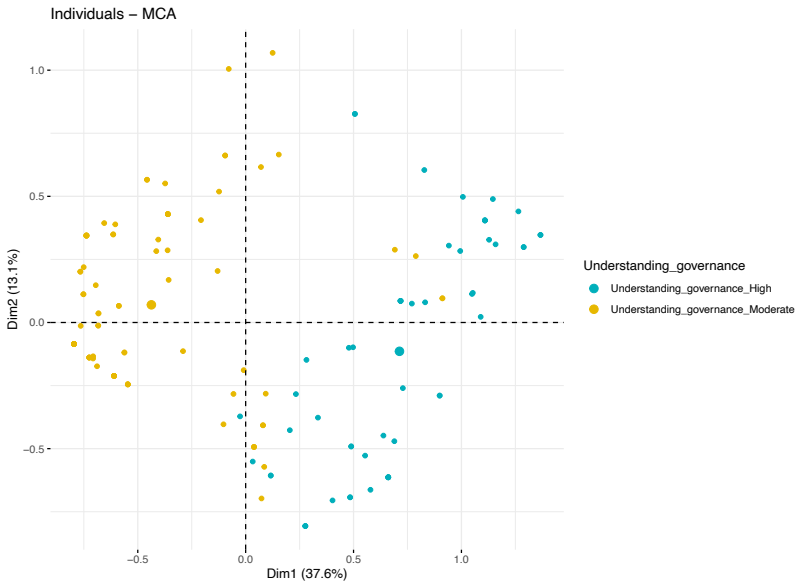
Understanding_feedstock
Understanding_feedstock_High
Understanding_feedstock_Moderate

(a)


Individuals – MCA
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Dim1 (37.6%)
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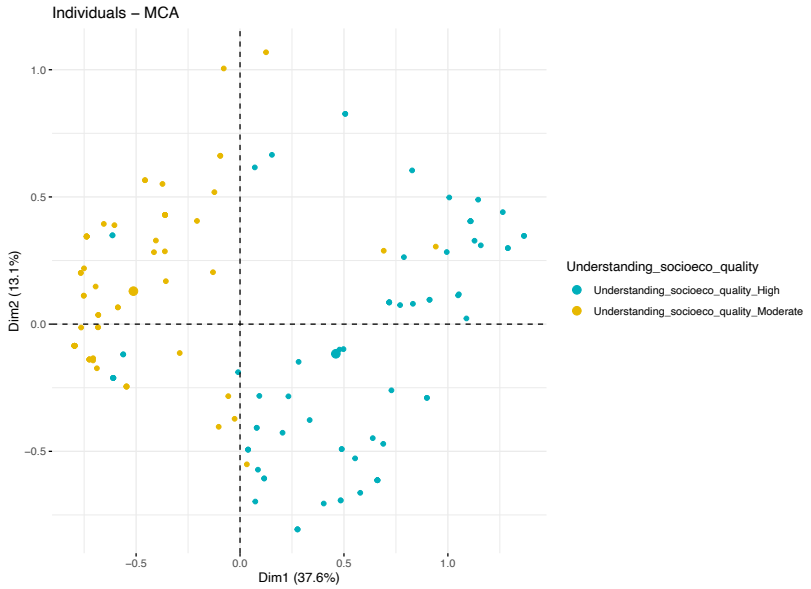
Understanding_governance
Understanding_governance_High
Understanding_governance_Moderate

(b)


Individuals – MCA
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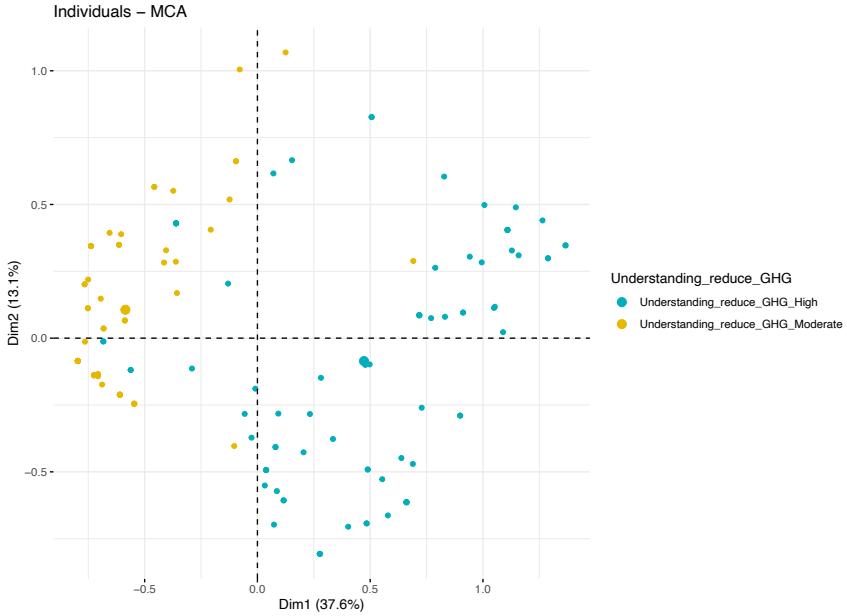
Understanding_socioeco_quality
Understanding_socioeco_quality_High
Understanding_socioeco_quality_Moderate

(c)


Individuals – MCA
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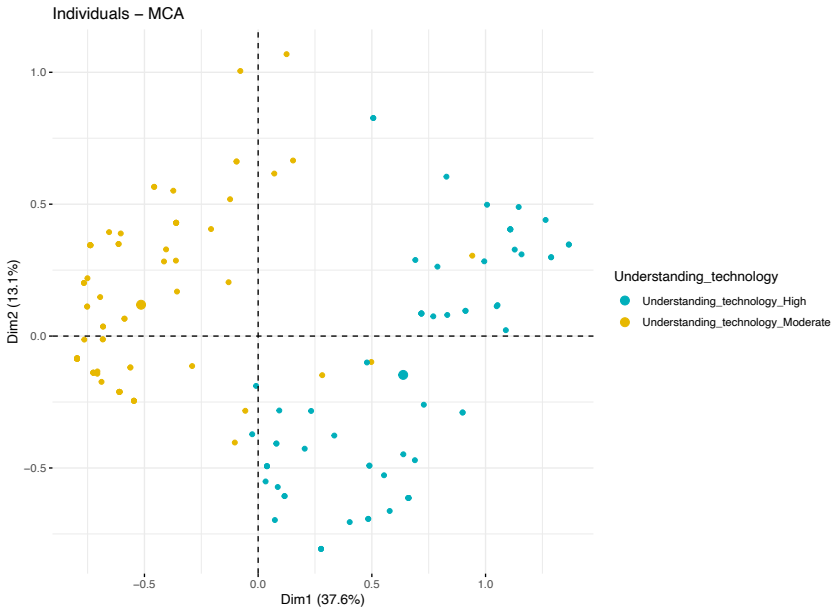
Understanding_reduce_GHG
Understanding_reduce_GHG_High
Understanding_reduce_GHG_Moderate

(d)


Individuals – MCA
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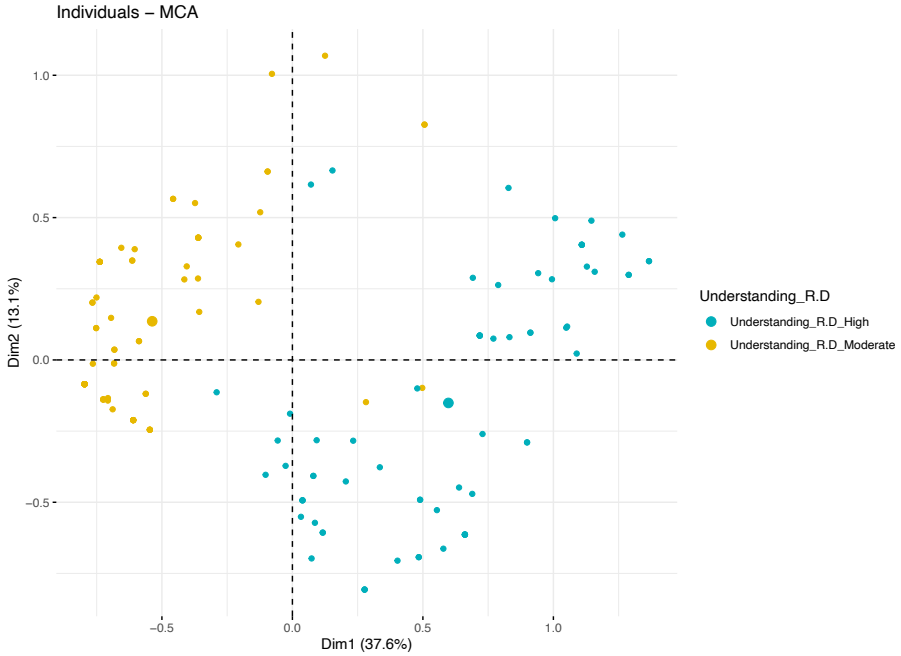
Understanding_technology
Understanding_technology_High
Understanding_technology_Moderate

(e)


Individuals – MCA
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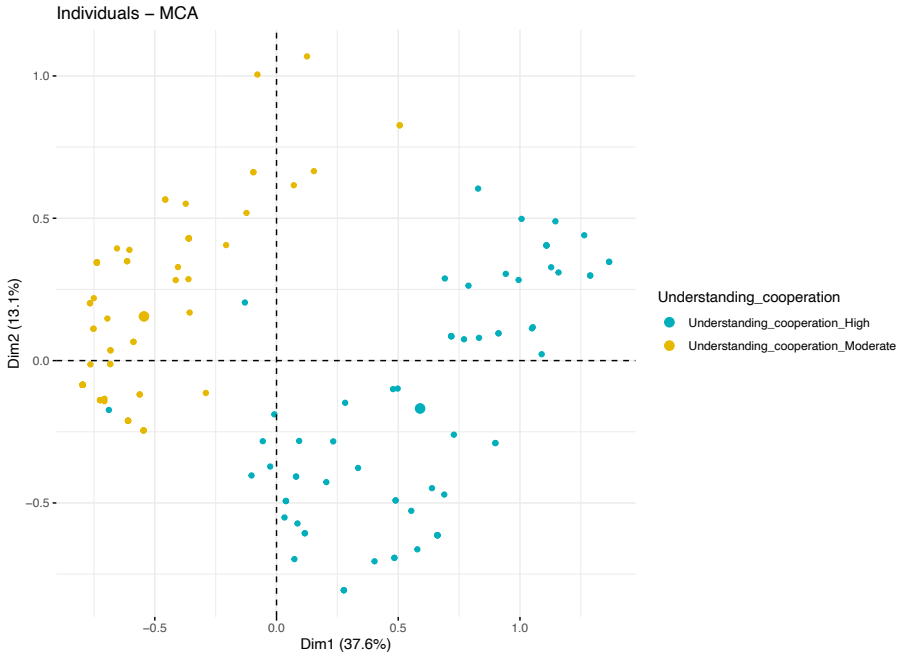
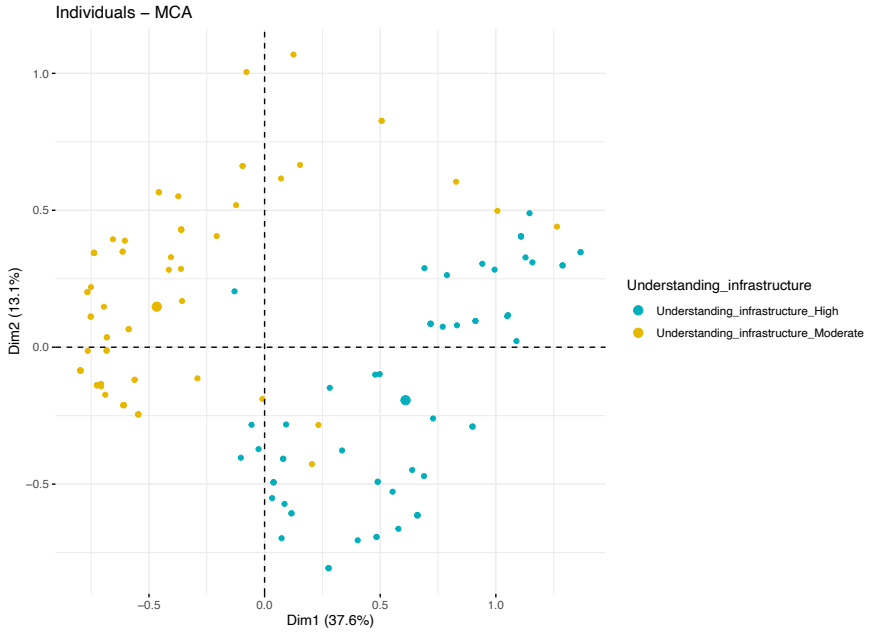
Understanding_R.D
Understanding_R.D_High
Understanding_R.D_Moderate

(f)

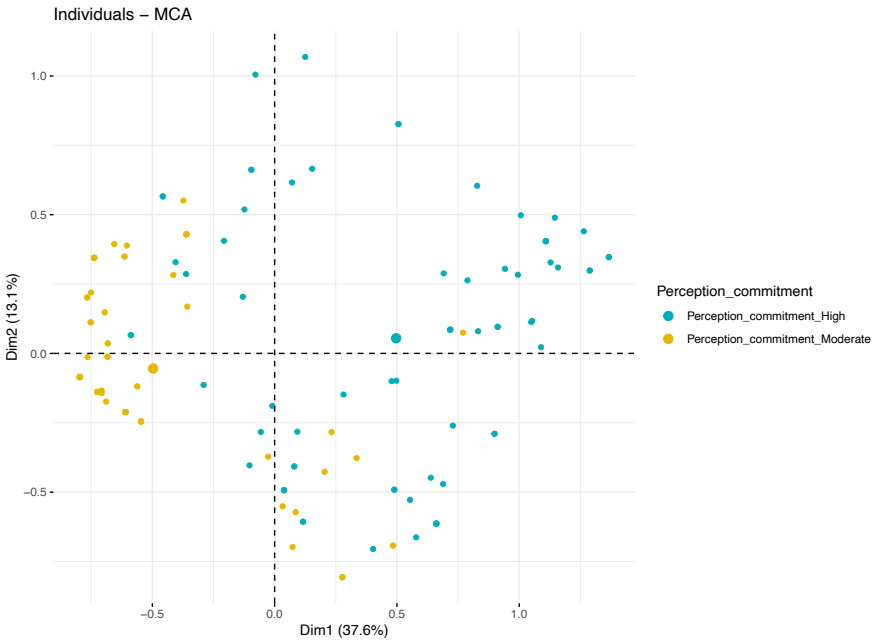


(g)



(h)

4. Stakeholders' perception in agricultural residue valorization: (a) commitment to reduce open burning, (b) planning, policies, and regulation, (c) dissemination of policies regulations, (d) supporting infrastructure, (e) education and training, (f) market share, and (g) integrated collaboration.


Individuals – MCA
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Dim1 (37.6%)
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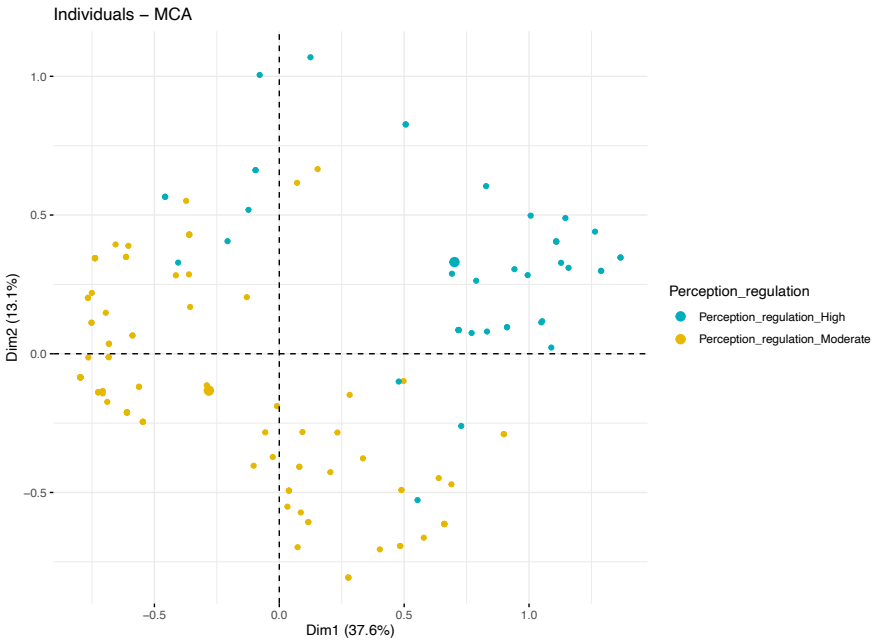
0.5
1.0
Perception_commitment
Perception_commitment_High
Perception_commitment_Moderate

(a)


Individuals – MCA
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Dim1 (37.6%)
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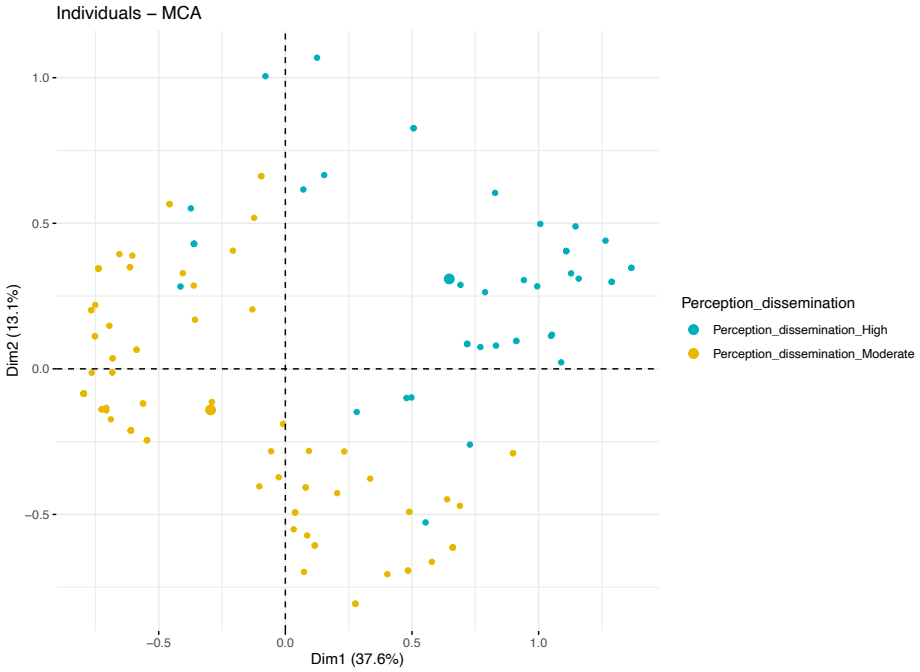
Perception_regulation
Perception_regulation_High
Perception_regulation_Moderate

(b)


Individuals – MCA
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Dim1 (37.6%)
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0.0
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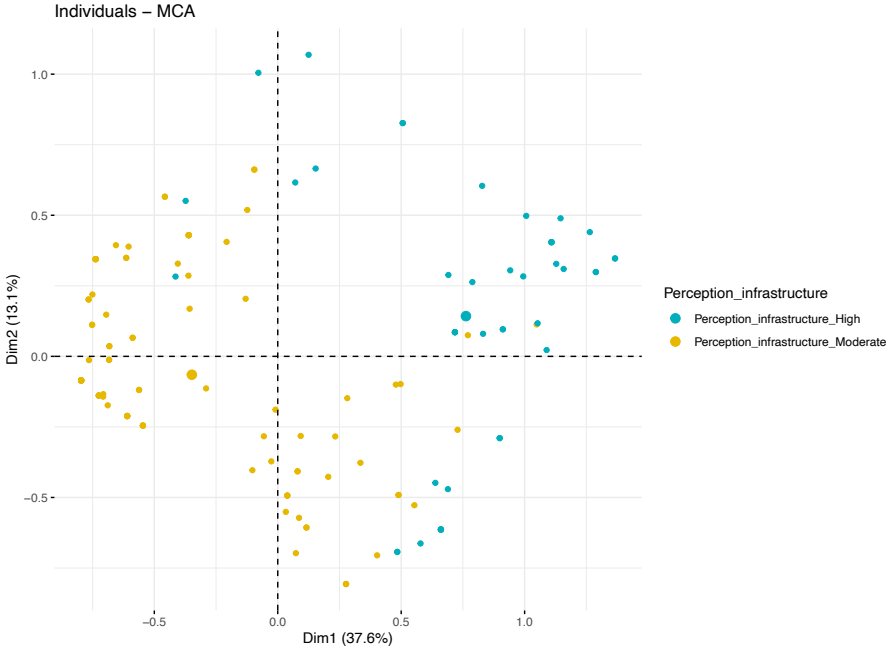
1.0
Perception_dissemination
Perception_dissemination_High
Perception_dissemination_Moderate

(c)


Individuals – MCA
Dim2 (13.1%)
Dim1 (37.6%)
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0.0
−0.5
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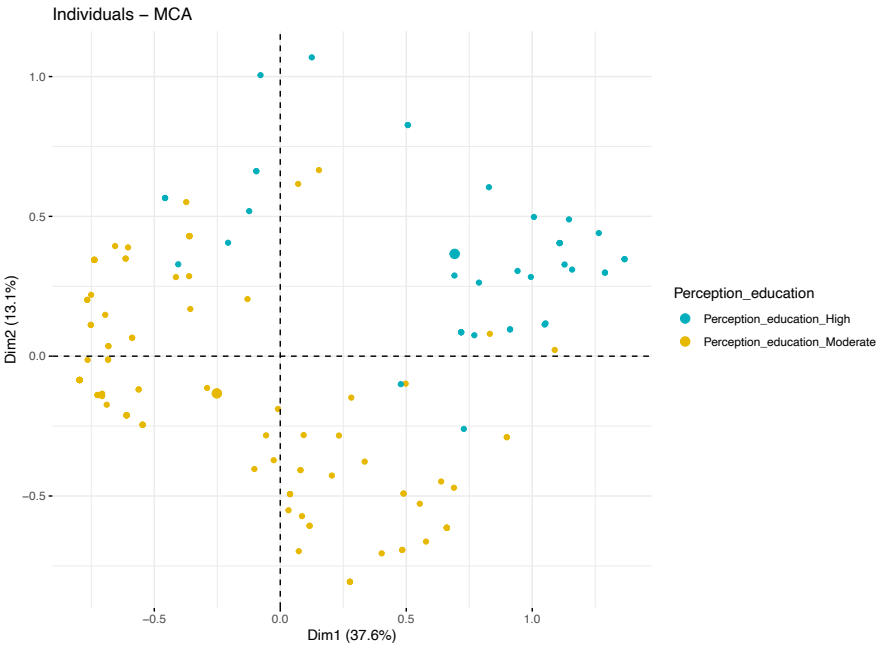
0.0
0.5
1.0
Perception_infrastructure
Perception_infrastructure_High
Perception_infrastructure_Moderate

(d)


Individuals – MCA
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Dim1 (37.6%)
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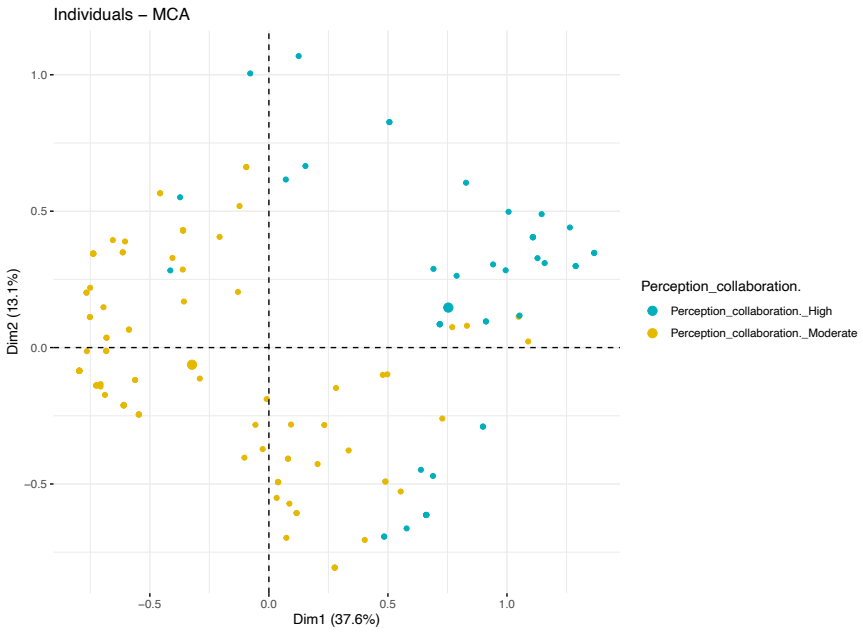
0.5
0.0
−0.5
−0.5
0.0
0.5
1.0
Perception_education
Perception_education_High
Perception_education_Moderate

(e)


Individuals – MCA
Dim2 (13.1%)
Dim1 (37.6%)
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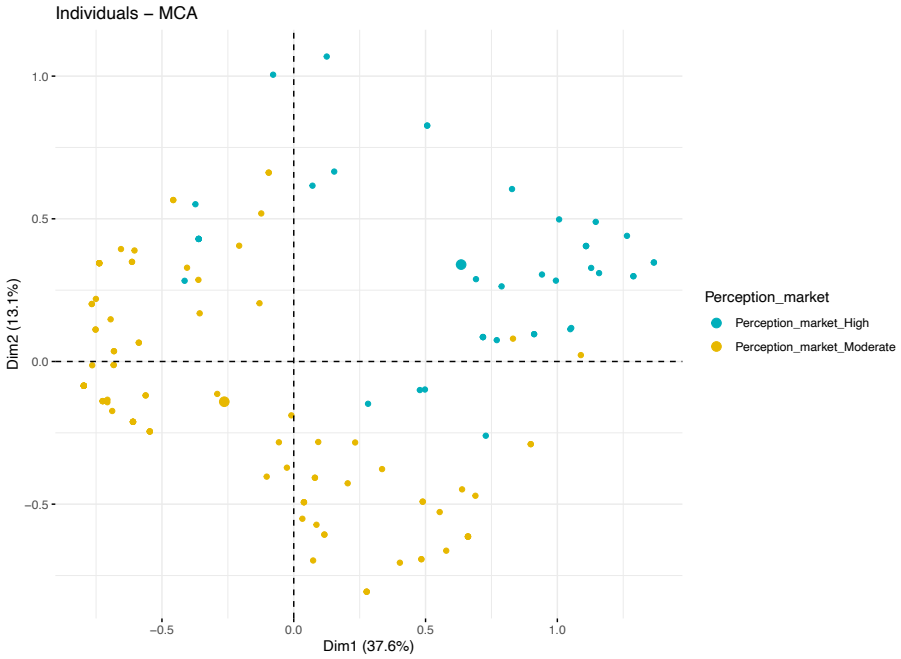
0.5
0.0
−0.5
−0.5
0.0
0.5
1.0
Perception_collaboration.
Perception_collaboration._High
Perception_collaboration._Moderate

(f)


Individuals – MCA
1.0
0.5
0.0
−0.5
Dim2 (13.1%)
−0.5
0.0
0.5
1.0
Dim1 (37.6%)
Perception_market
Perception_market_High
Perception_market_Moderate

(g)

Appendix H. Distance among biomass purchasing location and storage facilities

1. Centralized model

Table H-1. Centralized-Ngawi

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Sine	147.10	Kecamatan Geneng	120.50
Kecamatan Ngrambe	141.60	Kecamatan Gerih	125.10
Kecamatan Jogorogo	135.30	Kecamatan Kwadungan	127.90
Kecamatan Kendal	138.40	Kecamatan Pangkur	123.30
Kecamatan Paron	115.70	Kecamatan Karangjati	125.40
Kecamatan Kedunggalar	127.10	Kecamatan Bringin	120.70
Kecamatan Pitu	118.80	Kecamatan Padas	118.60
Kecamatan Widodaren	135.40	Kecamatan Kasreman	111.40
Kecamatan Mantingan	140.20	Kecamatan Ngawi	111.90
Kecamatan Karanganyar	140.70		

Table H-2. Centralized-Bojonegoro

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Margomulyo	98.40	Kecamatan Balen	61.30
Kecamatan Ngraho	84.50	Kecamatan Sukosewu	74.10
Kecamatan Tambakrejo	85.40	Kecamatan Kapas	66.60
Kecamatan Ngambon	91.00	Kecamatan Bojonegoro	60.50
Kecamatan Sekar	104.20	Kecamatan Trucuk	56.60
Kecamatan Bubulan	84.10	Kecamatan Dander	73.00
Kecamatan Gondang	99.80	Kecamatan Ngasem	80.80
Kecamatan Temayang	83.30	Kecamatan Gayam	78.50
Kecamatan Sugihwaras	73.10	Kecamatan Kalitidu	68.10
Kecamatan Kedungadem	74.90	Kecamatan Malo	70.40
Kecamatan Kepohbaru	68.10	Kecamatan Purwosari	79.10
Kecamatan Baureno	61.70	Kecamatan Padangan	80.90
Kecamatan Kanor	53.60	Kecamatan Kasiman	78.40
Kecamatan Sumberrejo	56.70		

Table H-3. Centralized-Tuban

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Kenduruan	43.30	Kecamatan Widang	49.30
Kecamatan Bangilan	49.50	Kecamatan Palang	36.60
Kecamatan Senori	44.10	Kecamatan Semanding	28.90
Kecamatan Singgahan	33.30	Kecamatan Tuban	23.80
Kecamatan Montong	20.80	Kecamatan Jenu	12.40
Kecamatan Parengan	49.70	Kecamatan Merakurak	18.10
Kecamatan Soko	50.90	Kecamatan Kerek	13.60
Kecamatan Rengel	41.40	Kecamatan Tambakboyo	8.10
Kecamatan Grabagan	34.90	Kecamatan Jatirogo	38.10
Kecamatan Plumpang	42.30	Kecamatan Bancar	21.20

Table H-4. Centralized-Lamongan

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Sukorame	85.50	Kecamatan Sarirejo	88.20
Kecamatan Bluluk	76.10	Kecamatan Deket	81.70
Kecamatan Ngimbang	75.60	Kecamatan Glagah	95.80
Kecamatan Sambeng	85.80	Kecamatan Karangbinangun	92.50
Kecamatan Mantup	95.70	Kecamatan Turi	77.60
Kecamatan Kembangbahu	86.50	Kecamatan Kalitengah	83.10
Kecamatan Sugio	71.60	Kecamatan Karanggeneng	77.80
Kecamatan Kedungpring	66.60	Kecamatan Sekaran	66.40
Kecamatan Modo	72.00	Kecamatan Maduran	69.90
Kecamatan Babat	54.30	Kecamatan Laren	64.10
Kecamatan Pucuk	63.70	Kecamatan Solokuro	64.60
Kecamatan Sukodadi	76.00	Kecamatan Paciran	63.30
Kecamatan Lamongan	80.50	Kecamatan Brondong	52.10
Kecamatan Tikung	86.90		

2. Decentralized model

Table H-5. Decentralized-Ngawi

Warehouse location: Kecamatan Paron

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Sine	23.10	Kecamatan Kedunggalar	9.60
Kecamatan Ngrambe	17.50	Kecamatan Pitu	18.60
Kecamatan Jogorogo	11.30	Kecamatan Widodaren	20.90
Kecamatan Kendal	14.20	Kecamatan Mantingan	25.40
Kecamatan Paron	0.00	Kecamatan Karanganyar	29.30

Warehouse location: Kecamatan Geneng

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Geneng	0.00	Kecamatan Bringin	28.10
Kecamatan Gerih	5.00	Kecamatan Padas	22.90
Kecamatan Kwadungan	16.80	Kecamatan Kasreman	16.60
Kecamatan Pangkur	17.60	Kecamatan Ngawi	10.60
Kecamatan Karangjati	29.50		

Table H-6. Decentralized-Bojonegoro

Warehouse location: Kecamatan Dander

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Ngambon	20.30	Kecamatan Kanor	29.70
Kecamatan Sekar	32.60	Kecamatan Sumberrejo	21.30
Kecamatan Bubulan	11.10	Kecamatan Balen	16.70
Kecamatan Gondang	30.30	Kecamatan Sukosewu	12.60
Kecamatan Temayang	13.70	Kecamatan Kapas	13.30
Kecamatan Sugihwaras	14.60	Kecamatan Bojonegoro	12.00
Kecamatan Kedungadem	25.90	Kecamatan Trucuk	16.50
Kecamatan Kepohbaru	30.60	Kecamatan Dander	0.00
Kecamatan Baureno	35.20	Kecamatan Ngasem	9.20

Warehouse location: Kecamatan Kalitidu

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Margomulyo	47.10	Kecamatan Malo	7.40
Kecamatan Ngraho	33.20	Kecamatan Purwosari	17.80
Kecamatan Tambakrejo	31.80	Kecamatan Padangan	18.30
Kecamatan Gayam	11.50	Kecamatan Kasiman	20.30
Kecamatan Kalitidu	0.00	Kecamatan Kedewan	27.10

Table H-7. Decentralized-Tuban

Warehouse location: Kecamatan Semanding

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Kenduruan	59.70	Kecamatan Widang	17.10
Kecamatan Bangilan	48.00	Kecamatan Palang	13.10
Kecamatan Senori	50.20	Kecamatan Semanding	0.00
Kecamatan Singgahan	38.40	Kecamatan Tuban	5.20
Kecamatan Montong	26.10	Kecamatan Jenu	12.30
Kecamatan Parengan	48.90	Kecamatan Merakurak	10.90
Kecamatan Soko	36.20	Kecamatan Kerek	24.40
Kecamatan Rengel	26.70	Kecamatan Tambakboyo	32.80
Kecamatan Grabagan	21.80	Kecamatan Jatirogo	62.80
Kecamatan Plumpang	15.40	Kecamatan Bancar	46.40

Table H-8. Decentralized- Lamongan

Warehouse location: Kecamatan Kalitidu

Feedstock originated	Distance to storage facility (km)	Feedstock originated	Distance to storage facility (km)
Kecamatan Sukorame	49.50	Kecamatan Sarirejo	7.30
Kecamatan Bluluk	45.00	Kecamatan Deket	3.50
Kecamatan Ngimbang	38.70	Kecamatan Glagah	18.90
Kecamatan Sambeng	32.40	Kecamatan Karangbinangun	15.20
Kecamatan Mantup	18.50	Kecamatan Turi	9.70
Kecamatan Kembangbahu	11.90	Kecamatan Kalitengah	19.30
Kecamatan Sugio	14.40	Kecamatan Karanggeneng	19.20
Kecamatan Kedungpring	27.30	Kecamatan Sekaran	22.10
Kecamatan Modo	36.50	Kecamatan Maduran	29.20
Kecamatan Babat	29.70	Kecamatan Laren	33.40
Kecamatan Pucuk	17.30	Kecamatan Solokuro	35.80
Kecamatan Sukodadi	7.80	Kecamatan Paciran	39.80
Kecamatan Lamongan	0.00	Kecamatan Brondong	45.00
Kecamatan Tikung	6.50		

Appendix I. An optimum material flows of various storage deterioration based on the scenarios centralized and decentralized

1. Centralized

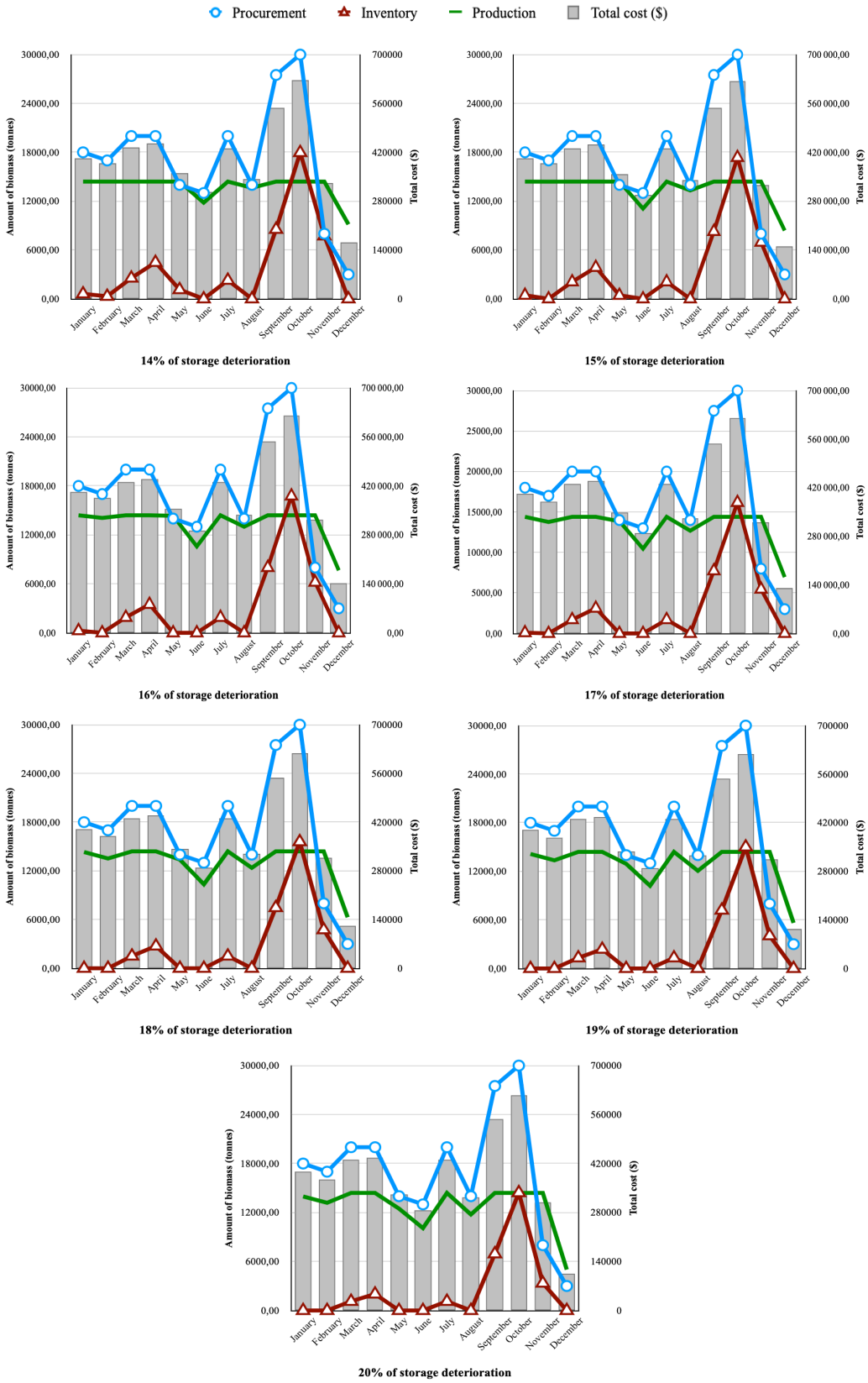


Figure I-1. Centralized-On ground unprotected storage type

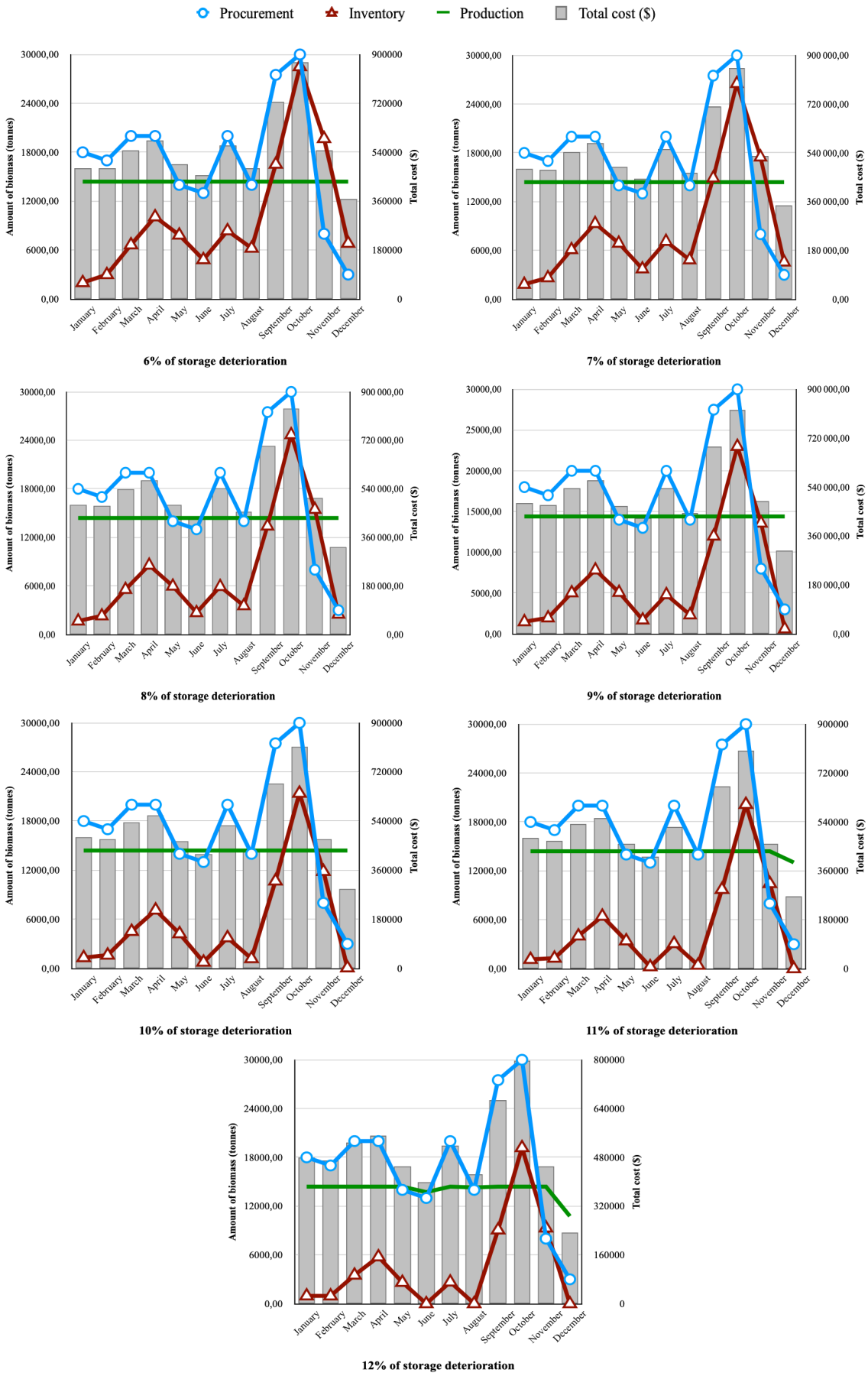


Figure I-2. Centralized-Trap on the gravel storage type

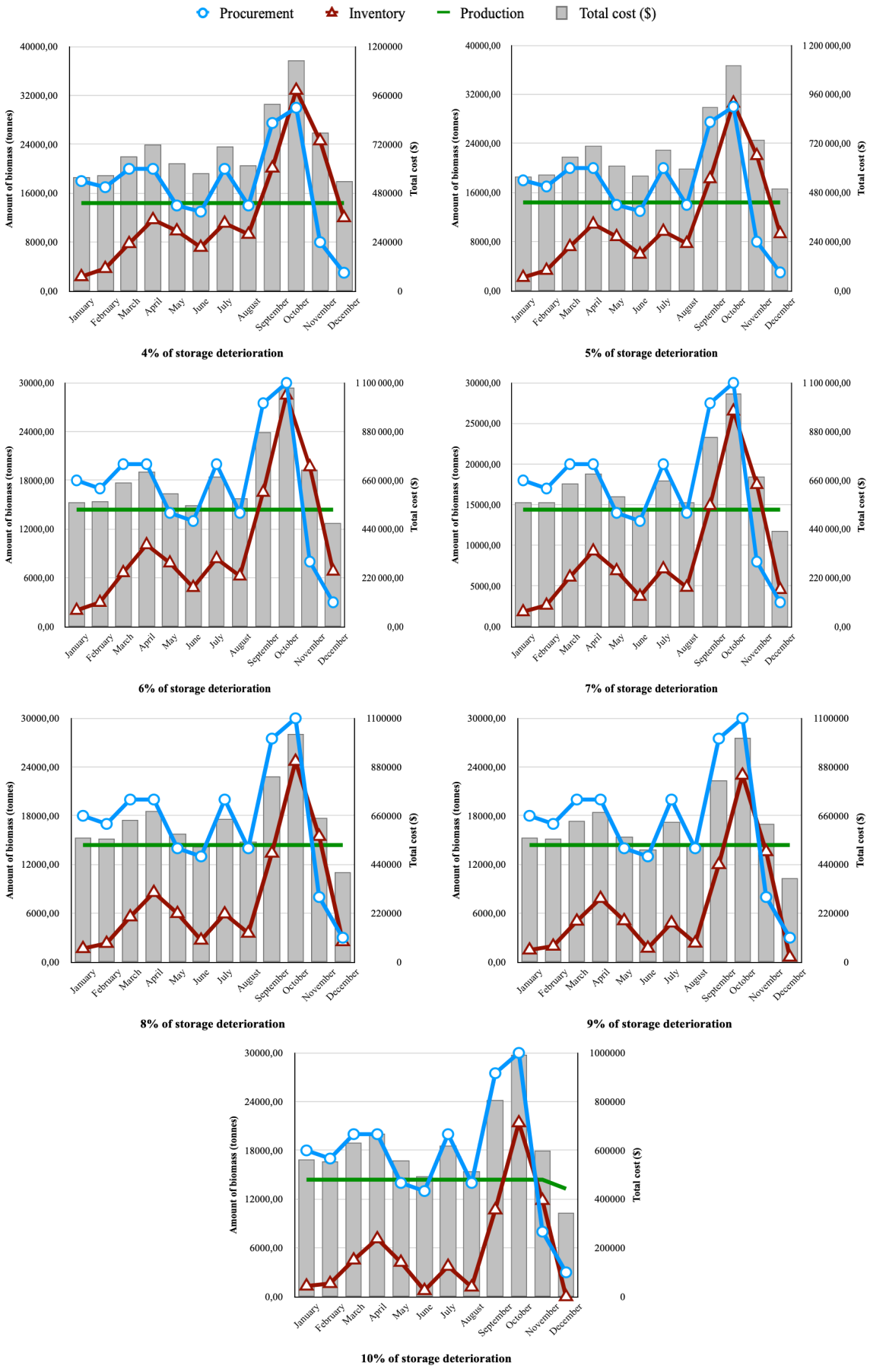


Figure I-3. Centralized-Open warehouse

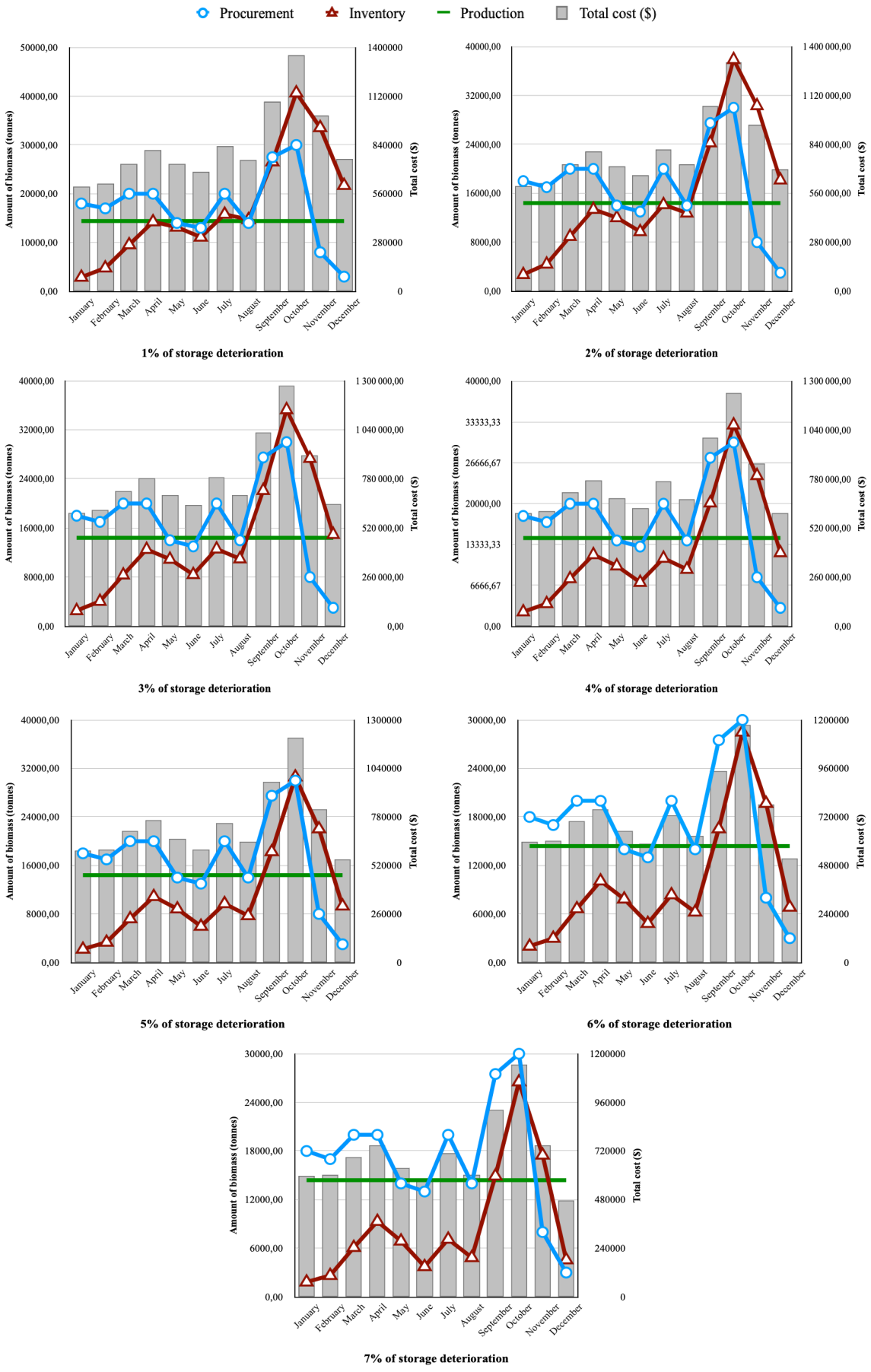


Figure I-4. Centralized-Close warehouse

2. Decentralized

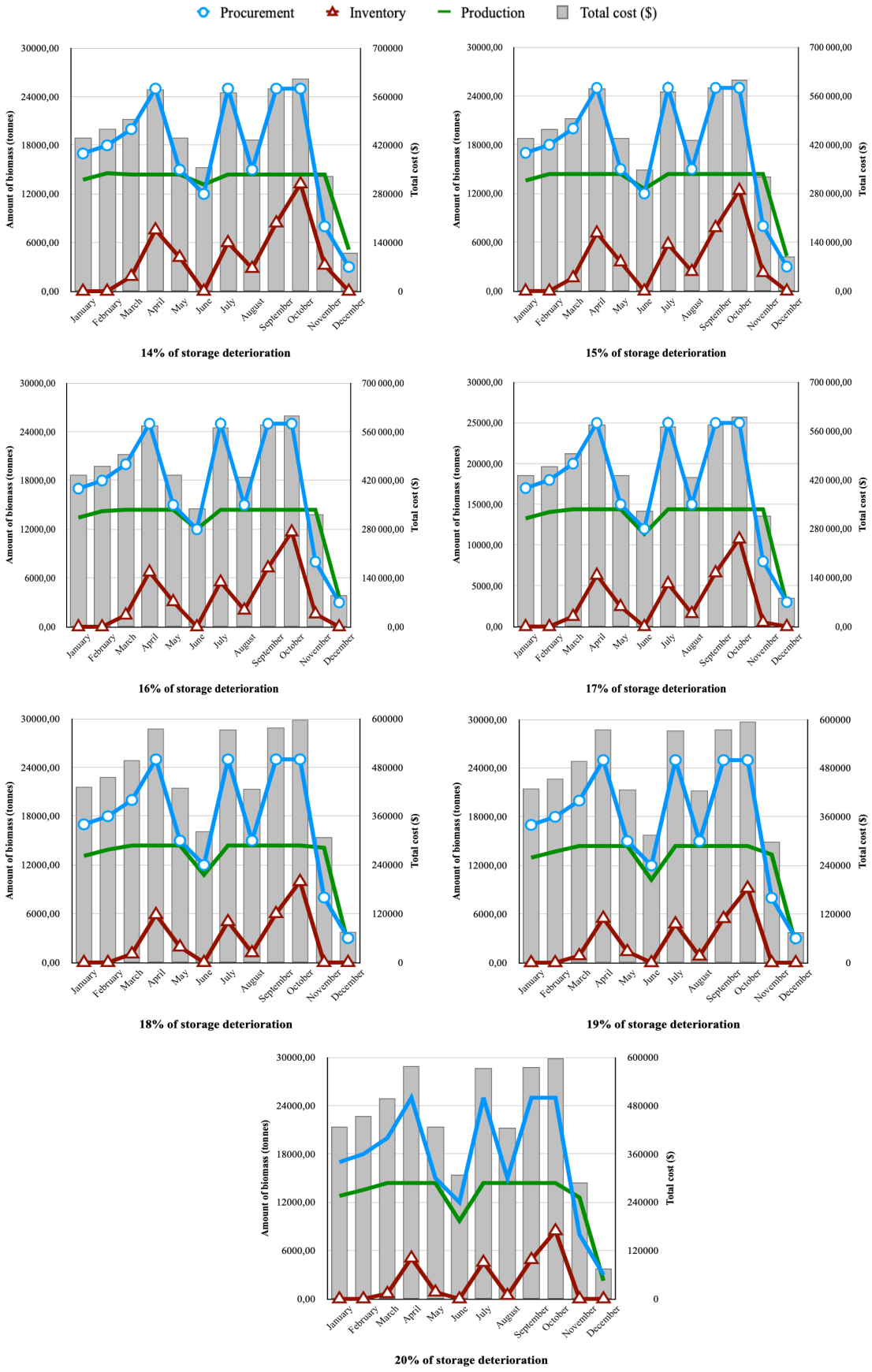


Figure I-5. Decentralized-On ground unprotected storage type

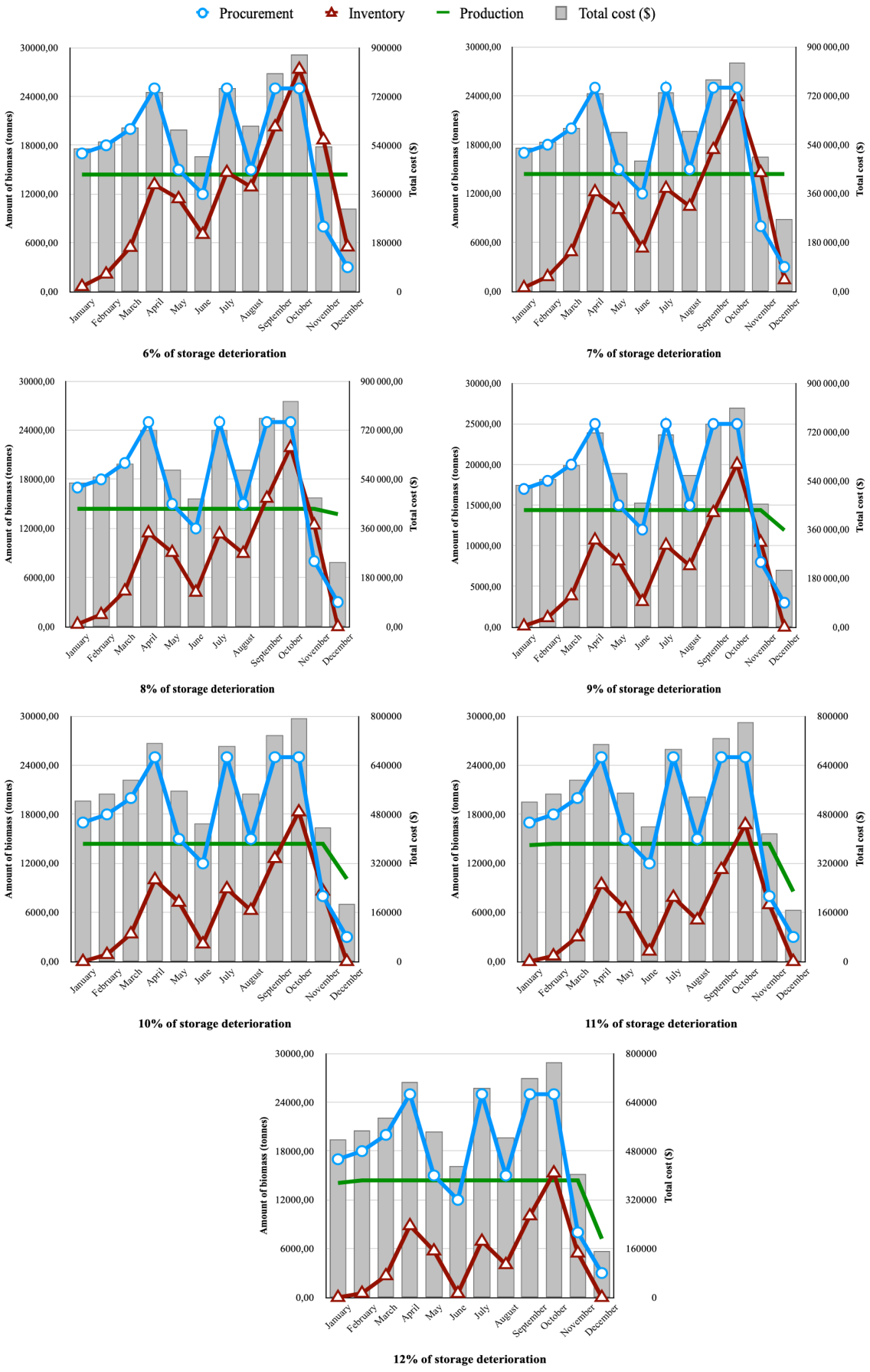


Figure I-6. Decentralized-Trap on the gravel storage type

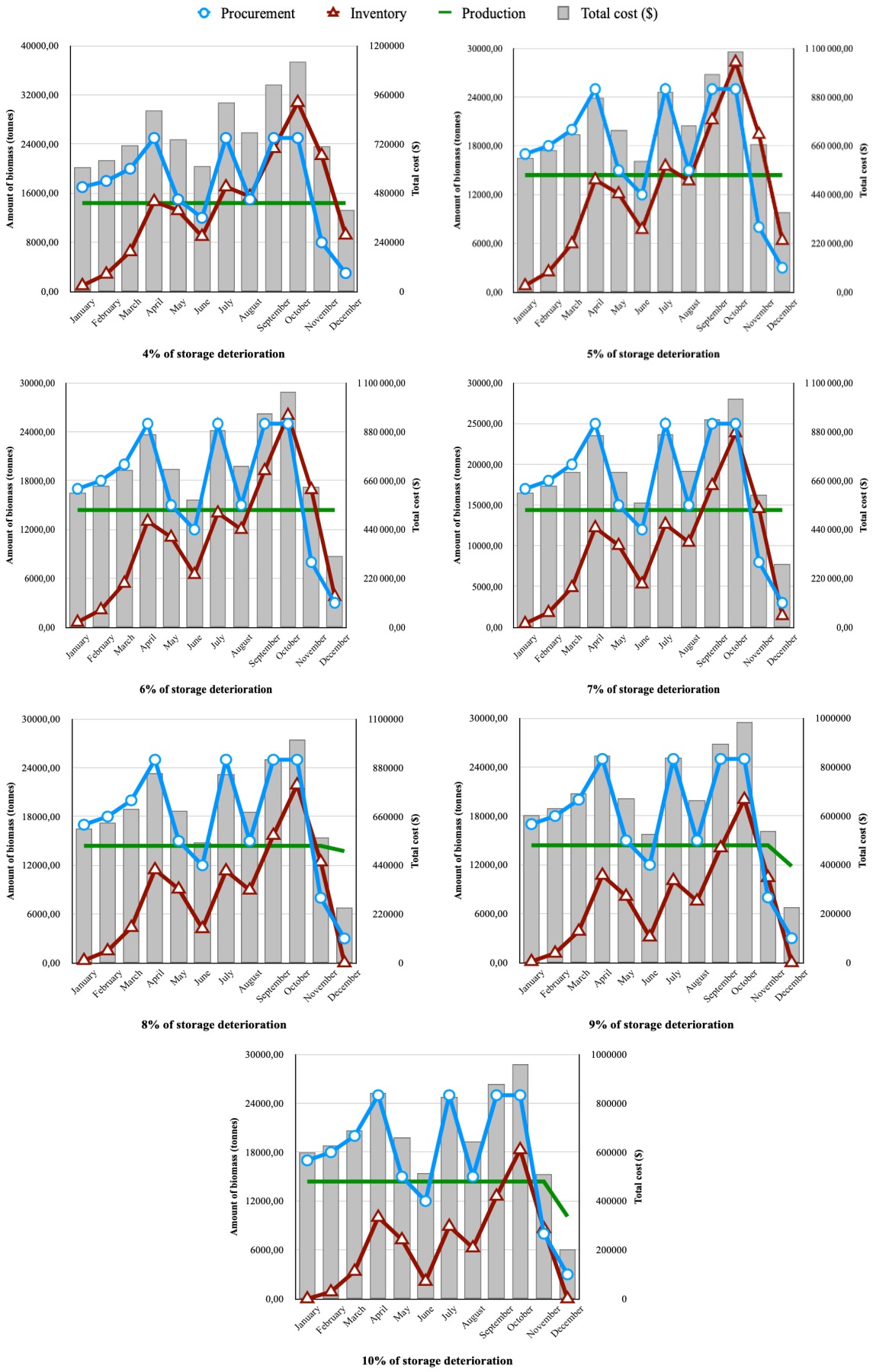


Figure I-7. Decentralized-Open warehouse

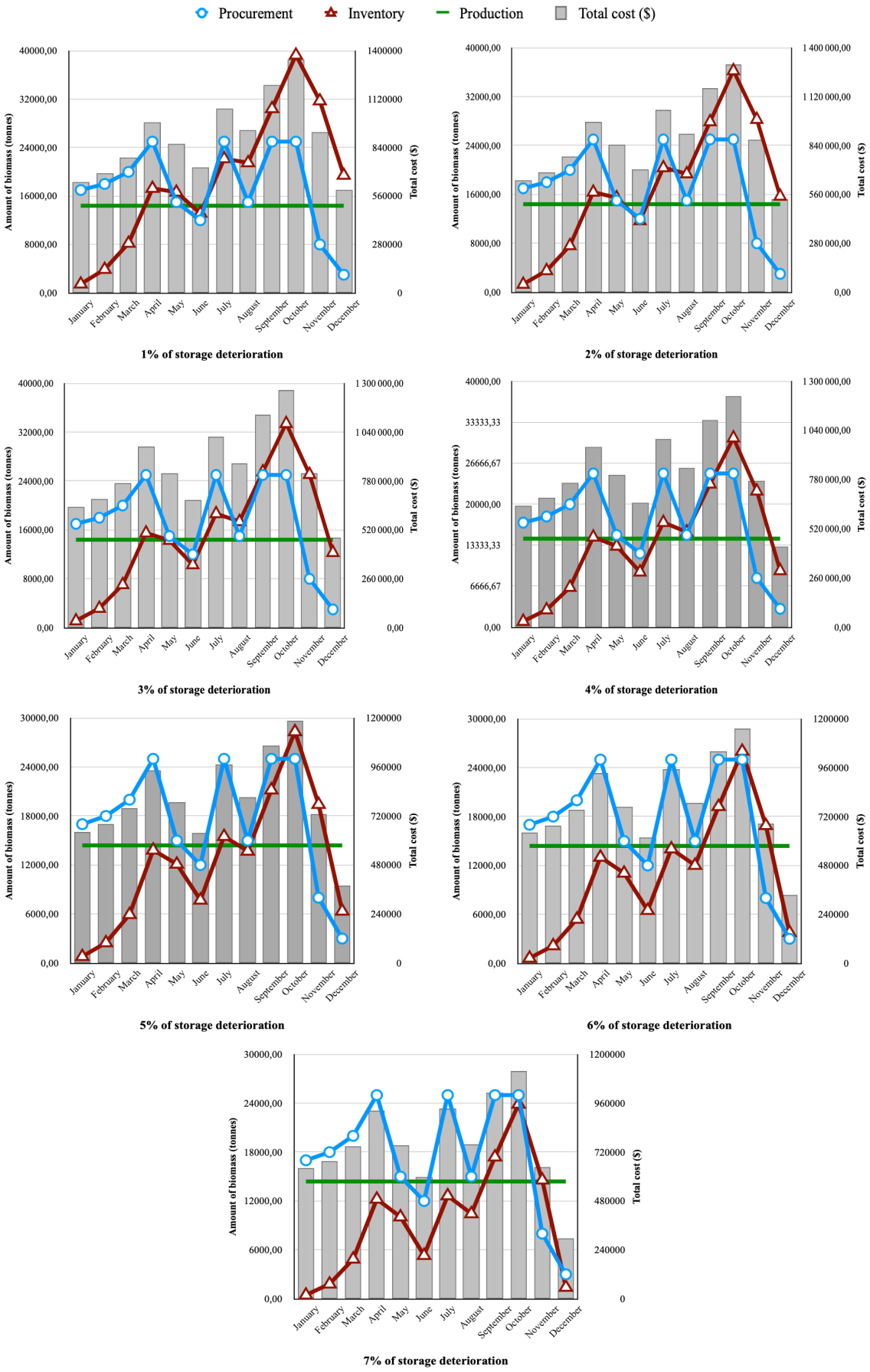
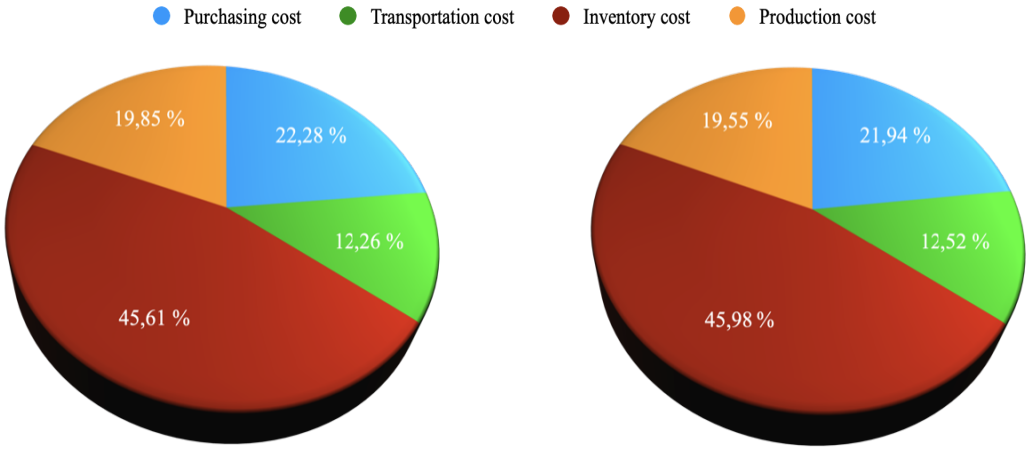


Figure I-8. Decentralized-Close warehouse

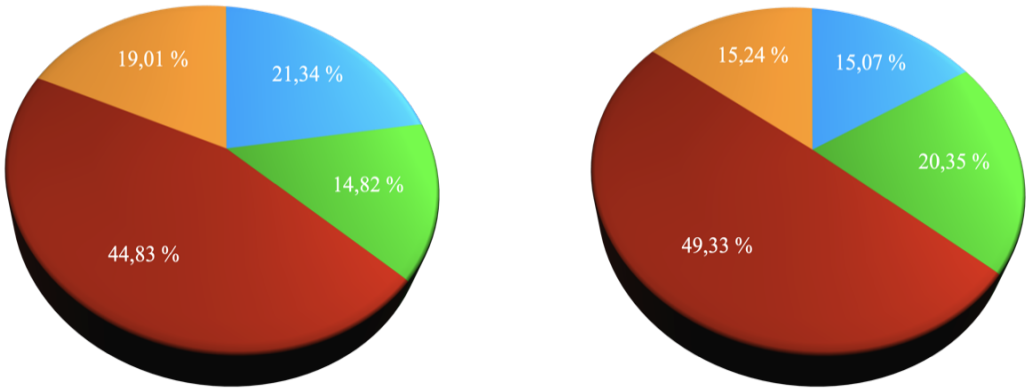
Appendix J. Total operational cost for centralized and decentralized distribution model according to the various of production capacity

1. Production capacity 10 tonnes per hour



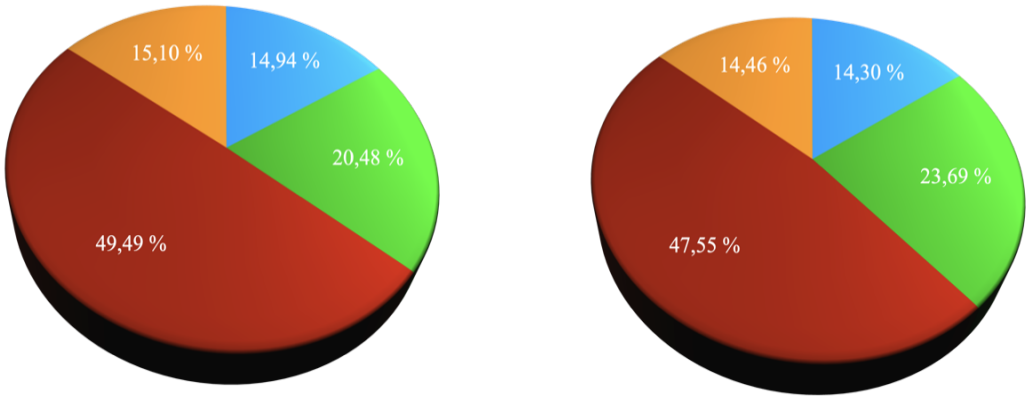
75% Centralized (HC)

50% Centralized (MC)



25% Centralized (LC)

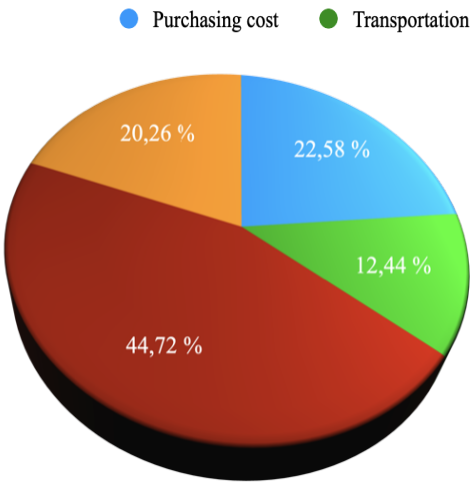
75% Decentralized (LD)



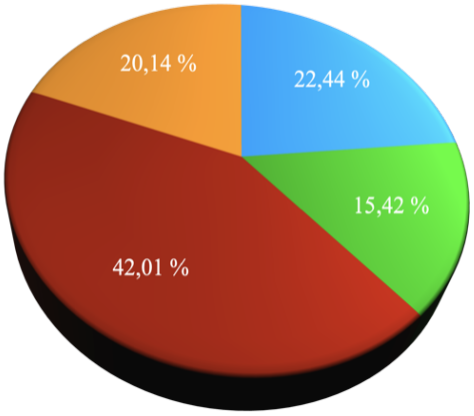
50% Decentralized (MD)

25% Decentralized (LD)

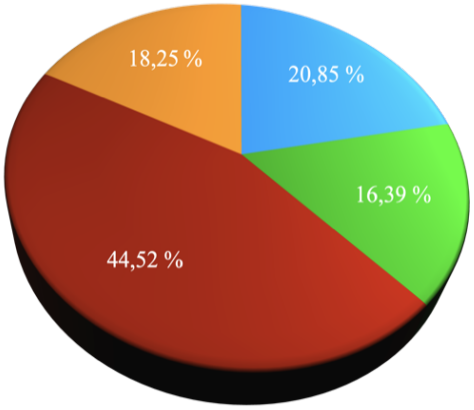
2. Production capacity 20 tonnes per hour



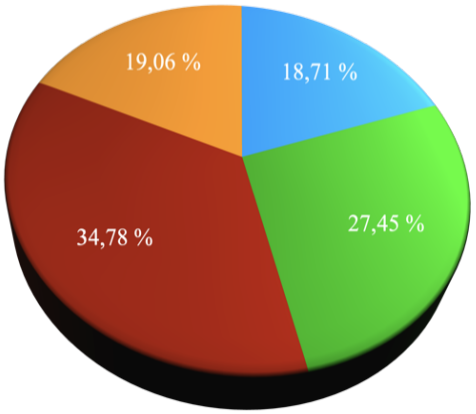
75% Centralized (HC)



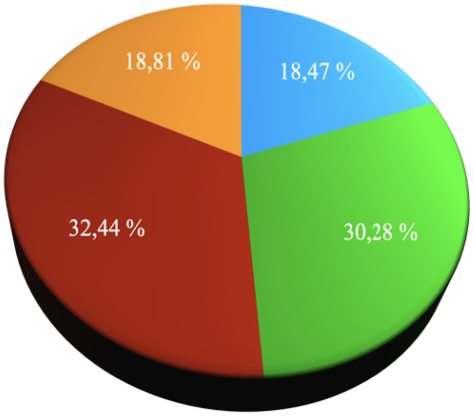
50% Centralized (MC)



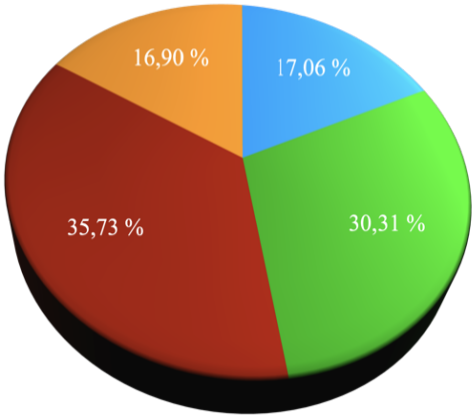
25% Centralized (LC)



75% Decentralized (LD)

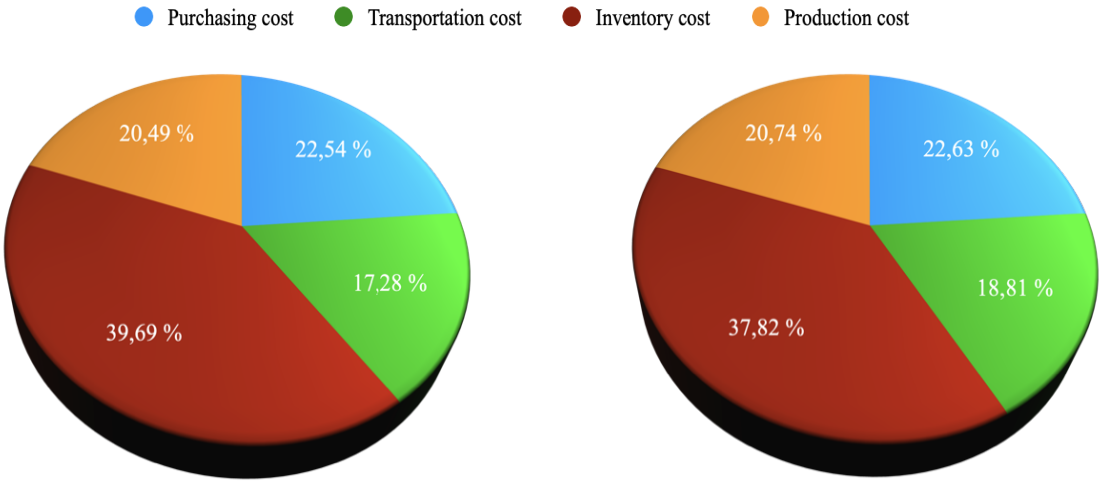


50% Decentralized (MD)



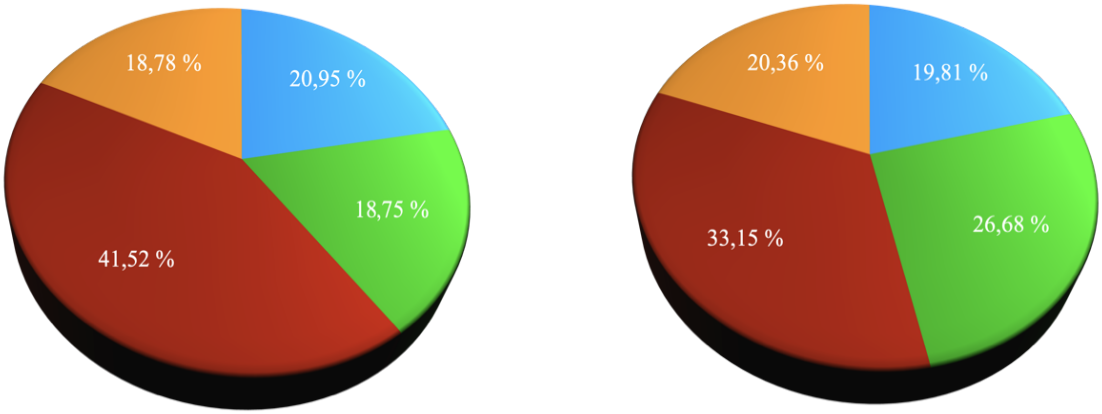
25% Decentralized (LD)

3. Production capacity 50 tonnes per hour



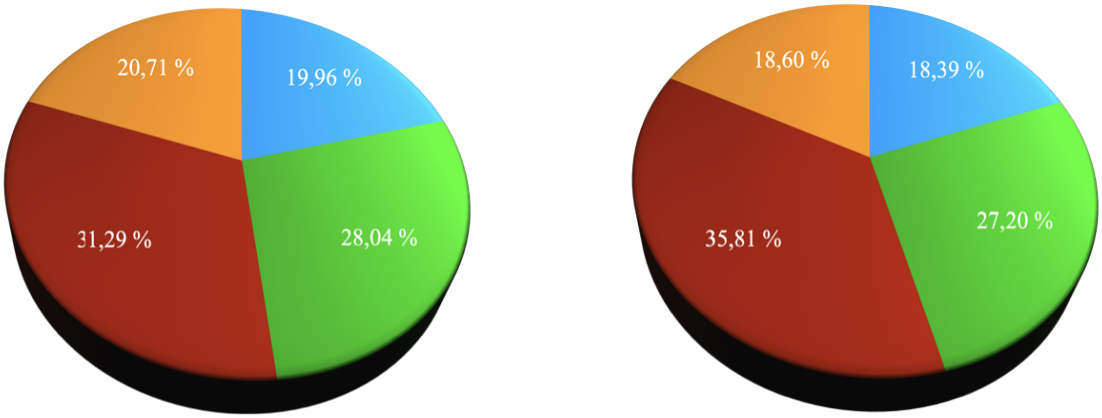
75% Centralized (HC)

50% Centralized (MC)



25% Centralized (LC)

75% Decentralized (LD)



50% Decentralized (MD)

25% Decentralized (LD)

(c)