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Coconut Shell-Based Briquettes for Sustainable Energy: A Bibliometric Study on Biomass Mixtures and Binder Materials

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Abstract

Coconut shell is one of the potential biomass resources that has been widely developed as a raw material for briquettes to support renewable energy initiatives and circular economy practices. This study aimed to explore the development, research focus, and future directions of cocomut shell briquette through a systematic literature review. The *Methodi Ordinatio* approach was employed for analysis, resulting in a final portfolio of 134 selected documents, which were the further examined to identify trends and research gaps. The findings showed that mixing coconut shell with other biomass such as from wood-based and agricultural-based residues could enhance the briquette performance. Moreover, alternative binders such as lignocellulosic carbohydrates and its derivatives, plant sap, and waste cooking oil offered promising substitutes for food-based materials. Oily biomass, such as eucalyptus wastes and pine resin, was also found to improve briquette performance due to its volatile content. In addition, the integration of automation technologies based on microcontrolers and the Internet of Things (IoT) has been applied to improve production efficiency and consistency. The findings of this study can serve as a foundation for future development focused on material formulation and technological innovations for coconut shell-based briquette production that are more efficient, sustainable, and responsive to future energy needs.

Keywords: Alternative binders, Bibliometric analysis, Biomass mixtures, Coconut shell briquettes.

1 Introduction

Global energy demand continues to rise in line with population growth and the pace of industrialization [1]. The reliance on fossil fuel sources has resulted in various negative environmental impacts, thereby encouraging the search for more sustainable energy alternatives. Renewable energy sources such as solar, wind, hydro, and biomass are being widely developed to reduce the strain on finite fossil resources. Among these, biomass holds a strategic position due to its renewable and widespread availability, particularly in the form of organic residues [2]. One notable application of biomass that has gained increasing attention is the production of biomass briquettes—commonly reffered as bio-briquettes—an alternative solid fuel that is environmentally friendly, cost-effective, and suitable for replacing conventional fossil-based energy sources [3].

The development of biomass briquettes has shown significant progress through the diversification of raw materials. Various types of biomass—such as rice husk, sugarcane baggase, wood residue, and coconut shell—have been utilized as primary feedstocks for briquette production [4–6]. Among these options, coconut shell stands out as a leading biomass source due to its high density, favorable fixed carbon content, and relatively high calorific value [7–8]. Moreover, the utilization of coconut shell supports the principles of biorefinery and circular economy by transforming organic waste into value-added alternative energy, while simultaneously reducing carbon emissions and waste volume [9–10].

Recent research trends on coconut shell biomass briquettes have become increasingly diserve and innovative. The focus of studies has expanded beyond basic characterization to include the exploration of production technologies, biomass blend formulations, and the development of sustainable natural binders [11–13]. Several recent studies have evaluted the use of agricultural and plantation waste—such as oil palm empty fruit bunches, corn stalk, and rice straw—as additives in coconut shell briquettes [14–16]. In addition, emerging research has begun to integrate technological approaches, such as microcontoller-based automation and the Internet of Things (IoT), into the briquette production process [17–20]. These developments highlight the need for a comprehensive literature synthesis that can consolidate scientific findings and identify research gaps that remain open for further investigation.

A systematic approach such as *Methodi Ordinatio* is considered effective in addresssing the need to evaluate the continouosly evolving research landscape [21–22]. This technique combines criteria of quality, citation count, and publication recency to construct a representative portfolio of documents [23]. By applying *Methodi Ordinatio*, the review findings can be developed into a visual map network that illustrates research cluster, dominant topics, and interrelated concepts. The use of this technique offers significant advantages in identifying research gaps and formulating strategic directions for future research development [24].

The aim of this study was to systematically explore and sythesize the developmet of research on coconut shell-based briquettes using the *Methodi Ordinatio* approach. This review also integrated bibliometric analysis based on a visual map network to obtain a comprehensive overview of research trends, scientific contributions, and potential future research directions. The findings of this study are expected to provide a strong scientific foundation for the development of more efficient, sustainable, and applicable coconut shell briquette innovations.

2 Material and Methods

2.1 Data Collection

Methodi Ordinatio, was used to structure systematic literature review, with data collection limited to the Scopus database [21, 23]. The main procedural steps are presented in Table 1. Data collection was conducted at the middle of January 2025 employing search query as "**briquette**" and "**coconut**", which outlined 157 documents with a total of 63 of keywords. The collected documents were the sorted by publication year—limited to the last decade (2015 to 2024)—and duplicate entries were removed using Mendeley as the reference manager, outlined as 142 documents. A thorough screening and reading of all documents were counducted to filter those relevant to this study. The final portfolio consisted of 134 documents and 25 keywords, which were further evaluated through bibliometric analysis and visualized using a visual map netwok.

Table 1. Main steps to perform the systematic review through *Methodi Ordinatio*.

Steps		Description	
Database search	**I**	**Initial portfolio**	
		Database	Scopus
		Keywords	63

		Number of documents	157
Filtering procedures	**II**	Elimination of duplicates and limiting to recent 10 years publication (2015 to 2024)	
	III	Screening title and keywords	
	IV	Reading of abstracts	
	V	Reading of full texts	
		Final portfolio	134
		Number of documents	25
		Keywords	
Content analysis	**VI**	Year of publication	
		Types of document	
		Keywords	

2.2 Bibliometric Analysis and Visual Maps Generation

Bibliometric analysis was conducted to synthesize the information obtained from the final portfolio (comprising 134 documents and 25 keywords), following a modified set of procedures [23–24]. The final portfolio was used to generate a visual map network with the assistance of VOSviewer v1.6.20, and the results served as a reference for conducting the systematic review in this study. the subsequent discussion was focused on key and critical parameters (based on visual map network), examined comprehensively to map potential directions for future development.

3 Results and Discussions

3.1 Visual Map Network and Bibliometric Results

Recent studies on the development of coconut shell-based briquettes has shown an increasing trend each year, as illustrated in Fig. 1. Discussion on combustion and the application of briquettes for stoves or cookers began in 2015 [25]. In subsequent years, studies began to focus on the engineering and optimization of the production process [26–27]. Starting in 2017, the addition of other biomass—such as tropical fruit waste, rice husks, water hyacinth, and wood residues—was explored to enhance the performace and characteristics of coconut shell-based briquettes [28–31]. From 2020 onwards, intensive studies were conducted on substituting binder materials, introducing alternatives such as plant sap and waste cooking oil (WCO) [13, 32–33]. More recent developments, beginning in 2023, have shifted toward techno-economic studies and environmental impact analyses, aimed at promoting more efficient practices and supporting the implementation of a circular economy [16, 34–38]. This is evidenced by the integration of internet- and microcontroller-based automation, as well as the emergence of agro-industrial and animal mannure as alternative briquette binders [17–18, 39–41].

Fig. 2 presents the distribution of publication types recorded over the past decade (2015–2024). Based on the final portfolio, experimental studies dominated the landscape with 67 documents, followed by conference papes with 60 documents. These figures indicate that research on the development of coconut shell-based briquettes has been predominantly conducted through direct experimentation to obtain primary data as sources of new scientific findings. Meanwhile, publication types such as reviews (4 documents) and book chapters (3 documents), highlight a lack of interest in summarizing and synthesizing research gaps related to coconut shell-based briquettes development. This remains a citical need, as expert perspective are essential in guiding future directions for the development of environtmentally friendly, high-performance, and economically valuable coconut shell-based briquettes.

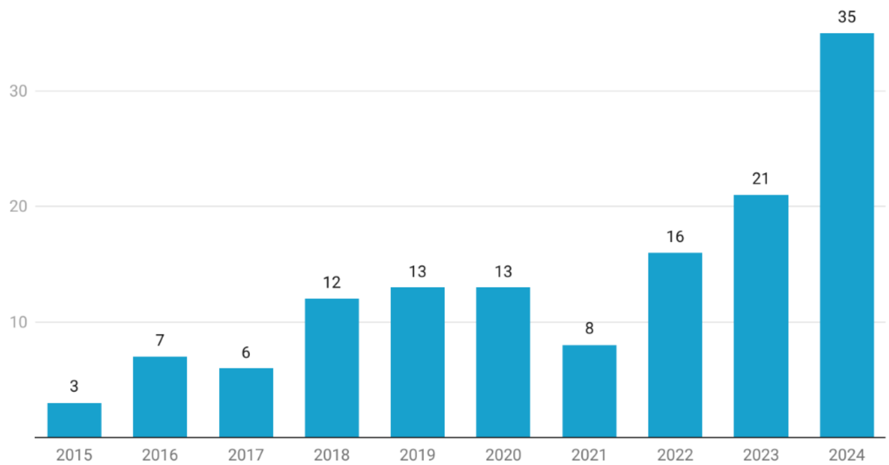

Figure 1. Distribution of the number of published documents based on years of publication over the past of decade (2015 to 2024).

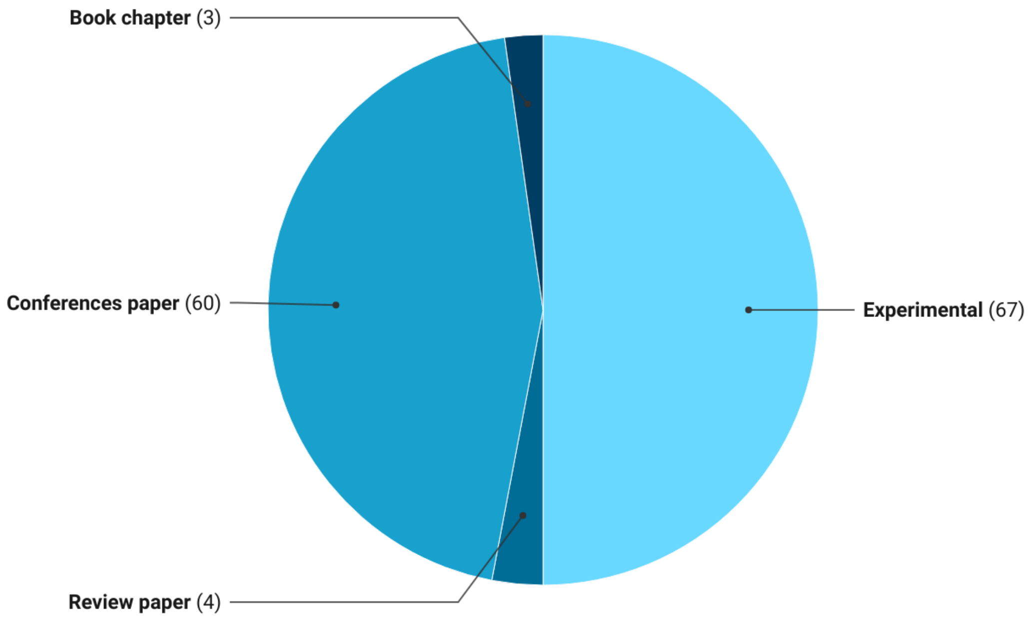

Figure 2. Distribution of the number of published documents based on publication categories over the past of decade (2015 to 2024).

Subsequently, the research trends in coconut shell-based briquettes developments—after filtered and screened into the final portfolio of 134 documents—were visualized as a visual map network, as shown in Fig. 3. Five distinct clusters were identified, each representing key research over the past decade: (i) briquette characteristics and performance; (ii) sustainable development; (iii) energy sources and utilization; (iv) adhesives or binders; and (v) recent developments. A noteworthy insight revealed through bibliometric approach is the growing emphasis, particularly in the past five years, on investigating biomass mixtures and binder materials used in the production of coconut shell-based briquettes. Several binder materials identified from the final portfolio include plat sap, WCO, agro-industrial waste, and animal manure—all of which have been shown to enhance the calorific value of coconut shell-based briquettes [28, 32–33, 40, 42–43].

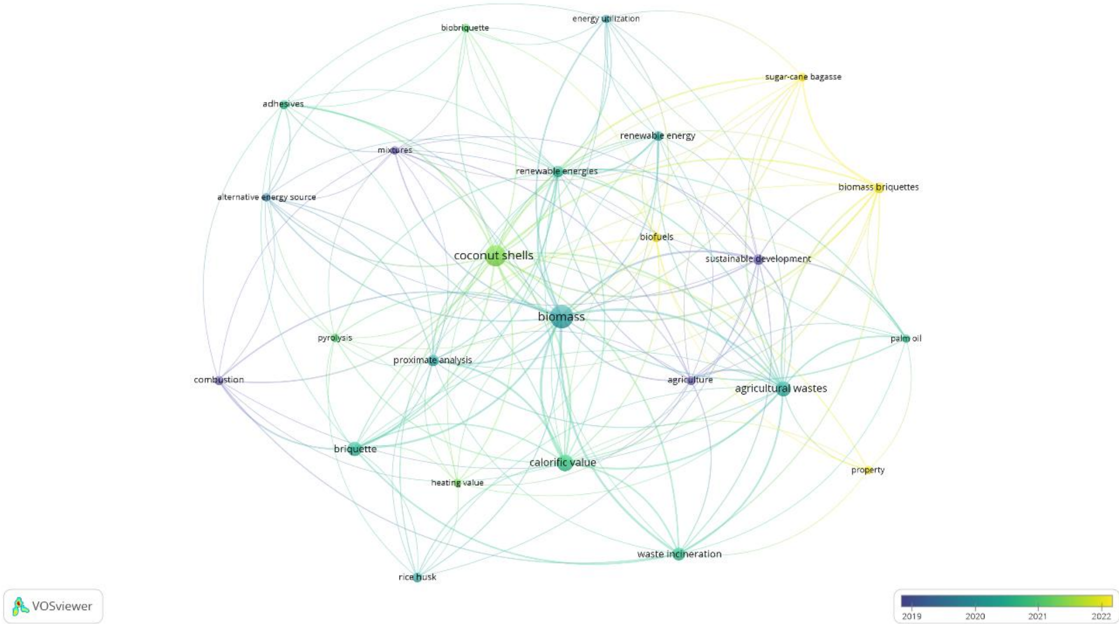

Figure 3. Visual map network of the developments on coconut shell-based briquettes over the past decade (2015 to 2024).

3.2 An Overview on Biomass Mixtures for Coconut Shell-Based Briquettes

Various types of biomass haave been successfully combined in the development of coconut shell-based briquettes, including rice husks, sugarcane bagasse, and oil palm resdiues. As shown in Fig. 4, new findings have emerged involving additional biomass combinations such as rice straw, wood residues, and agro-industrial waste. Coconut shell-based briquettes blended with wood residues—such as rubber rods, sawdust, and eucalyptus wastes—demonstrated high performance, with calorific value ranging from 6,300–8,000 cal/g [44–46]. This is attributed to the denser structure of wood residues compared to other agro-industrial biomass, particularly in terms of lignin content [47]. Various wood residues are known to contain at least 25% lignin within their lignocellulosic structure, whereas other agro-industrial biomass sources typically contain lower lignin content, ranging from 10–25% [48]. This phenomenon is further supported by data in Table 2, which shows that coconut shell-based briquettes combined with agro-industrial residues—such as straw, husks, and bagasse—have calorific values below 6,000 cal/g.

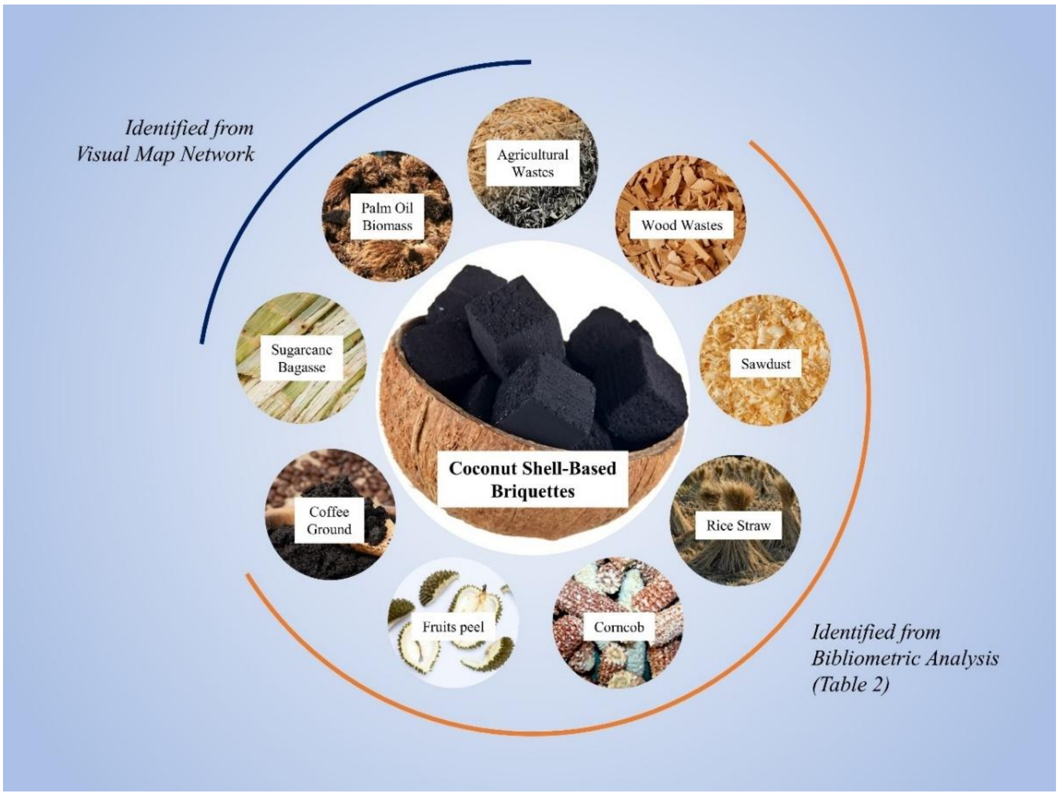

Figure 4. Various biomass mixtures on the developing of coconut shell-based briquettes based on visual map network and bibliometric analysis findings.

Overall, the proportion of coconut shell charcoal is generally higher than that of other biomass-derived charcoals. A greater proportion of coconut shell charcoal, particularly when combined with rice husk charcoal, has been shown to enhance briquette performance. For instance is the results from Rodiah [32], that reported a higher calorific value of 5,257 cal/g with a 2:1 ratio of coconut shell-to-rice husk charcoal, compared to 1:1 ratio which yielded a calorific value below 5,000 cal/g. However, despite its high calorific value, the proximate analysis showed an excessively high volatile mattter, approximately 48.99%. In addition, several studies that employed higher ratios of coconut shell charcoal—combined with rice straw, eucalyptus wastes, or coffee grounds—did not improve the proximate characteristics or overall performance of the briquette [11, 45, 54]. These findings highlight the need for further investigation based on the compiled data in this study

Table 2. Biomass mixtures on the recent developments of coconut shell-based briquettes.

Types of Biomass	Ratio[a]	MC[b]	VM[b]	AC[b]	FC[b]	CV[c]	Ref.
Rice straw	1:4	n.d.	n.d.	n.d.	n.d.	4,580	[11]
Rice husks	1:1	7.63	23.12	20.21	49.04	4,966	[49]
	1:1	7.52	23.40	21.16	47.92	4,886	[50]
	1:2	3.55	48.99	3.41	44.05	6,257	[32]
Sawdust	3:1	2.73	t.d.	1.75	t.d.	7,054	[51]
	3:1	4.23	t.d.	1.76	t.d.	7,561	[12]
	1:1	5.63	38.77	1.87	59.36	6,673	[52]
	1:1	1.00	23.44	8.28	67.28	7,564	[3]
Madan wood wastes	1:1	11.6	13.4	4.2	70.8	6,345	[44]
Rubber rods	1:1	5.87	4.76	3.56	86.81	8,082	[46]
Eucalyptus wastes	1:4	13.99	82.50	2.66	14.02	7,814	[45]
Corncob, Sugarcane bagasse	6:10:20	4.14	n.d.	n.d.	n.d.	5,945	[53]
Coffee grounds	1:3	7.84	36.24	9.38	46.54	4,637	[54]
Durian peel	3:2	13.83	1.69	11.67	72.81	5,284	[55]
Rambutan peel	1:9	4.05	t.d.	4.83	52.36	6,673	[56]

[a] The ratio of other biomass as mixture to coconut shell charcoal.

[b] Unit expressed in pecent (%); MC = moisture content; VM = volatile matter; AC = ash content; and FC = fixed carbon.

[c] Calorific value (CV) expressed in calory per gram (cal/g).

n.d. means the parameter was not determined on the relevant studies.

Interestingly, brqiuettes with other types of biomass that did not mentioned yet showed higher performance, with calorific value exceeding 7,000 cal/g, particularly in the case of sawdust charcoal addition at a 3:1 ratio [12, 51].

Based on studies on briquette performance modelling, volatile matter and fixed carbon are the proximate characteristics that significantly influence the calorific value of briquettes [57–59]. This has been demonstrated in study bu Handayani *et al.* [52], which reported lower briquette performance compared to the findings of Dewantoro *et al.* [3]. This phenomenon occurs because a high volatile matter leads to a lower fixed carbon (calculated by difference method), thereby reducing the potential energy released during oxidation—combustion reactions [60]. Further supporting this theory are the results of Kongpraset *et al.* [44], who reported a calorific value of 6,345 cal/g with a fixed carbon of 70.8%, which is lower than the results of Hamzah *et al.* [46], who obtained a calorific value of 8,082 cal/g and a fixed carbon of 86.81%. Both studies usde wood residues as biomass mixtures on coconut shell-based briquettes formulation. However, a constrasting finding emerged from the combination of coconut shell with eucalyptus waste—also a wood-based biomass—which exhibited a relatively low fixed carbon only 14.02%, yet a high calorific value of 7,814 cal/g [45]. This anomaly is attributed to the presence of residual volatile oils, which are highly flammable and differ in nature from conventional particulate volatile matter. These oils enhance the energy performance of the developed briquettes despite the lower fixed carbon [61].

3.3 Various Types of Binder Materials for Coconut Shell-Based Briquettes

One of the key aspects in the development of coconut shell-based briquettes highlighted in the visual map network is the type of binder materials. Table 3 lists various types of binders that have been employed in the production of coconut shell-based briquettes, with tapioca flour being the most dominat. This raises a concern, as tapioca serves as a satple food in many countries and its extensive use in briquette production may potentially conflict with food access and security [62–63]. This issue must be addressed promptly, as increasing the proportion of tapioca has been shown to improve the calorific performance of coconut shell-based briquettes. Based on the results of the bibliometric study, several alternative binders have been explored, including carbohydrate derivatives, plant sap, animal manure, and even microorganisms such as fungi. These findings are crucial, as they offer the potential to substitute tapioca with more environmentally friendly and sustainable binders that do not compromise food resources [64–65].

Table 3. The effect of various binder materials toward calorific value in the development of coconut shell-based briquettes.

Briquettes Formulation	Binders	CV[a]	Ref.
Rice husks and coconut shell (1:1)	6% Tapioca flour	4,966 kal/g	[49]
Rice husks and coconut shell (1:1)	8% Tapioca flour	4,886 kal/g	[50]
Sawdust and coconut shell (3:1)	6% Tapioca flour	7,561 kal/g	[12]
Sawdust and coconut shell (3:1)	10% Tapioca flour	7,054 kal/g	[51]
Coconut shell	25% Cassava peel	6,266 kal/g	[66]
Eucalyptus wastes and coconut shell (1:4)	0,5% carboxymethyl celllose (CMC)	7,814 kal/g	[45]
Coconut shell	7% EFB-based hydrogel with citric acid addition	7,878 kal,g	[3]
Rambutan peels and coconut shell (1:9)	20% Molasess	6,297 kal/g	[56]
Rice husks and coconut shell (1:2)	4% Starch and 4% Mango sap	6,257 kal/g	[32]
Rice husks and coconut shell (n.d.)	Pine resin	9,352 kal/g	[42]
Sugar palm dregs fiber, cassava dregs, and coconut shell (7:13:4)	*Ganoderma lucidum* (filamentous fungi)	4,522 kal/g	[67]

[a] CV = calorific value of developed briquettes.
n.d. means the parameter was not determined on the relevant studies.

In addition to the type of binder, the binder-to-briquette ratio also plays a critical role in determining the performance of coconut shell-based briquettes. As shown in Table 3, carbohydrate-based binders and their derivatives—such as tapioca flour and carboxymethyl cellulose (CMC)—are among the most commonly used materials in coconut shell-based briquette development. Tapioca flour, when applied at a ratio of 6–10%, has been shown to produce a calorific value as 4,800 to 7,500 cal/g [12, 49–51]. Meanwhile, CMC, a modified carbohydrate compound, resulted in a higher calorific value of 7,814 cal/g, even with a much lower addition ratio of just 0.5% [45]. This indicates that carbohydrate modification can significantly reduce the required binder ratio while maintaining excellent briquette performance. Another noteworthy finding is the potential of binder blending, such as combination of starch with mango sap, which can reduce starch dependency [32]. Furthermore, the use of biomass-derived binders presents a renewable and circular approach [68]. Several types of biomass have been applied as binders in coconut shell-based briquette prodcution, including cassava peel (25% addition yielding 6,266 cal/g) [66], modified empty fruit bunches (modified EFB, 7% addition yielding 7,870 cal/g) [3], and molasses (20% addition yielding 6,297 cal/g) [56]. These results emphasize that event at relatively high ratios, biomass-based binders can enhance the value of coconut shell-based briquettes, supporting the implementation of sustainable circular economy practices.

In addition to carbohydrate-based binders and their derivatives, several alternative binders have been developed over the past decade, including plant sap and filamentous fungi. As previously discussed, plant sap can be used as a complementary binder to carbohydrate compounds, effectively reducing the required ratio while still maintaining good briquette performance [32]. Furthermore, plant sap has also been applied as a standalone binder, such as pine resin, which is known to contain volatile oils—similar to the case of combining coconut shell-based briquettes with eucalyptus waste. Coconut shell-based briquettes bound with pine resin have demonstrated high calorific performance, reaching up to 9,352 cal/g [42]. This phenomenon highlights the potential application of binders containing volatile and combustible oils as a strategy to further improve briquette energy performance. However, the use of such alternative binders requires more comprehensive investigation, especially regarding techno-economic aspects, including production cost and resource availability. A recent finding from the bibliometric study also reveals the emerging use of animal manure as a binder, which presents a promising renewable alternative for the future development of coconut shell briquettes [40, 43].

3.4 Future Novel Development

The combination of coconut shell-based briquette matrix with other biomass types and the use of alternative binders beyond tapioca flour presents a promising direction for future briquette development, as shown on Fig. 5. The utilization of wood-based biomass (or residues derived from agroforestry activities) has been shown to enhance both the physical characteristics and performance of briquettes. However, fruit peels have also demonstrated encouraging potential, as evidenced by the use of durian and rambutan peels [55–56]. These findings offer opportunities to increase the value chain of agro-industrial residues and serve as tangible examples of circular economy practices. Moreover, the substitution of food-based binders, such as tapioca flour, is urgently needed to address emerging concerns related to food security [3]. One of the most promising binder alternatives identified in the literature is plant sap, which possesses high potential due to its natural adhesive properties and renewable origin as a plant exudate. This potential has been validated through the use of mango sap and pine sap, which have demonstrated calorific values of 6,257 cal/g and 9,352 cal/g, respectively, when used as binders in coconut shell briquette formulations [32, 42].

An interesting finding that emerged from this study is the utilization of oil-containing biomass in coconut shell-based briquette development. The presence of oil in briquettes can enhance both performance and energy potential, as demonstrated by the use of eucalyptus waste as a biomass mixture and pine resin as a binder [42, 45]. These materials are known to contain essential oils, which are volatile and highly flammable, thereby contributing to the increased calorific value of the briquettes [61]. This phenomenon suggests the potential application of WCO, a by-product of the food agroindustry that is increasing in volume annually [33]. Although the use of WCO in coconut shell-based briquette development has been widely studied since 2020, its actual application remains limited. In addition, recent advances in production technologies—particularly the implementation of integrated systems with microcontroller-based automation and Internet of Things (IoT) capabilities—present new avenues for further innovation in the sustainable development of coconut shell-based briquettes [17–19].

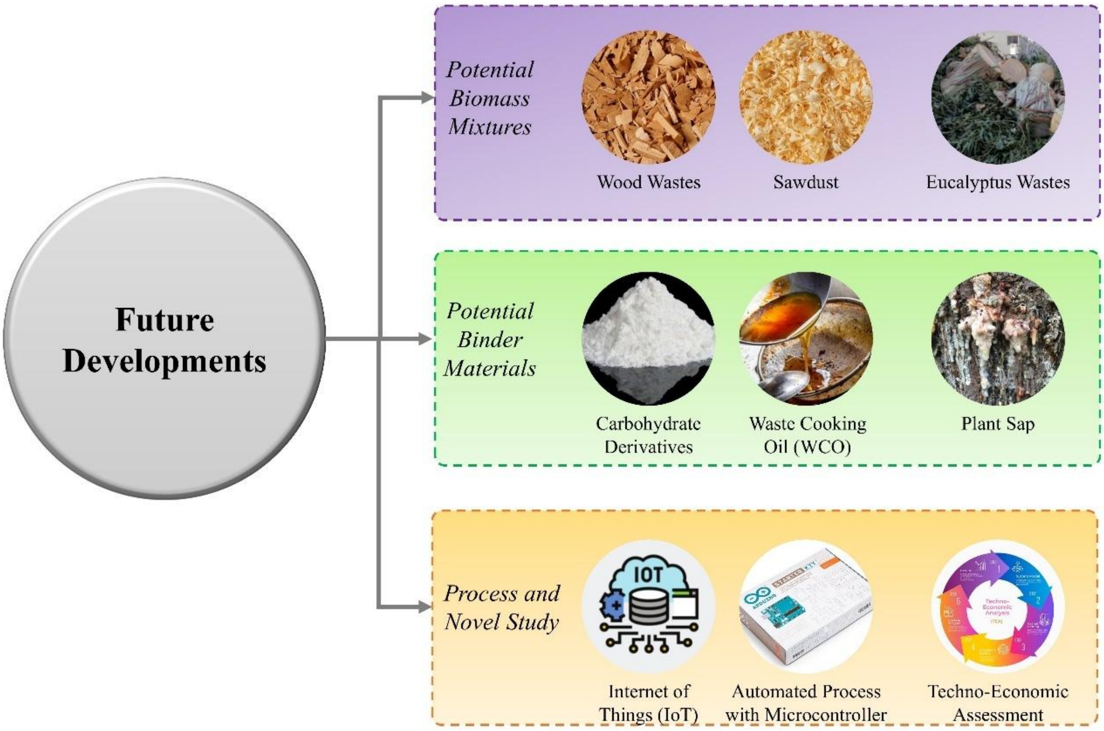

Figure 5. Future potential developments outlined from this study.

4 Conclusions

The development of biomass briquettes based on coconut shell has shown significant progress in terms of raw materials, energy characteristics, and production efficiency. In this context, the combination of various types of biomass and the exploration of alternative binders have emerged as promising aspects for future innovation. Biomass mixtures such as sawdust, straw, and agro-industrial residues have been proven to enhance the calorific value and combustion performance of briquettes. Alternative binders—including plant sap, WCO, animal manure, carbohydrate derivatives from lignocellulosic biomass, and even microorganisms such as filamentous fungi—offer substantial potential to reduce reliance on food-based materials. Furthermore, the utilization of biomass containing oil compounds—such as eucalyptus waste and pine resin—has shown positive effects on briquette performance due to their flammable volatile content. Innovations in automated production systems using microcontrollers and Internet of Things (IoT) technologies also signal a new direction toward greater efficiency and process standardization. Overall, these findings provide a strong foundation for the advancement of coconut shell briquettes that are not only technically superior but also aligned with circular economy principles and long-term sustainability.

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