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The Strategic Importance of Palm Oil as a Source of Renewable Energy

Loso Judijanto*

IPOSS Jakarta, Indonesia, losojudijantobumn@gmail.com.

***Correspond Author:** Loso Judijanto, IPOSS Jakarta, Indonesia, losojudijantobumn@gmail.com.

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Abstract

Palm oil has emerged as a critical renewable energy resource due to its high yield, extensive cultivation, and policy support in major producing countries. This research seeks to examine the critical role of palm oil in advancing renewable energy frameworks, focusing on its contributions to energy security, technological advancements, environmental impact, and socioeconomic development. Employing a qualitative literature review approach, this research synthesises findings from over 80 scientific publications and policy documents to provide a comprehensive understanding of the topic. Data collection involved systematic retrieval and screening of peer-reviewed articles, reports, and official statistics primarily from academic databases and institutional repositories. The analysis applied thematic content synthesis to identify key patterns and relationships related to palm oil's role in renewable energy production, sustainability challenges, and policy frameworks. Results indicate that palm oil significantly contributes to biodiesel production, biogas generation, and biomass power, backed by advancements in technology that boost both energy conversion effectiveness and ecological sustainability. In addition, the sector is instrumental in generating rural employment and driving local economic progress, although issues such as certification barriers and regulatory inconsistencies remain. The findings underscore the necessity of integrated governance and continuous innovation to maximise palm oil's renewable energy potential while addressing sustainability concerns. In conclusion, palm oil holds a multifaceted strategic position in advancing renewable energy goals, with implications for policy refinement and sectoral development. Future research should focus on improving smallholder inclusion and developing robust sustainability assessment tools to further enhance palm oil's role in clean energy transitions.

Keywords: Palm Oil, Renewable Energy, Biodiesel, Qualitative Literature Review, Sustainability

1. Introduction

Over the past twenty years, the worldwide appetite for renewable energy has grown rapidly, propelled by the pressing necessity to lessen reliance on fossil fuel sources, reduce climate change impacts, and secure sustainable energy for the long term [1]. International initiatives, including the Paris Accord and the United Nations SDGs, highlight the critical need to fast-track the move toward cleaner energy solutions, more sustainable energy sources [2]. Amid these evolving energy paradigms, bioenergy has gained renewed attention, particularly in developing countries endowed with vast agricultural resources [3]. Among various bioenergy feedstocks, palm oil has emerged as a prominent subject of contention owing to its remarkable oil productivity per hectare, cost-efficiency, and year-round harvestability [4]. Palm oil holds significant value not only in the food sector but also across numerous industrial uses, but is also increasingly viewed as a viable source of renewable energy, primarily in the form of biodiesel and biogas generated from palm oil mill effluent (POME) [5]. This dual-use nature of palm oil places it at the intersection of energy, agriculture, and sustainability debates [6].

The strategic significance of palm oil in the renewable energy transition is especially prominent in Southeast Asia, where Indonesia and Malaysia rank among the top producers worldwide [7]. For instance, in Indonesia, biodiesel produced from palm oil now plays a central role in the country's total energy portfolio, supported by government mandates such as the B30 program, which requires diesel fuel to be blended with 30% biodiesel [8]. Such policies are intended not only to reduce fossil fuel imports but also to stimulate rural economies, promote energy independence, and reduce greenhouse gas emissions [9]. Despite its expansion in the energy sector, palm oil development has faced multifaceted issues and widespread critique. Environmental groups and international observers have raised concerns and unfair accusations regarding deforestation, biodiversity loss, peatland degradation, and the greenhouse gas emissions caused by land-use conversion [10]. Moreover, the perceived trade-offs between food security and energy production have sparked debates on the sustainability of bioenergy pathways derived from palm oil [11]. In response to these controversies, increased focus has been placed on certification systems such as the Roundtable on Sustainable Palm Oil (RSPO) and the Indonesian Sustainable Palm Oil (ISPO), designed to guarantee that palm oil production for energy meets environmental and social standards [12].

Technological advancements have also shaped the significance of palm oil in progressing renewable energy initiatives. Recent innovations in biomass conversion, POME treatment, and second-generation biofuels have expanded the potential of palm oil beyond conventional biodiesel [13]. Produced as a secondary product during palm oil processing, POME has emerged as a valuable feedstock with strong potential for biogas generation, contributing to energy generation while simultaneously addressing industrial waste management issues [14]. These developments underscore the evolving complexity of palm oil's role in modern energy systems [15]. In addition, the strategic positioning of palm oil as a renewable energy source must be examined within the broader context of global energy justice and socio-economic equity [16]. Smallholder farmers, who control a significant portion of palm oil plantations in Indonesia, are critical actors in ensuring that the energy transition is inclusive and sustainable [17]. Their participation in sustainable energy value chains depends on factors such as access to technology, financing, infrastructure, and institutional support [18]. Failure to incorporate smallholders into renewable energy strategies could exacerbate inequality and limit the broader developmental benefits of the energy transition [19].

Given this intricate interplay between environmental sustainability, energy policy, technological innovation, and rural livelihoods, a comprehensive and critical examination of the strategic relevance of palm oil for renewable energy purposes is firmly supported. Previous studies have predominantly examined either the ecological risks associated with palm oil production or its value in economic terms [20]. However, few studies have synthesized the full spectrum of strategic factors that define palm oil's current and potential role in global and national renewable energy agendas. This study seeks to fill that gap by conducting a qualitative literature review of scholarly articles, institutional reports, and policy analyses published over the last decade. The review does not rely on field observations or focus group discussions; rather, it synthesizes insights from previously published sources to ensure analytical integrity and avoid fictitious or unsubstantiated claims. Through this approach, the objective of this study is to formulate a thorough comprehension of the strategic roles, positive impacts, and challenges related to promoting palm oil as a central component in renewable energy. Specifically, the objective of this paper is to critically evaluate the strategic importance of palm oil in supporting renewable energy transitions, with a focus on its potential contributions to energy security, environmental sustainability, economic development, and technological innovation. By doing so, this research provides important perspectives for policymakers, scholars, and industry professionals aiming to understand and manage the opportunities and difficulties associated with bioenergy from palm oil in the realm of sustainable development.

2. Literature Review

2.1. Global Perspectives on Renewable Energy and Bioenergy

The international energy sector is experiencing a profound shift as countries fast-track their move away from fossil fuels toward cleaner, renewable energy options [21]. Bioenergy, derived from organic materials, has become a cornerstone of this shift due to its versatility, scalability, and compatibility with existing energy infrastructure [22]. Among various bio-based feedstocks, the production of biodiesel increasingly relies on palm oil as a significant input, particularly in tropical countries with high agricultural productivity. Its oil yield, which surpasses other crops such as soybean and rapeseed, positions palm oil as an economically attractive and technically feasible biofuel source [23]. Bioenergy derived from palm oil offers dual benefits of climate mitigation and rural economic development [24]. However, global discourse surrounding palm oil remains polarized, with advocates emphasizing its renewable potential, while critics underscore its environmental and social risks. These opposing narratives necessitate a comprehensive and evidence-based evaluation of palm oil's strategic importance within renewable energy systems [25].

2.2. Palm Oil in National Energy Strategies

Palm oil holds strategic importance in shaping renewable energy policies in top-producing nations like Indonesia and Malaysia. Indonesia's biodiesel policy, particularly the B30 mandate requiring a 30% blend of palm oil-derived biodiesel with conventional diesel, exemplifies a state-driven approach to reducing fossil fuel dependence while promoting local industries [26]. This policy is backed by presidential regulations and supported by public-private investment schemes. The success of such initiatives is reflected in Indonesia's increasing biofuel production capacity and its ambition to become a global bioenergy hub [27]. Nonetheless, national strategies involving palm oil must balance economic benefits with environmental responsibilities [28]. The expansion of biodiesel demand has been linked to deforestation and peatland conversion, which contribute to significant carbon emissions if not managed sustainably. As such, strategic frameworks that incorporate sustainability standards and traceability mechanisms are essential [29].

2.3. Technological Developments in Palm Oil-Based Bioenergy

Technological innovation has enhanced the potential of palm oil as a renewable energy option extending past conventional biodiesel uses. Advances in biomass gasification, enzymatic transesterification, and biogas recovery from palm oil mill effluent (POME) have expanded the range of energy products derived from palm oil [30]. POME, once regarded as a pollutant, is now recognized as a valuable substrate for biogas generation through anaerobic digestion systems [31].

Additionally, incorporating residues from palm oil, including empty fruit bunches and kernel shells, into cogeneration setups has been successful in producing electricity, especially in rural off-grid areas [32]. These technologies not only improve energy efficiency but also contribute to circular economy practices within the palm oil sector. Nevertheless, adoption at scale remains constrained by infrastructural limitations, inconsistent feedstock quality, and financing barriers [33].

2.4. Environmental and Sustainability Considerations

Despite its energy potential, the sustainability of bioenergy derived from palm oil is still under close and critical review. Several studies have pointed out the indirect land use change (ILUC) effects and carbon debt associated with converting forests into oil palm plantations [34]. While some life-cycle assessments (LCAs) show that palm-based biodiesel can achieve significant GHG reductions compared to fossil fuels, others argue that such benefits are neutralized when plantation extensions illegally encroach on primary forests or peatlands [35]. Initiatives like the Roundtable on Sustainable Palm Oil (RSPO) and the Indonesian Sustainable Palm Oil (ISPO) were established to tackle sustainability issues and promote greater accountability among stakeholders [36]. Although these schemes have improved traceability and governance, their effectiveness is still challenged by weak enforcement, limited smallholder participation, and market fragmentation.

2.5. Socioeconomic Dimensions and Smallholder Inclusion

The socio-economic impact of palm oil-based bioenergy is another strategic factor that requires careful analysis. In Indonesia, smallholder farmers contribute to nearly 40% of the nation's total oil palm output, making them vital actors in the renewable energy supply chain. However, smallholders often lack access to the technology, finance, and knowledge required to participate in bioenergy programs, resulting in unequal distribution of benefits [37]. Empowering smallholders through inclusive policies, training programs, and cooperative models can strengthen the resilience of palm oil-based bioenergy systems while promoting social equity. Several pilot projects have demonstrated that smallholder engagement in biodiesel cooperatives and biogas units can increase rural income, reduce reliance on fossil fuels, and promote community-based energy solutions [38].

2.6. Policy and Regulatory Frameworks

An enabling policy framework is crucial for effectively incorporating palm oil into renewable energy strategies. In Indonesia, a cooperative effort between the Ministry of Energy and Mineral Resources (MEMR), the Ministry of Agriculture, and BPDP-KS has created a multi-stakeholder governance framework to promote biofuel advancement [39]. These institutions are responsible for subsidy allocation, research and development, and regulatory oversight. However, regulatory inconsistencies and overlapping mandates among agencies often hinder policy coherence and long-term planning. Furthermore, international trade dynamics and sustainability criteria imposed by export markets such as the European Union introduce additional complexity into national policy implementation [40].

3. Methodology

The research adopts a qualitative methodology, specifically employing a qualitative literature review to examine the strategic significance of palm oil as a renewable energy source. The qualitative literature review is selected due to its suitability for synthesizing existing knowledge, identifying theoretical gaps, and critically analyzing academic and institutional discourses without engaging in empirical fieldwork. The type of qualitative research adopted here emphasizes interpretive analysis, aiming to construct a comprehensive understanding based on previously published scholarly materials. The primary research instrument is the researcher as a conceptual analyst, who systematically identifies, interprets, and synthesizes relevant literature to explore the multifaceted roles of palm oil within the context of renewable energy. Data collection was conducted through the purposive selection of peer-reviewed journal articles, policy documents, institutional reports, and technical publications published between 2015 and 2025. These sources were retrieved from major academic databases, including Scopus, Web of Science, and Google Scholar, using specific search terms such as "palm oil bioenergy," "renewable energy policy," "biodiesel palm oil," and "sustainable palm oil development." Inclusion criteria were based on relevance to the research objectives, academic rigor, and credibility of the publishing source, while duplication and non-scholarly materials were excluded. The literature data collected were then analyzed using thematic analysis, which involved identifying recurring patterns, key themes, and conceptual relationships across the selected documents. This process allowed the researcher to categorize strategic dimensions such as technological advancement, policy integration, socio-economic impacts, and environmental considerations of palm oil-based energy systems. The analysis was interpretive in nature, focusing on meaning-making through critical comparison and contextual understanding rather than quantification. Through this qualitative literature review, the study aims to provide a synthesized and structured narrative that reflects the strategic relevance of palm oil in achieving renewable energy goals within both national and global frameworks.

4. Results

This section presents a comprehensive synthesis of findings from the qualitative literature review on the essential contribution of palm oil to renewable energy initiatives. The results are organized into six key themes covering production contributions, technological advancements, environmental impacts, socioeconomic effects, policy frameworks, and global trade dynamics.

4.1. Contribution of Palm Oil to the Global Renewable Energy Mix

Analysis of the literature reveals that palm oil contributes significantly to the global supply of renewable energy, especially within the biodiesel industry. As of 2023, palm oil-based biodiesel accounted for approximately 36% of global biodiesel production, positioning it among the top three feedstocks globally [41]. In countries like Indonesia and Malaysia, over 9.6 billion liters of biodiesel were produced annually, with more than 75% sourced from crude palm oil (CPO) [42]. These figures reflect the strategic alignment of the palm oil industry with national energy diversification policies. In Indonesia, the mandatory B30 biodiesel blending policy, enforced since 2020, has substantially increased domestic palm oil absorption, redirecting around 9.2 million kiloliters of CPO from the food sector to energy applications annually [43]. This policy is projected to reduce diesel fuel imports by up to 20%, saving the government approximately USD 3.9 billion per year [44].

4.2. Technological Advancements and Efficiency Gains

A significant body of research documents technological improvements in palm-based energy conversion. One of the key developments includes transesterification efficiency, with conversion rates improving from 85% to 98% over the last decade due to enzymatic catalysts and heterogeneous acid-base catalysts [45]. Similarly, biogas recovery from palm oil mill effluent (POME) has seen increasing adoption, with methane yields reaching 24–28 m^3/ton POME, depending on operational parameters [46]. In regions like Riau and North Sumatra, over 115 biogas plants have been commissioned, generating more than 150 MW of renewable electricity collectively [47]. Moreover, the use of empty fruit bunches (EFBs) and palm kernel shells (PKS) for cogeneration has enabled off-grid power generation in rural areas. In Malaysia, these biomass sources contributed approximately 625 GWh of electricity in 2022, reducing dependence on coal-fired power in several provinces [48].

4.3. Environmental Performance and GHG Emissions Reduction

Palm oil-based biodiesel has demonstrated tangible reductions in greenhouse gas (GHG) emissions. According to multiple life-cycle assessments, when produced under sustainable conditions, palm biodiesel can reduce GHG emissions by 56–65% compared to conventional fossil diesel [49]. For example, one study shows that ISPO-certified palm biodiesel achieves an emission intensity of 38.2 gCO_2eq/MJ, well below the European Union's RED II threshold of 50 gCO_2eq/MJ [50]. Indonesia's national GHG inventory estimates that the expanded use of palm biodiesel under the B30 mandate has helped avoid 25.6 million tons of CO_2-equivalent emissions annually [51]. Furthermore, methane capture from POME has a carbon offset potential of up to 1.2 million tons of CO_2eq per year, if applied at scale across all mills [52].

4.4. Socioeconomic Contributions and Employment Creation

The renewable energy utilization of palm oil contributes significantly to employment and rural development. In Indonesia alone, the palm oil sector supports 17 million jobs, with an estimated 8.4 million people directly involved in upstream activities (planting, harvesting) and the remainder in midstream and downstream processing [53]. The integration of smallholder farmers into biodiesel value chains has also shown promising outcomes. Participation in community-based bioenergy projects has increased household income by 18–27% in pilot regions like Jambi and West Kalimantan [54]. However, despite their importance, smallholders face persistent challenges related to certification, access to capital, and market inclusion. Less than 20% of smallholder land is certified under sustainability schemes like RSPO or ISPO, limiting their entry into regulated biodiesel markets [55].

4.5. Policy Impacts and Institutional Support

The expansion of palm oil as a renewable energy source has been significantly influenced by policy measures. The 2015 establishment of BPDP-KS brought financial subsidies aimed at supporting biodiesel blending, with disbursements reaching IDR 51.8 trillion (approx. USD 3.4 billion) by 2022 [56]. This mechanism ensures price parity between biodiesel and fossil diesel, encouraging industry compliance. Additionally, the General National Energy Plan (RUEN) outlines a target of 23% renewable energy share in Indonesia's energy mix by 2025, with palm-based biodiesel expected to contribute more than 40% of the liquid biofuel component [57]. The government's downstream policy has also promoted export restrictions on CPO and increased local processing, driving domestic value addition and energy security [58]. Nevertheless, regulatory overlaps among ministries and inconsistent enforcement of sustainability requirements continue to undermine the sector's coherence and long-term planning capability [59].

4.6. Global Trade Dynamics and Sustainability Pressures

Global market dynamics also shape the strategic position of palm oil in the energy sector. For instance, the European Union used to be the primary importer of Indonesian palm biodiesel, has implemented increasingly strict sustainability criteria through Directive (EU) 2018/2001, that designates palm oil as a feedstock associated with significant ILUC risk [60]. This classification has prompted a pivot toward non-EU markets, such as China, India, and domestic consumption strategies to mitigate export dependency. Despite these challenges, some producers have managed to align with international sustainability standards, enabling continued access to premium markets. In 2023, the worldwide demand for certified sustainable palm oil (CSPO) climbed to 14.7 million metric tons, marking a 20% growth compared to the prior year [61]. The findings indicate that palm oil holds strategic importance in renewable energy systems due to its high productivity, policy backing, socioeconomic significance, and evolving technological innovations. Nonetheless, its full potential can only be realized under rigorous environmental and institutional governance. The findings serve as a basis for deeper discussion on balancing energy security, economic benefit, and sustainability goals.

5. Discussion

The discussion of this study synthesizes the essential strategic functions of palm oil within renewable energy, reflecting the comprehensive qualitative literature review findings. Firstly, the role of palm oil within the global renewable energy mix highlights its crucial significance, especially in biodiesel production. With palm oil-based biodiesel accounting for approximately 36% of global biodiesel output and constituting over 75% of Indonesia's biodiesel feedstock, it is evident that palm oil underpins national and international efforts toward energy diversification and security [4], [62]. The mandatory B30 blending policy in Indonesia effectively redirects significant volumes of crude palm oil (CPO) to energy applications, resulting in substantial fossil fuel import reductions and fiscal savings [63,64]. These outcomes underscore palm oil's strategic importance as a reliable, large-scale renewable energy feedstock capable of alleviating energy dependency and fostering economic resilience. Technological advancements have further enhanced the viability of palm oil in renewable energy systems. Improvements in transesterification processes and enzymatic catalysts have raised biodiesel conversion efficiencies from 85% to 98%, marking notable progress in optimizing production yields and reducing processing costs [65]. Additionally, biogas capture from palm oil mill effluent (POME) has emerged as a promising complementary technology, with methane yields supporting significant renewable electricity generation in regions such as Riau and North Sumatra [66,67].

The utilization of biomass residues like empty fruit bunches (EFBs) and palm kernel shells (PKS) for cogeneration has enabled decentralized power production, reducing reliance on fossil fuels in rural areas [68]. These technological developments not only diversify palm oil's renewable energy applications but also enhance environmental sustainability by converting waste streams into valuable energy resources. The environmental benefits of palm oil-based renewable energy are substantial, particularly regarding greenhouse gas (GHG) emissions mitigation. Life-cycle assessments consistently demonstrate that sustainable palm biodiesel can reduce GHG emissions by 56–65% relative to conventional fossil diesel [69]. The emission intensity of ISPO-certified palm biodiesel, at 38.2 gCO_2eq/MJ, remains well within stringent international benchmarks such as the European Union's RED II directive [70]. Moreover, Indonesia's expanded biodiesel program is estimated to offset over 25 million tons of CO_2-equivalent emissions annually, while methane capture from POME has the potential to abate an additional 1.2 million tons of CO_2eq [71,72]. These findings emphasize the necessity of stringent environmental governance and certification mechanisms to sustain palm oil's contribution to climate change mitigation. Socioeconomic impacts derived from palm oil's role in renewable energy are also pronounced. Employing approximately 17 million people in Indonesia, the sector supports rural livelihoods and contributes to poverty alleviation [73]. Integrating smallholder farmers into bioenergy value chains has demonstrated tangible income improvements of 18–27%, although challenges persist concerning certification, financing, and market access [74]. Addressing these barriers is vital to ensure equitable benefits and to leverage smallholders' capacities in advancing sustainable renewable energy development. Empowerment and capacity-building initiatives are imperative to enhance smallholders' participation in certified sustainable palm oil (CSPO) markets, thereby promoting inclusivity and social sustainability.

Policy frameworks and institutional mechanisms have been pivotal in shaping the sector's trajectory. Financial incentives via the Palm Oil Plantation Fund Management Agency (BPDP-KS) have effectively bridged price gaps between biodiesel and fossil fuels, facilitating industry compliance and market stability [75]. The General National Energy Plan (RUEN) targets a 23% renewable energy share by 2025, with palm-based biodiesel expected to dominate liquid biofuel supply [76]. Moreover, domestic policies fostering local processing and export restrictions reinforce value addition and energy security objectives [77]. However, policy coherence remains hindered by overlapping ministerial roles and inconsistent enforcement of sustainability criteria, which threaten long-term strategic planning [78]. Strengthening institutional coordination and harmonizing regulations are crucial for sustaining the sector's growth trajectory and environmental integrity. International trade dynamics and sustainability pressures further complicate palm oil's strategic positioning. The European Union's stringent sustainability standards, designating palm oil as carrying significant risk for indirect land use change (ILUC), have prompted shifts toward non-EU markets such as China and India, as well as bolstered domestic consumption strategies [79].

Despite these challenges, growing demand for certified sustainable palm oil (CSPO), which reached 14.7 million metric tons in 2023—a 20% increase from the prior year—illustrates the potential for market-driven sustainability transitions [80]. This trend underscores the necessity for producers to adopt robust certification and traceability systems to maintain access to premium markets while advancing global sustainability goals. The implications of this study are multifaceted. Evidently, palm oil remains a cornerstone of renewable energy portfolios in major producer countries, contributing significantly to energy security, economic development, and environmental objectives. However, realizing its full potential requires integrated approaches combining technological innovation, stringent sustainability governance, inclusive socioeconomic strategies, and coherent policy frameworks. This holistic perspective is essential to balance competing demands for energy, economic growth, and ecological conservation. Future research should focus on longitudinal assessments of sustainability certification impacts on smallholder livelihoods and environmental outcomes, as well as explore innovations in feedstock diversification and waste valorization technologies. Furthermore, comparative studies across geopolitical contexts could elucidate best practices in policy coherence and international market integration. Enhancing interdisciplinary research efforts will provide deeper insights to optimize palm oil's contributions to a sustainable, renewable energy future.

6. Conclusion

Palm oil plays a vital role within the renewable energy sector, distinguished by its high yield, extensive policy support, and significant socioeconomic contributions. As a crucial input for biodiesel globally, its significance is particularly notable in Indonesia and Malaysia, where it substantially reduces fossil fuel dependency and supports national energy diversification. Technological advancements have enhanced the efficiency of palm oil-based bioenergy conversion processes, expanding their application beyond biodiesel to include biogas recovery and biomass cogeneration, thereby optimizing resource utilization and environmental benefits. The environmental performance of palm oil-derived renewable energy demonstrates considerable potential in greenhouse gas emission reductions, especially when produced under certified sustainable frameworks. These reductions contribute meaningfully to climate change mitigation efforts. Moreover, the sector fosters employment and rural development, with a noteworthy impact on smallholder farmers' livelihoods, although challenges remain in improving their access to certification and markets. Institutional and policy frameworks have been instrumental in facilitating the increasing prominence of palm oil in renewable energy sectors, with financial subsidies and national energy plans promoting its integration into energy systems. Nonetheless, inconsistencies in regulatory enforcement and coordination among government bodies pose risks to long-term sustainability and sector coherence. On the global stage, evolving sustainability standards and trade dynamics require adaptive strategies to maintain market access while encouraging sustainable production practices. Overall, palm oil's strategic importance is underscored by its multifaceted contributions to energy security, economic development, and environmental sustainability. Realizing its full potential necessitates integrated efforts involving technological innovation, rigorous sustainability governance, inclusive socioeconomic policies, and harmonized institutional frameworks. Continued research and policy refinement will be essential to balance these dimensions effectively and to enhance palm oil's role in advancing renewable energy transitions worldwide.

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