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Government policies to reduce palm oil waste pollution in Indonesia: An evaluation of environmental and socio-economic sustainability

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Abstract

This study aims to evaluate the success of government policies in reducing palm oil waste pollution in Indonesia, with a focus on environmental and socio-economic sustainability. Inefficient palm oil waste management causes water, soil, and air pollution, which exacerbates environmental damage and endangers public health. A mixed methodology approach was used in this study, integrating policy analysis, environmental impact analysis, and socio-economic evaluation. The findings indicate that although a regulatory framework exists, its implementation remains inconsistent due to regulatory fragmentation, inadequate law enforcement, and low compliance from the industry. This study highlights the importance of circular economy policies and green investment incentives in improving sustainable waste management practices. Despite these initiatives, smallholder farmers and rural communities face significant barriers in accessing sustainable waste management technologies, limiting the inclusive benefits of mitigation strategies. In conclusion, this study recommends improvements in the regulatory framework, enhanced coordination across sectors, and increased financial incentives for sustainable technologies. Long-term policies should also incorporate digital monitoring systems and community-oriented efforts to enhance policy effectiveness. The practical implications of this study highlight significant challenges and opportunities in palm oil waste management while offering policy recommendations for more sustainable and equitable business development.

Keywords: Ecological sustainability, Government policy, Palm oil, Socio-economic impacts, Waste Pollution.

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1. Introduction

The palm oil sector is a fundamental component of the Indonesian economy, significantly contributing to employment, GDP, and rural development. As a global leader in crude palm oil (CPO) production, Indonesia produces around 60 per cent of the world's palm oil, thus playing an important role in international markets and local livelihoods, especially in agricultural regions such as Sumatra and Kalimantan, where plantations are expanding rapidly [1, 2]. The sector not only facilitates large-scale operations but also generates income for millions of smallholders, underlining its importance to Indonesia's socio-economic stability [3]. The rapid expansion of the palm oil industry is linked to various environmental and social sustainability issues, particularly related to waste management. By-products of palm oil production, including palm oil mill effluent (POME), empty fruit bunches (FFB), and palm kernel shells (CPKS), can cause considerable ecological disruption [4, 5]. In addition, the management of solid waste generated by the palm oil industry, such as empty fruit bunches and palm kernel shells (TKKS), poses a significant problem, as inadequate disposal practices can exacerbate land degradation and increase carbon emissions [6, 7].

In addition, socio-economic factors also hinder waste management efforts. Many small farmers and independent factory operators do not have the financial resources or technological proficiency required to implement sustainable waste management procedures [8]. The resulting socio-economic consequences, especially in rural areas, are evident in the health impacts and reduced agricultural yields due to polluted water supplies. This approach should prioritize the incorporation of sustainable practices within the sector and, at the same time, meet the socio-economic requirements of stakeholders to promote a balance between economic gains and environmental preservation. The palm oil sector in Indonesia offers both prospects and obstacles. While critical to economic development, proper management of palm oil waste is essential to reduce environmental degradation and promote social justice for affected communities. A transition to sustainable practices, supported by strong governance and stakeholder engagement, is essential to ensure the long-term sustainability of this critically important sector.

The palm oil sector in Indonesia faces various obstacles that hinder the efficient management of palm oil waste, although legal frameworks have been designed to address these issues. A major concern is the ineffectiveness of current government regulations and tactics. Indonesia has implemented several regulations, including Indonesian Sustainable Palm Oil (ISPO) accreditation and environmental impact assessment (AMDAL), to regulate the business. Nonetheless, these frameworks often lack adequate enforcement and compliance procedures, resulting in environmental degradation [9, 10]. Particular problems arise from inconsistencies between policy development and implementation. Despite the existence of explicitly defined policies, many palm oil mills lack adequate wastewater treatment facilities and often operate without adequate oversight due to inadequate monitoring systems, in addition to the risks associated with corruption and mismanagement [11, 12]. These gaps lead to considerable shortcomings in environmental accountability, reducing the overall effectiveness of government initiatives. Strict oversight is essential, as increased oversight can result in better compliance with existing regulations.

In addition, there is a significant lack of integrated environmental and socio-economic evaluation in existing frameworks. Existing research has focused only on environmental implications, often ignoring essential socio-economic issues, including local community engagement, financial constraints, and the sustainability of rural livelihoods [13]. Given these issues, there is an urgent need to re-evaluate the government's methods of dealing with palm oil waste. This research aims to assess the shortcomings of current policies, evaluate their effectiveness, and identify significant barriers to implementation. It aims to provide evidence-based recommendations to improve regulatory enforcement and promote sustainable and inclusive waste management solutions [14]. Emphasizing integrated assessments will improve understanding of the complex interactions between environmental policies and socio-economic conditions, thereby aiding the development of governance frameworks that promote sustainability in the palm oil industry [15].

Ultimately, confronting these difficulties is not just an academic endeavor; it has profound consequences for policymakers, industry stakeholders, and society at large. Improving governance in the palm oil industry is critical to ensuring sustainability and protecting the livelihoods of smallholders who depend on this important sector for their economic well-being [16].

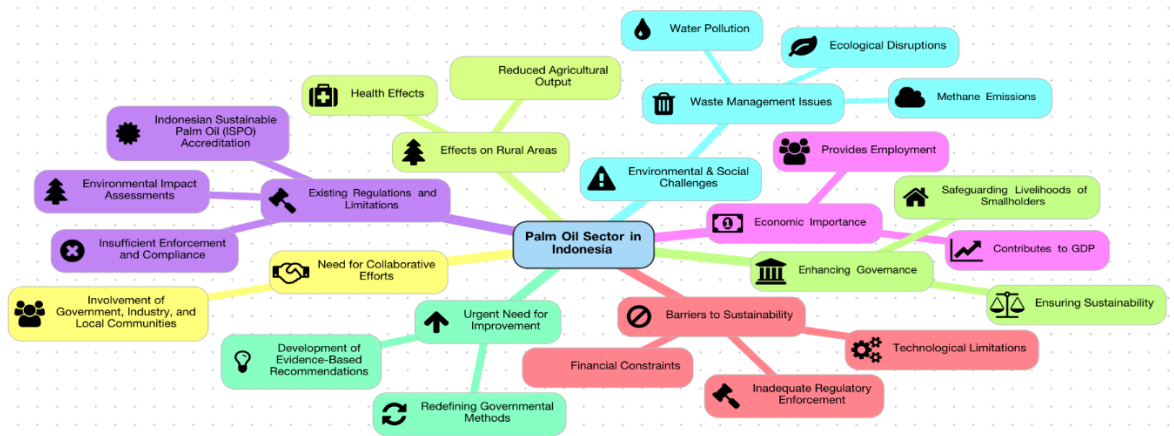

Figure 1.
Concept Map of Research Issues in the Oil Palm Sector in Indonesia.

This mind map shows the intricacies of the palm oil industry in Indonesia by emphasizing various interconnected factors, including environmental, social, economic, regulatory, and sustainability challenges. From an academic perspective, many theoretical frameworks can be used to analyze the relationships in this figure, including sustainability transition theory, institutional theory, and stakeholder theory. The palm oil sector in Indonesia faces a range of environmental and social issues, including water pollution, ecological disruption, methane emissions, and impacts on rural populations. This is in line with research highlighting the substantial ecological consequences of the palm oil sector if it is not addressed sustainably. Therefore, the application of circular economy principles and mitigation solutions is crucial to reduce these negative impacts. In addition, social impacts, including health impacts and decreased agricultural productivity around plantations, suggest that the sustainability of the sector is intrinsically linked to the well-being of local communities.

Regulatory and governance elements are important components in the organization of the palm oil industry in Indonesia. This figure emphasizes the importance of Indonesian Sustainable Palm Oil (ISPO) accreditation and Environmental Impact Assessment (AMDAL). Nonetheless, there are still several challenges faced, including inadequate regulatory enforcement and insufficient industry compliance. From an institutional theory perspective, inadequate regulatory enforcement signals a gap between formal policies and their implementation on the ground. This is compounded by technological limitations and financial constraints that hinder innovation in waste management and production efficiency. To improve sustainability, collaboration between government, industry, and local communities is an essential component, as illustrated in the diagram. This approach is in line with stakeholder theory, which states that the sustainability of the industrial sector requires the active participation of various stakeholders. Evidence-based policy formulation and better governance are important components to maintain the sustainability of the sector. This analysis shows that the palm oil sector in Indonesia is at the intersection of economic development and environmental sustainability. A comprehensive strategy combining evidence-based policies, technical advancements, and better governance is essential to facilitate the transition to a more sustainable and inclusive palm oil business.

2. Literature Review

2.1. Sustainability Theory in the Environmental and Economic Context of Sustainability

The theory offers a paradigm for understanding the reciprocal relationship between environmental stewardship, economic progress, and social equity. Elkington's Triple Bottom Line paradigm underscores the importance of aligning ecological conservation, economic efficiency, and social equity to achieve sustainable outcomes across sectors. In the palm oil business, maintaining this balance is particularly important as the sector has considerable environmental impacts, exemplified by sizeable waste streams such as palm oil mill effluent (POME), empty fruit bunches (FFB), and palm kernel shells (CKS) [17]. Inadequate treatment of these waste products can result in contamination and resource depletion, thus highlighting the importance of sustainability principles in industrial waste management techniques.

Implementing a sustainability-oriented strategy requires stakeholders to adopt environmentally responsible waste management practices, comprehensive regulatory structures, and cutting-edge technical innovations. This comprehensive plan is essential to reduce environmental impacts while ensuring that economic activities in the palm oil sector remain viable and socially responsible [18]. In addition, incorporating sustainability theory into policy formulation can improve understanding of the interaction between environmental and economic elements in the palm oil sector, thereby informing more efficient waste management methods [19].

2.1.1. Circular Economy Principles in Industrial Waste Management

The Circular Economy (CE) paradigm advocates a transition from the conventional linear economy, characterized by a "take-make-dispose" approach, to a regenerative economic model. The principles of the Circular Economy emphasize resource efficiency, waste minimization, and value preservation through practices known as the 3Rs: reduce, reuse, and recycle. In the palm oil industry, the application of circular economy principles increases waste valorization capacity by converting biomass waste into useful resources, including bioenergy, organic fertilizer, and raw materials for various industries [20]. POME can be converted into biogas, while TKKS can serve as nutrient-dense compost or feedstock for pulp and paper manufacturing.

Despite its benefits, the shift to a circular economy in palm oil waste management faces issues such as technological barriers, regulatory limitations, and financial constraints. Successful implementation of the circular economy concept requires cooperative efforts to improve technological capabilities, change regulatory structures, and offer financial incentives to parties involved in sustainable activities. In addition, encouraging stakeholder engagement and public awareness is essential to enable the shift to a circular economy and optimize the benefits derived from palm biomass waste [21].

2.1.2. Environmental Policy Model for Industrial Pollution Mitigation

The Environmental Policy Model (EPM) offers a framework for understanding government measures designed to reduce industrial pollution. Jaffe et al. classify these policies into three main categories: command-and-control regulations, market-based instruments, and voluntary agreements [22]. Command-and-control regulations, including the Environmental Protection and Management Law (Law No. 32/2009) and Indonesian Sustainable Palm Oil (ISPO) certification, are examples of direct legislative initiatives aimed at reducing the environmental impacts of palm oil waste [23, 24]. These regulations delineate emission standards and compliance requirements that are essential to promote sustainable palm oil production.

Market-based instruments (MBIs), including tax incentives and pollution charges, encourage environmentally friendly practices among producers. These instruments provide economic incentives for companies to implement optimal practices in waste management and pollution mitigation. In contrast, voluntary agreements, exemplified by projects such as the

Roundtable on Sustainable Palm Oil (RSPO), offer a framework for industry-driven sustainability commitments. The concept allows companies to voluntarily comply with sustainability criteria, encouraging a culture of accountability within the palm oil industry.

The implementation of these environmental regulations poses barriers, especially in developing countries such as Indonesia, where institutional capacity may be constrained. Therefore, understanding the dynamic interactions among these policy instruments and their practical consequences is crucial for formulating effective interventions that promote sustainability in the palm oil sector [25].

2.1.3. Effectiveness of Environmental Regulations in Indonesia's Industrial Sector

The effectiveness of environmental regulations in Indonesia's palm oil sector is hindered by numerous implementation barriers. The Indonesian Sustainable Palm Oil (ISPO) certification scheme, designed to enforce sustainability standards, shows low compliance rates among palm oil mills due to several significant barriers: inadequate regulatory enforcement, limited technical assistance, and insufficient financial incentives. Empirical studies reveal that local governments typically lack the capacity to effectively monitor industry pollution, resulting in serious environmental degradation in many oil palm-producing districts [26]. Moreover, in the absence of a strict monitoring system and an efficient incentive framework, the implementation of sustainable waste management methods remains inadequate. The cultural and economic variables that influence oil palm cultivation in Indonesia further complicate compliance. Research shows that many palm oil mills operate within regulatory gray areas, compromising environmental and social justice outcomes [27]. Rectifying these implementation shortcomings is critical, as existing frameworks do not encourage a culture of compliance capable of facilitating significant environmental progress.

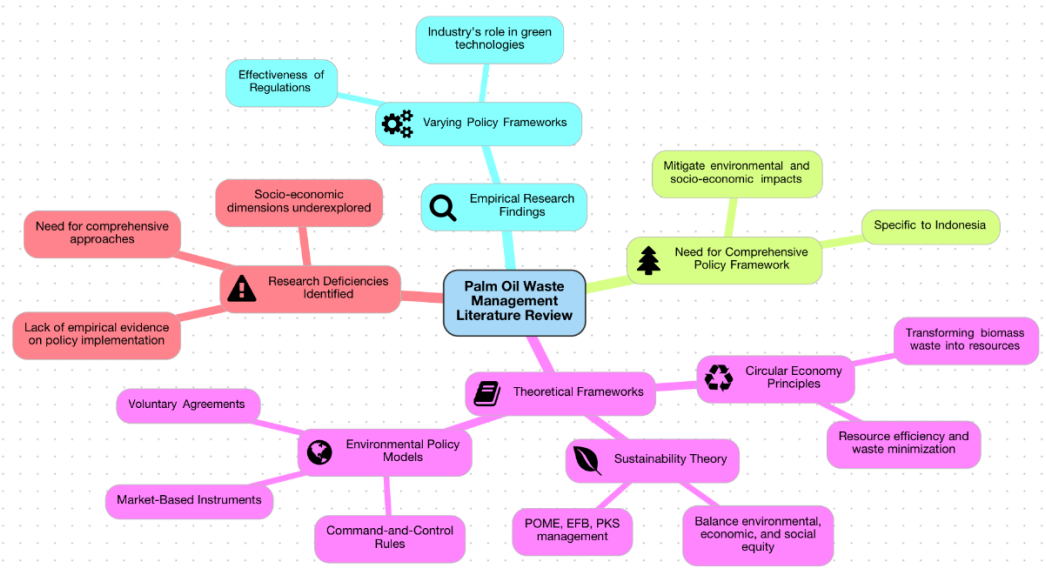

Figure 2.
Concept Map of Research Literature Review.

The literature review on palm oil waste management identified many theoretical frameworks that support the analysis of policies and practices. The main theory used was the Principle of Circular Economy, which underlines the importance of converting biomass waste into reusable resources. This strategy aims to improve the efficiency of resource use and reduce waste generated by the palm oil sector. By embracing circular economy ideas, the sector can reduce environmental problems while generating new economic value from waste that was previously considered worthless. This research is essentially based on the theory of sustainability and circular economy. This approach emphasizes the balance between environmental, economic, and social aspects of waste management. In the world of palm oil, sustainability is not only assessed by technical waste management but also by its impact on the welfare of surrounding communities and the competitiveness of the industry. Waste management, including POME (Palm Oil Mill Effluent), FFB (Palm Oil Empty Bunches), and Palm Kernel Shells (PKS), is critical to achieving a balance, seeing each type of waste as a possible resource rather than an environmental burden.

From a policy theory point of view, these differences in the implementation of environmental policies show that the success of regulations is strongly influenced by the social, economic, and political circumstances in each place. The palm oil sector has significantly contributed to the advancement of green technology innovation; however, the transition to more sustainable practices will be slow without strong regulatory support. The integration of circular economy theory, sustainability, and environmental policy is critical to understanding the dynamics of palm oil waste management at global and national scales.

3. Research Methodology

This study uses a qualitative methodology through a case study approach to examine government strategies and the effectiveness of policies designed to reduce palm oil effluent pollution in Indonesia. The case study method allows for an in-

depth analysis of the complex dynamics of policy design and implementation across multiple contexts. Qualitative methodology was used to elucidate stakeholder viewpoints and understand the social, economic, and environmental determinants that influence the success of regulations [28]. The research used a variety of data collection methods, including document analysis, semi-structured interviews, and participatory observation, to obtain comprehensive data.

This includes analyses of government policies on palm oil waste management, which include Government Regulations (PP), Presidential Regulations (Perpres), Ministerial Regulations (Permen), Regional Spatial Plans (RTRW), and other relevant regulatory documents. The analysis also includes academic research, scientific publications, and data from international organizations on industrial pollution mitigation policies in the palm oil sector. An analysis of sustainability reports from leading palm oil companies in Indonesia facilitated the evaluation of industry compliance with environmental regulations.

Semi-structured interviews will be conducted with key players, consisting of government officials from the environment and forestry sector, academics, environmental activists, and palm oil industry representatives. These interviews aim to gain insights into policy effectiveness, barriers to implementation, and possibilities for improving sustainability-oriented policies [29]. On-site observations of the palm oil industry will provide insight into actual waste management techniques, the application of sustainable technologies, and compliance with applicable regulations. This strategy aims to highlight the mismatch between policy objectives and implementation on the ground, thereby improving understanding of the practical realities faced by the industry.

Framework for Sustainability Assessment. This methodology will assess the consequences of policies across three key dimensions: environmental, social, and economic. It will evaluate the effectiveness of palm oil waste management strategies in reducing environmental pollution, improving community welfare, and ensuring the economic sustainability of the palm oil industry. By applying this combination of qualitative methodologies, this research seeks to make a significant contribution to understanding the issues and opportunities associated with palm oil waste management in Indonesia. The research aims to generate evidence-based policy recommendations that focus on sustainability and practical implementation.

4. Results and Discussion

4.1. Evaluation of Government Policies Related to Palm Oil Waste Management in Indonesia

The Indonesian government has enacted various laws and regulatory frameworks to reduce the environmental impact of palm oil waste. These policies include national laws, ministerial regulations, and regional initiatives aimed at ensuring sustainable palm oil waste management. Law No. 32 of 2009 on Environmental Protection and Management is the basic regulatory instrument that requires companies, especially palm oil mills, to adopt environmentally friendly waste management procedures. In addition, Government Regulation No. 101/2014 on Hazardous and Toxic (B3) Waste Management categorizes several by-products of palm oil processing, including Palm Oil Mill Effluent (POME) and solid waste, as B3 waste that requires proper treatment and disposal methods.

Presidential Instruction No. 6/2019 on the National Action Plan for Sustainable Palm Oil is an important policy that aims to improve the sustainability of the palm oil sector by strengthening environmental governance, improving smallholder compliance, and refining waste management strategies. In addition, the Minister of Environment and Forestry Regulation No. 5/2020 on Environmentally Friendly Industry Business Licensing provides incentives for palm oil companies that implement circular economy principles in their waste management. These policies are in line with Indonesia's dedication to the Sustainable Development Goals (SDGs), namely Goal 12 (Responsible Consumption and Production) and Goal 13 (Climate Action).

4.1.1. Implementation at National and Regional Level

The implementation of palm oil waste management regulations differs at the national and regional levels, depending on local government capabilities, enforcement strategies, and industry compliance. The Ministry of Environment and Forestry (MoEF) collaborates with the Ministry of Industry and the Coordinating Ministry for Economic Affairs to develop policies, monitor, and assess the effectiveness of relevant regulations at the national level. This inter-ministerial collaboration aims to implement environmental regulations, facilitate the adoption of cleaner production technologies, and advance sustainable land use planning in the palm oil sector.

Provincial and district governments play an important role at the local level in implementing national policies through regulations and enforcement mechanisms tailored to local conditions. The local Environmental Agency (DLH) oversees industry compliance, grants environmental permits, and sanctions palm oil mills that do not comply with waste management regulations. Several provinces, including Riau, Kalimantan, and Sumatra, have implemented moratorium policies to reduce deforestation caused by oil palm plantation expansion and to mitigate waste pollution. Nonetheless, there are still barriers to the implementation of local policies, including inadequate law enforcement, a lack of experts in waste management, and limited financial resources for the development of waste treatment facilities.

4.1.2. Obstacles and Shortcomings in Policy Implementation

Despite the existence of comprehensive policies, there are still several gaps that hinder the efficient implementation of palm oil waste management laws in Indonesia. The main obstacles are regulatory inconsistencies and overlapping jurisdictions across several ministries and agencies, which often result in bureaucratic bottlenecks in the licensing and supervision process. In addition, shortcomings in the supervision and enforcement process allow certain palm oil mills to avoid compliance with environmental standards, thus perpetuating environmental damage.

One of the reasons for this difficulty is the absence of economic incentives and financial assistance for smallholders and small-scale oil palm processing units. Limited access to finance and technology prevents many smallholders from investing in more sustainable waste management systems, so they continue to rely on traditional methods that adversely affect the environment. Dealing with these difficulties requires a multi-stakeholder strategy that includes government entities, industry players, civil society groups, and local communities. Increasing institutional capacity, improving inter-agency cooperation, and incorporating community-based waste management methods can substantially increase the effectiveness of palm oil waste management strategies in Indonesia.

This study seeks to evaluate the strengths and shortcomings of the adopted policy by evaluating the regulatory framework and assessing policy implementation at the national and sub-national levels. The findings of this study will contribute to evidence-based suggestions for improving the sustainability of palm oil waste management in Indonesia, in line with the long-term sustainable development agenda and environmental protection.

4.1.3. Socio-Economic Consequences of Waste Reduction Strategies

Palm oil industry waste management has significant environmental, social, and economic impacts, especially for smallholders and workers in the sector. The palm oil business in Indonesia provides income for millions of workers in plantations, processing, and other supply chain industries [30]. Exclusionary waste management regulations can exacerbate economic pressures on smallholders, who often lack the capacity to implement sustainable practices. Policies that require more stringent waste management, such as the adoption of bioenergy or biocomposting-based waste treatment technologies, often require considerable upfront costs [31]. For large companies, this challenge can be overcome through higher economies of scale. However, for smallholder farmers, limited access to capital and technology is a significant barrier [32]. Therefore, it is crucial to develop policies that incorporate incentive mechanisms for farms, such as green financing initiatives or effective collaboration with industry in waste management [33].

The implementation of waste mitigation measures using environmentally friendly technologies can create new employment opportunities in renewable energy and the circular economy. The transformation of palm oil waste into biogas and biofuels has created employment opportunities in many palm oil-producing locations. Nonetheless, there is potential for job disruption caused by automation in waste management procedures at palm oil mills, which could reduce labor in conventional processing industries [34]. Therefore, it is imperative that waste reduction regulations are complemented by training programs for employees to facilitate their adaptation to more sustainable sector requirements. In this situation, prioritizing access and engagement of smallholders and workers in more sustainable partnerships and policies is critical. Inclusive and sustainability-oriented policies can improve the welfare of smallholders and workers in the palm oil business, ensuring fair economic returns for all stakeholders involved.

4.2. Policy Functions in Expanding Green Investment and Circular Economy

A key objective of waste reduction in palm oil businesses is to facilitate the shift towards a sustainable circular economy. A circular economy prioritizes the reuse, recycling, and repurposing of waste as a resource to reduce environmental consequences and improve economic [35]. This methodology can be applied in the palm oil sector by using Palm Oil Mill Effluent (POME) to produce biogas and converting Empty Palm Oil Bunches (TKKS) into charcoal or organic fertilizer [36]. Policies that encourage green investments in waste management have the potential to attract additional investors into the renewable energy industry and biomass-based companies. Countries such as Malaysia and Thailand have instituted tax incentive programs and subsidies for investment in the bioenergy industry, facilitating palm oil companies in the development of waste-to-energy conversion systems. By adopting similar regulations, Indonesia can increase its investment attractiveness in the bioeconomy sector while facilitating the achievement of national renewable energy goals.

The success of this method requires collaboration between the government, the commercial sector, and local communities. Governments should ensure that regulations on green investments do not only favor large companies but also provide sufficient access for small and medium-sized enterprises (SMEs) to engage in the circular economy [37]. Robust vetting procedures are essential to prevent "greenwashing," where companies proclaim sustainability without genuine efforts in waste reduction [38]. Comprehensive palm oil waste mitigation strategies, aligned with sustainability principles, have the ability to generate broad economic benefits, improving the welfare of farmers and workers while promoting green investment and industry innovation. To ensure the success of these policies, a comprehensive approach is required, which includes financial assistance, human resource capacity building, and strengthened governance and environmental monitoring [39].

Palm oil waste reduction policies aligned with sustainability principles can generate broad economic benefits, improving the welfare of farmers and workers while promoting green investment and industry innovation. For this strategy to be effective, a comprehensive approach is needed, which includes financial assistance, human resource capacity building, and strengthening governance and environmental monitoring.

4.2.1. Challenges in Policy Implementation

The implementation of waste reduction measures for the palm oil sector in Indonesia faces a variety of issues, which include legislative, institutional, intergovernmental cooperation, industry compliance, and socio-economic aspects that affect policy success. These issues often hinder the achievement of environmental and socio-economic sustainability goals expected by the government and other stakeholders. A major problem in implementing palm oil effluent mitigation plans in Indonesia is regulatory fragmentation and insufficient cooperation between central and local governments. Various regulations regarding industrial waste management have been promulgated, including Government Regulation (PP) No. 22 of 2021 on Environmental Protection and Management, which establishes a framework for companies to monitor their waste and

emissions. This strategy, together with the Indonesian Sustainable Palm Oil (ISPO) Certification, aims to ensure the sustainability of the palm oil industry [40].

Despite explicit laws, implementation at the local level often faces challenges. The gap between central policy and local conditions hinders certain regions from implementing existing regulations. Lack of institutional capacity to implement regulations is a considerable difficulty [41]. Extensive regional autonomy has resulted in gaps in policy interpretation and implementation, leading to inconsistencies in the enforcement of waste management standards in different regions. In some regions, inadequate human and technical resources in environmental agencies hinder effective industry oversight, but in other regions, inadequate enforcement allows companies to avoid environmental liability.

Inter-agency coordination across different government bodies is also a concern. The Ministry of Environment and Forestry (MoEF), Ministry of Agriculture, and Ministry of Industry each have different functions in regulating the palm oil sector; however, there are often overlapping policies or a lack of coordination in their implementation. For example, regulations that encourage the use of palm oil waste as an energy source often clash with land governance and forestry regulations, which restrict companies from accessing more creative waste treatment technologies [42]. The involvement of multiple stakeholders in the ISPO framework is a measure implemented to improve the consistency and effectiveness of policy implementation. Nonetheless, there are still obstacles faced, especially regarding the effective collaboration of various stakeholders to achieve sustainability goals. Coordinated and cooperative policies are essential to overcome these challenges and ensure that all stakeholders, including smallholders and industry, can participate in sustainable waste management.

4.2.2. Level of Industry Compliance with Environmental Regulations

The palm oil sector's compliance with environmental regulations is an important factor in the implementation of waste minimization programs. Despite the existence of sustainability standards such as ISPO and the Roundtable on Sustainable Palm Oil (RSPO), compliance levels show significant variability among organizations, especially between large companies and smallholders. Large companies that have access to technology and financial resources are more likely to comply with environmental requirements, given the benefits of a global reputation and access to overseas markets that expect high standards of sustainability. In contrast, smallholders and medium-sized enterprises often face significant barriers in meeting regulatory obligations, caused by financial limitations and lack of access to effective waste treatment technologies. Determinants Affecting Compliance Levels, viz. Smallholders often face pressure to increase production to meet market demand, resulting in a lack of priority for investment in waste treatment technologies. This constraint makes them unable to implement sustainable waste management procedures.

Deficiencies in supervisory measures: Inadequate implementation of supervisory and enforcement measures hinders compliance. Certain companies identified as environmental polluters often face only nominal administrative penalties, which do not substantially change their behavior. The reduced effectiveness of law enforcement arises from a range of issues including corruption, industry lobbying, and lack of transparency in licensing procedures and environmental impact assessments. The level of compliance is influenced by public knowledge and community involvement in environmental impact monitoring. Communities and non-governmental organizations (NGOs) can contribute significantly to monitoring industry compliance and promoting better policy implementation. Large companies with technological and financial capabilities are more likely to comply with environmental regulations due to their motivation to uphold a global reputation and access overseas markets that require higher sustainability standards. In contrast, smallholders and medium-sized enterprises face significant barriers in meeting regulatory obligations due to financial limitations and lack of access to effective waste treatment technologies.

Moreover, compliance with environmental regulations in business is compromised by inadequate monitoring systems and insufficient penalties for violators. Research shows that, in certain cases, companies found guilty of environmental pollution face only small administrative penalties or fines that do not provide an adequate deterrent effect. Inadequate levels of enforcement are attributed to several causes, including corruption, industry lobbying activities, and a lack of transparency regarding licensing and impact assessment processes. To improve industry compliance, regulations should both penalize through sanctions and incentivize by facilitating companies to adopt environmentally friendly technologies. A more inclusive sustainability certification program, along with financial assistance for smallholders, can be a solution to improve compliance with stricter waste management regulations.

4.3. Socio-economic Factors Affecting the Implementation of Effective Waste Mitigation Policies

The implementation of palm oil waste mitigation measures in Indonesia depends not only on the legislative framework and industry compliance, but is also influenced by many social and economic variables. A major obstacle is the considerable economic gap between large companies and smallholders, leading to differences in capacity for sustainable waste management. Smallholders often face economic pressure to increase production to meet market demand, making investment in waste treatment technologies a lower priority [43]. This results in shortcomings in the implementation of sustainable effluent mitigation policies.

Instead, social factors such as public awareness and community involvement in environmental impact monitoring influence the success of policy implementation. Certain regions have established community-based programs to monitor industrial effluent contamination; however, these projects often do not receive adequate support from the government in terms of funding and legal protection. From an economic point of view, the costs associated with enforcing environmental legislation are a significant barrier. Many organizations consider investment in waste treatment technologies as an additional burden that can reduce their profitability. Therefore, environmental policies should be formulated to offer economic

incentives for industries to invest in sustainable solutions. Carbon tax initiatives and green energy subsidies can be instituted to encourage the use of green technologies in the palm oil industry.

In addition, geopolitical considerations and global market forces also influence the implementation of waste mitigation initiatives. Palm oil importing countries, including the European Union and the United States, have increased sustainability demands for palm oil products, forcing the Indonesian government to modify local policies to maintain competitiveness in the global market. The implementation of palm oil effluent mitigation policies in Indonesia faces various challenges, including regulatory and institutional barriers, insufficient industry compliance, and socio-economic factors affecting policy success. A comprehensive policy strategy is needed to address these difficulties, which includes improving institutional capacity, incentive structures for businesses and smallholders, and strengthening community engagement in environmental monitoring. In addition, increased collaboration between governments, the business sector, and the international community is essential to ensure that waste reduction strategies are environmentally effective and conducive to sustainable socio-economic growth.

4.4. A Policy Model for Sustainability in Indonesia

The application of circular economy principles is essential to improve waste management efficiency in the palm oil industry, especially in the realm of sustainability-focused policies. The circular economy paradigm emphasizes reducing waste through reuse and recycling, in addition to utilizing waste as a resource [44]. In wealthy countries such as the Netherlands and Germany, these ideas have been enacted through tax incentives and laws that encourage technological innovation in waste management [45]. The Indonesian government can establish the necessary regulations to convert waste into economically viable goods, such as biodiesel from used palm oil, organic fertilizer from palm empty bunches, and biogas from wastewater. Fiscal policies that offer tax incentives for companies that use recycling technologies and reduce carbon emissions can significantly advance the adoption of circular economy ideas.

The use of Public-Private Partnership (PPP) models can accelerate innovation in palm oil waste management. Collaboration between the government, the private sector, and research institutions can drive the advancement of new technologies, including microbial engineering for the decomposition of palm oil waste and the application of enzymes to improve the efficiency of waste-to-energy conversion.

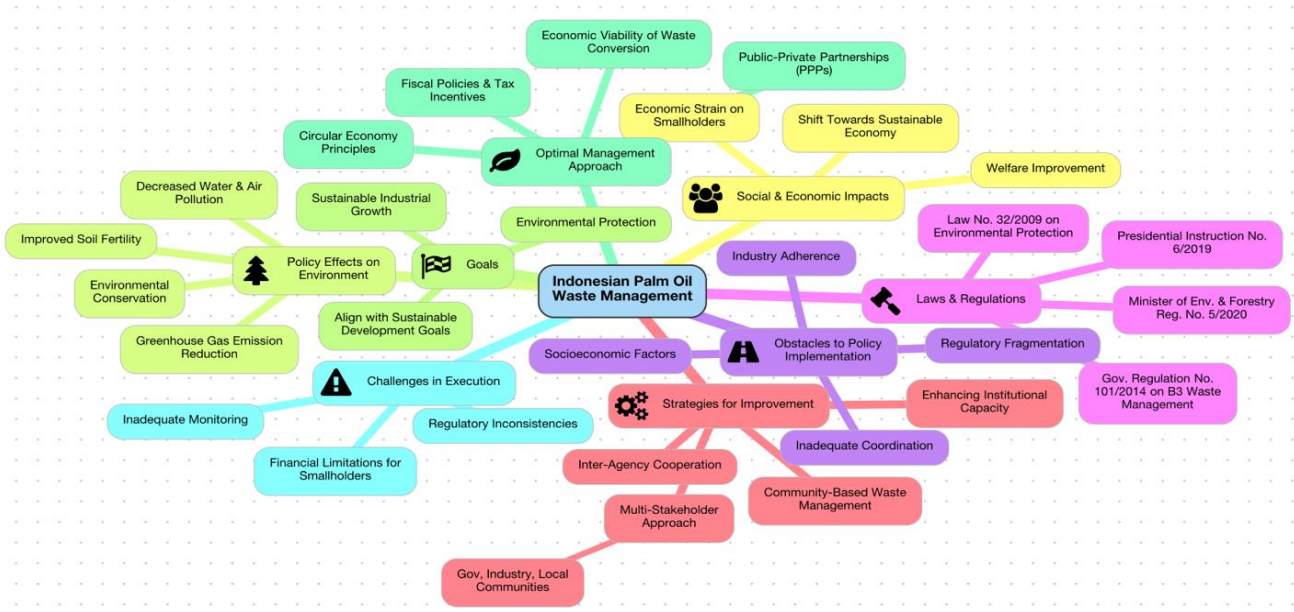

Figure 3.
Concept Map of Research Results.

Palm oil waste management in Indonesia is a multifaceted issue that encompasses environmental, economic, social and regulatory dimensions. Indonesia, as the world's leading producer of palm oil, faces significant issues in the management of waste generated by the sector. The data presented provides a comprehensive overview of the elements affecting palm oil waste management, covering policy objectives, socioeconomic impacts, implementation challenges, existing restrictions, and potential improvement measures. This investigation utilises academic and scientific methodologies to shed light on the dynamics of the palm oil waste management system in Indonesia.

The primary objective of the palm oil wastewater management strategy is to reduce adverse environmental impacts. The implementation of this policy is expected to reduce water and air pollution, improve soil fertility, lower greenhouse gas emissions, and support broader environmental conservation initiatives. This strategy is in line with the concept of circular economy, which promotes the use of waste as a useful resource. Nonetheless, the implementation of this programme faces significant obstacles, particularly on the social and economic fronts. A key challenge is the economic pressure faced by smallholder farmers who do not have access to sustainable waste management technologies. Financial constraints force many farmers to continue using old, unsustainable practices. Therefore, economic incentives and technological assistance are

needed to facilitate their transition to more sustainable manufacturing systems. In contrast, the public-private partnership (PPP) model is a technique that can accelerate the transition to a more sustainable economy. Cooperation between the government, the business sector, and communities can increase investment in waste management, create new jobs, and improve the welfare of neighbouring communities.

5. Conclusions

Firstly, this investigation reveals important conclusions regarding the effectiveness of palm oil waste mitigation strategies in Indonesia. While there are many regulations governing waste management in the palm oil sector, the implementation of these policies still faces several obstacles, such as insufficient industry compliance, ineffective monitoring systems, and inadequate cooperation between the central and local governments. Existing policies are still reactive and have not comprehensively adopted circular economy-based sustainability principles.

Secondly, from an environmental perspective, palm oil waste management strategies have shown favorable impacts in reducing water, soil, and air pollution, especially through the adoption of biogas capture technology for the treatment of Palm Oil Mill Effluent (POME). Nonetheless, there are still shortcomings in the application of this technology in most palm oil mills, particularly in rural areas with inadequate infrastructure.

Thirdly, from a socio-economic perspective, the policies enacted are not sufficient to guarantee fair benefits for farmers and laborers in the palm oil industry. Most regulations prioritize the regulation of large companies, while smallholders still experience limitations in accessing environmentally friendly technologies and incentives. This indicates the need for more inclusive policy formulation to ensure that all parties in the palm oil supply chain can benefit from sustainability initiatives.

The success of palm oil waste reduction strategies depends on a combination of strong regulations, economic incentives, and technological advances in waste management. Without a comprehensive approach, current policies will remain incomplete and suboptimal in achieving long-term sustainability goals. Improving Regulations and Incentives for the Green Industry Based on Circular Economy Principles. To increase the effectiveness of palm oil waste mitigation programs, strengthening regulations based on circular economy principles is required. These regulations should guide the industry to optimize the utilization of waste as an economically valuable resource, not just as a by-product of production. Potential policy initiatives to be implemented include: Mandating palm oil companies to use renewable energy-based waste treatment technologies, including biogas and biochar, with specific performance goals to be achieved within a specified timeframe; Imposing progressive environmental taxes on companies that do not comply with sustainability requirements, while providing tax incentives or preferential access to export markets for those that effectively reduce emissions and manage waste; Establishing a green certification program that offers a competitive advantage to companies that adopt sustainable production methods, aligned with the Roundtable on Sustainable Palm Oil (RSPO) and Indonesian Sustainable Palm Oil (ISPO) criteria.

Increased collaboration between government, industry, and civil society on waste reduction. The success of palm oil waste management strategies depends not only on the participation of the government and industry but also requires the involvement of civil society and non-governmental organizations (NGOs) in policy monitoring and advocacy.

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