

Agricultural Mechanization, Ownership and Rural Class Relations in Indonesia: A Scoping Review

Komang Ariyanto*, Saharuddin, Rilus A Kinseng

Rural Sociology Study Program, Department of Communication and Community Development Sciences, Faculty of Social Sciences and Human Ecology, IPB University, Bogor, Indonesia. *Corresponding Author's Email: komangariyanto998@gmail.com

Abstract

Agricultural mechanization is widely promoted as a means of improving productivity, reducing rural labor shortages and strengthening food security in developing countries. However, its socioeconomic consequences depend on machinery type, ownership, access arrangements and institutional governance. This scoping review examines how mechanization affects rural class formation, labor relations, gender relations, machinery access and surplus distribution in Indonesia. The review followed the Arksey and O'Malley framework and PRISMA-ScR reporting guidance. A structured Scopus search conducted in March 2026 identified 179 documents; after screening by document type, language, publication period and substantive relevance, 30 studies published between 2014 and 2026 were included. The data were charted and synthesized narratively through a Marxian economic-sociology framework. The findings indicate that mechanization can improve technical efficiency, production timeliness and labor productivity, but its effects vary across machines, agricultural operations, farm sizes and access models. High-capacity machinery and direct ownership tend to favor larger farmers and service providers, whereas custom hiring expands access but may create rental dependency and reduce smallholder autonomy. Harvest and postharvest mechanization may displace manual and women's labor, whereas collective ownership and UPJA can either broaden access or reproduce elite capture depending on governance. Regional comparisons with Vietnam, Thailand, Malaysia and the Philippines indicate that Indonesia follows an intermediate but institutionally diverse pathway. Inclusive mechanization requires appropriately scaled technologies, accountable service institutions, inclusive credit, gender-responsive training and secure land rights. However, publication and language bias, regional concentration and methodological heterogeneity limit causal inference and generalizability.

Keywords: Agricultural Mechanization, Class Stratification, Marxian Economic Sociology, Relations of Production, Rental Dependency.

Introduction

Agricultural mechanization is widely recognized as a key driver of structural transformation and agricultural development in developing countries (1). By replacing or complementing human and animal labor with machinery, mechanization can reduce production time, alleviate labor shortages, improve labor productivity and increase the efficiency of land preparation, planting, harvesting and postharvest operations (2, 3). It is also regarded as an important strategy for strengthening food security and sustaining agricultural production in contexts where rural wages are rising and the agricultural workforce is changing (4, 5). However, mechanization is not merely a technical intervention. Its consequences depend on who owns, controls, finances and accesses machinery. From a Marxian economic-sociology perspective, machinery forms part of the productive forces and may reshape relations of

production by influencing class formation, labor relations, surplus distribution and agrarian power (6). Indonesia provides an important setting for examining these dynamics because mechanization is developing within a highly heterogeneous agrarian structure. Agriculture remains dominated by small and medium-scale farms, fragmented landholdings, substantial regional disparities and unequal access to credit, infrastructure, extension services and machinery (3, 7–9). The country's archipelagic geography further creates considerable variation in farming systems, labor markets and institutional capacity. Consequently, mechanization follows multiple pathways. Some farmers obtain machinery through government assistance, farmer organizations, or collective ownership, whereas many depend on machinery-service providers and rental markets because direct ownership remains financially inaccessible

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(5, 10). This combination of smallholder dominance, regional diversity and unequal access makes Indonesia an important case for evaluating the distributive consequences of mechanization. Mechanization is also closely linked to broader transformations in Indonesia's rural economy. Rising agricultural and nonagricultural wages have encouraged farmers to substitute machinery for hired labor, yet the benefits are distributed unevenly. Larger farmers are generally better positioned to expand cultivated land, adopt machinery and exploit complementarities between land and capital-intensive technologies (5). In contrast, many smallholders remain constrained by limited capital and dependence on machinery rental services. Mechanization may therefore reinforce the advantages of those who already possess land, financial resources and access to machinery-service networks rather than reducing structural inequalities. This raises an important question: does mechanization reduce production constraints for smallholders, or does it strengthen the position of rural actors who already control productive assets?

Public policy has accelerated mechanization through machinery-assistance programs and the expansion of machinery-service enterprises, enabling farmers to access machinery without purchasing it individually (5). While these initiatives reduce financial barriers, they also raise concerns regarding machinery allocation, governance and unequal access. Fragmented landholding, high machinery costs, weak service systems and persistent gender barriers further limit the inclusiveness of mechanization (9). Consequently, mechanization should be evaluated not only by technical performance but also by the institutional arrangements governing access to productive resources.

Evidence from Indonesia demonstrates that mechanization produces uneven social and economic outcomes. Studies of rice farming in Java show that labor-saving technologies reduce labor demand while reshaping the organization of agricultural work, including women's participation (11). Larger farmers often benefit more from the complementarity between land and machinery, whereas smallholders become increasingly dependent on rental services (5). Although rental markets expand their technological access, they may shift control over

production timing, service prices and operational decisions to machinery owners and service providers (9, 12, 13). Landless workers face declining employment opportunities as manual labor is replaced, whereas women may lose traditional agricultural roles without equivalent opportunities for training, ownership, or nonfarm employment (11, 14). Furthermore, labor mobility does not necessarily improve household welfare when workers lack the skills and assets required to enter more productive sectors (15).

These developments indicate that mechanization is fundamentally a question of distribution as well as technology. A Marxian perspective is therefore useful because it highlights ownership of the means of production and the unequal distribution of benefits and costs associated with technological change. Machinery owners may accumulate surplus through rental markets, service provisions and economies of scale, whereas smallholders who depend on hired machinery may gain productivity while surrendering part of their surplus through service payments. Concepts such as rural bourgeoisie, semi-proletarianization and forced proletarianization serve as analytical lenses for interpreting empirical evidence on agrarian change and class differentiation.

Despite the growing literature on agricultural mechanization in Indonesia, existing evidence remains fragmented. Most studies focus on productivity improvement, labor-saving effects, machinery adoption, farm size, government assistance, or service efficiency (1, 9, 12, 16). Although these studies provide valuable insights, they rarely integrate technical outcomes with broader questions of ownership, class formation, surplus distribution, gender relations and labor displacement. Consequently, systematic evidence remains limited regarding who controls mechanized assets, who bears the costs of access, who captures the resulting benefits and how mechanization affects landowners, smallholders, women and landless workers differently. This gap is particularly important because mechanization in Indonesia is expanding simultaneously through public programs and private machinery-service markets.

This review critically synthesizes the literature on agricultural mechanization and rural class dynamics in Indonesia. Specifically, it examines the technological, economic and institutional drivers

of mechanization; the effects of machinery ownership, rental arrangements and service markets on different rural groups; and the implications for labor demand, smallholder autonomy, gender relations and surplus distribution. Using a scoping review methodology, the study identifies conceptual and empirical gaps in the literature (17). Rather than assuming that mechanization inevitably produces either inclusive development or greater inequality, the review argues that its consequences depend on who owns machinery, who controls access to it and how the resulting benefits and costs are distributed within Indonesia's agrarian institutions.

Methodology

This study employed a scoping review design to map the available literature on agricultural mechanization, rural class relations and distributional outcomes in Indonesia. A five-stage scoping-review framework was applied, incorporating subsequent methodological refinements (17, 18). To improve reporting transparency, the review was also reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) (19). The review process consisted of five stages: identifying the research questions, identifying relevant studies, selecting eligible studies, charting the data and synthesizing the findings.

A structured literature search was conducted in the Scopus database. The search strategy combined three groups of keywords concerning agricultural mechanization, the Indonesian rural context and socioeconomic or distributional outcomes: (TITLE-ABS-KEY("agricultural mechanization" OR "farm machinery" OR "mechanized farming" OR tractors OR "combine harvester")) AND (TITLE-ABS-KEY(Indonesia OR "rural Indonesia" OR "Indonesian farmers" OR "smallholder farmers" OR peasants OR "farm households")) AND (TITLE-ABS-KEY(benefit* OR profit* OR income OR advantage* OR access* OR inequality OR "economic impact"))

The search was conducted on March 2026 and was limited to studies published between 2014 and 2026. The search results were exported to Microsoft Excel for record management and duplicate removal. Because the search was conducted in Scopus only, the review should be described as a structured Scopus-based search rather than as a search of all available academic literature.

Studies were screened using predefined inclusion and exclusion criteria. The criteria focused on smallholder and rural agricultural mechanization in Indonesia, while allowing comparative studies from relevant Global South contexts. Table 1 presents the eligibility criteria applied during the study-selection process.

Table 1: Inclusion and Exclusion Criteria (12, 17)

Criterion	Inclusion Criteria	Exclusion Criteria
Literature Type	Peer-reviewed journals	Books, conference papers, book chapters, editorials, erratum or corrigendum
Timeframe	2014-2026	Before 2014
Language	English	All other languages
Focus Area	Small-scale agricultural mechanization	Large-scale industrial monocultures only
Context	Indonesia (and comparative Global South contexts)	High-income Western countries
Variable Focus	Land-labor-machine nexus, class differentiation, technical efficiency	Purely technical or mechanical engineering papers
Key Indicators	Mean tractor power, tillage/seeding rates, revenue loss, combine harvester	General farm management with no machine focus

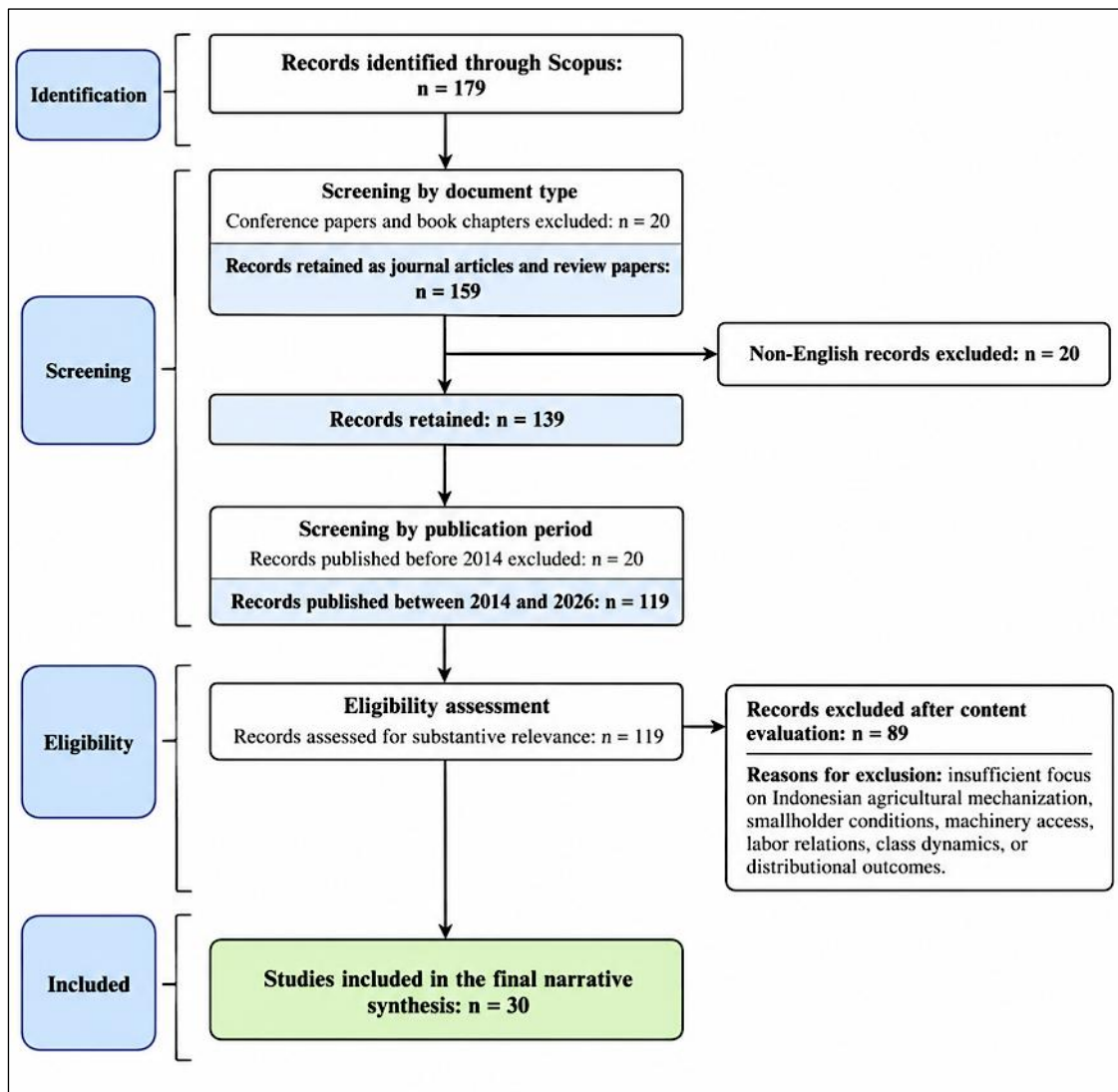


Figure 1: PRISMA-ScR Flow Diagram

The literature search conducted through the Scopus database initially identified 179 documents. The records were subsequently screened according to document type, language, publication period and substantive relevance. First, conference papers and book chapters were excluded, whereas journal articles and review papers were retained, resulting in 159 documents. Second, records published in languages other than English were excluded, leaving 139 documents. Third, studies published outside the 2014–2026 timeframe were excluded, resulting in 119 documents. Finally, the remaining records were assessed according to their substantive relevance to agricultural mechanization, smallholder farmers, labor relations, machinery access and rural class dynamics in Indonesia. This final assessment resulted in 30 studies being included in the review. The selection process is presented

in Figure 1, which illustrates the identification, screening, eligibility assessment and inclusion of studies. In total, 149 records were excluded during the filtering and relevance-assessment stages: 20 based on document type, 20 on language, 20 on publication year and 89 on substantive relevance. The final sample therefore consisted of 30 relevant studies, representing approximately 16.8% of the records initially identified.

This study frames agricultural mechanization in rural Indonesia as a process influenced by distribution and class dynamics rather than merely a technical solution. It explores who benefits from the socioeconomic advantages brought by mechanization and how these benefits are shared among various rural classes. This study examined factors such as land ownership, credit access and extension services that affect smallholders' capacity to adopt or utilize machinery. It also

investigates how owning production tools, such as tractors and combine harvesters, compares to depending on custom hiring services in terms of impacting long-term technical efficiency, income stability and livelihood resilience (20). Finally, the study draws on comparative insights from China's gradual mechanization development to guide more inclusive and context-aware policy measures in Indonesia.

This review contributes to agrarian theory and policy discussions by presenting a focused analysis of access to agricultural mechanization in rural Indonesia. A comparison of experiences of China and Afghanistan reveals that mechanization is not only a tool for increasing productivity but also a factor influencing rural power dynamics. First, we propose that the advantages of mechanization are unevenly distributed, favoring those with purchasing power and land management rights, thus reinforcing existing class structures and enabling the elite to capture technological resources. Second, although custom hiring services and government subsidies might temporarily increase access for smallholders, these solutions offer more precarious and conditional benefits than the direct ownership of assets, leaving small farmers vulnerable to market fluctuations and service-scale displacement. By placing these hypotheses within the context of the labor–land–machine relationship, this study aims to guide pro-

farmer policies that encourage the use of technologies suitable for different scales and prevent mechanization from worsening structural inequality in rural Indonesia.

Results and Discussion

Distinguishing Mechanization Types and their Socioeconomic Consequences

Agricultural mechanization should not be treated as a homogeneous intervention. Different machines perform different operations, require different levels of capital and technical knowledge and produce different effects on labor demand, productivity, gender relations and rural class formation. A two-wheel tractor used for land preparation, for example, does not have the same socioeconomic consequences as a combine harvester used for harvesting, whereas machinery ownership does not have the same implications as access through custom-hiring services. Table 2 distinguishes mechanization according to operational function, scale and access arrangement. This classification prevents the assumption that all forms of mechanization produce identical socioeconomic effects. This distinction is essential for avoiding the assumption that all forms of mechanization automatically produce the same pattern of inequality.

Table 2: Typology of Agricultural Mechanization and Potential Socioeconomic Effects in Rural Indonesia

Mechanization Type	Representative Technologies	Main Technical Effect	Potential Socioeconomic Effect	Marxian Interpretation and Indonesian Concern
Small-scale Land Preparation	Hand tractors, two-wheel tractors, small power tillers	Reduces physical labor and improves the timeliness of land preparation	May benefit smallholders, but access depends on rental availability and operator fees	May broaden access to productive forces, although nonownership can create rental dependency (8, 9, 13)
Large-scale Land Preparation	Four-wheel tractors, heavy tillers, large-scale equipment	Increases operational capacity and reduces labor requirements over larger areas	Favors farmers with larger plots, capital and access to credit	May strengthen economies of scale and the control of fixed capital by rural elites (7, 13, 21, 22)
Crop Establishment And Crop Care	Mechanical seeders, transplanters, mechanical weeders, sprayers	Improves planting precision and reduces labor intensity in	Benefits depend on farm size, crop type, technical skills and affordability	May reduce demand for specific labor tasks while increasing demand for skilled operators

		selected operations		
Harvest Mechanization	Combine harvesters, reapers, mechanical threshers	Reduces harvesting time, labor requirements and postharvest losses	May improve productivity but can reduce employment during peak harvest periods, particularly for landless and female workers	May increase the bargaining power of machine owners and service providers (9, 23–25)
Postharvest Mechanization	Rice hullers, dryers, shellers, milling equipment	Reduces processing time and improves product quality	May create new service-based income but can displace traditional processing labor	May shift value capture from household labor to machinery owners and service providers (7, 9)
Custom-Hiring Services	UPJA, private rental agents, machinery-service providers	Expands access without requiring direct machinery ownership	Can reduce entry costs but may expose farmers to price volatility, delays and unequal bargaining power	Represents access to, but not control over, the means of production (8, 12, 16)
Collective or Shared Ownership	Farmer groups, cooperatives, Group Business Models	Pools capital and distributes machinery-use costs	May improve inclusiveness, although governance problems and elite capture remain possible	Can democratize ownership if transparent, but may reproduce hierarchy if control is concentrated (9, 26–29)

The first distinction concerns the scale of machinery. Small-scale equipment, such as hand tractors and two-wheel tractors, is generally more compatible with fragmented holdings and may be accessible through farmer groups or rental services. Its immediate effects may include reduced physical drudgery, faster land preparation and lower dependence on animal labor. However, small-scale machinery does not automatically create ownership-based empowerment. When farmers depend on external operators, they may still face service charges, scheduling constraints and limited control over the labor process. In contrast, large-capacity machinery, including four-wheel tractors and combine harvesters, requires greater initial capital and sufficient land or service demand to achieve economic viability. These characteristics may favor larger farmers and capitalized service providers, particularly when machinery is indivisible and underutilized on small plots (7, 8, 13, 21, 25).

The second distinction concerns the agricultural operation being mechanized. Land preparation, planting, crop care, harvesting and postharvest processing do not have identical labor effects. Harvesting and threshing machinery may

substantially reduce the seasonal labor demand because these operations are labor-intensive and time-sensitive. Earlier research in Java revealed that tractors, threshers and other labor-saving technologies changed the organization of rice production and affected women's participation in agricultural work (9, 23, 30). Mechanized planting and crop-care technologies may generate different outcomes because they require specialized operators, technical skills, maintenance and complementary inputs. Evidence from Vietnam shows that mechanization can be high in terms of land preparation and harvesting while remaining limited in terms of planting, transportation and other operations (31). Similarly, evidence from the Philippines indicates that land preparation and shelling are more mechanized than planting, crop care and drying (32). These findings demonstrate that national mechanization indices can conceal important differences between production stages. Postharvest mechanization deserves particular attention because it affects both value distribution and gender relationships. Rice hullers, dryers, shellers and threshers can reduce processing time, improve product quality and lower physical labor requirements. Moreover, these machines may

displace household-based processing activities traditionally performed by women or low-income workers (9, 27, 28). The resulting effect is not necessarily a simple decline in employment. Some workers may move into machine operation, transport, maintenance, or marketing, whereas others may lose access to agricultural income and enter precarious nonfarm employment. The socioeconomic outcome depends on whether training, ownership and alternative employment opportunities accompany the introduction of machinery.

The third distinction concerns the mode of access. Direct ownership provides greater control over the timing, intensity and organization of production than does rental access. Owners may use machines on their own land, rent them to others and accumulate income through service provision. Renters, by contrast, obtain temporary access but remain dependent on the availability, price and scheduling decisions of service providers (8, 12, 16, 33). Custom hiring can therefore be either an inclusive mechanism or a source of rental dependency. Its outcome depends on competition among providers, transparency in pricing, service quality and the bargaining capacity of smallholders. The same machine may consequently produce different social effects depending on whether it is individually owned, privately rented, or collectively managed.

Collective ownership offers a potential alternative to both individual ownership concentration and purely commercial rental markets. Farmer groups, cooperatives, UPJA (Agricultural Machinery Service Management Unit) and group business models can pool capital, spread maintenance costs and provide access to farmers who cannot purchase machinery individually (9, 33–36). However, collective ownership does not automatically eliminate class differentiation. Better-connected members may control machinery schedules, financial decisions and access to government programs, creating the possibility of elite capture (8, 9, 21, 22, 37). Therefore, collective models are most likely to promote inclusive mechanization when they include transparent accounting, rotating management, publicly available service schedules, gender-inclusive participation and mechanisms for resolving disputes.

This typology modifies the Marxian interpretation of mechanization in three ways. First, the substitution of machinery for labor is strongest in particular operations, especially harvesting, threshing and selected postharvest activities, rather than across the entire agricultural production process. Second, the concentration of surplus depends on the scale and indivisibility of the machine, the number of users and the organization of service provision. Third, class effects are shaped not only by the machine itself but also by ownership, credit, governance and labor-market conditions. Therefore, the statement that “mechanization reinforces capital dominance” should be qualified as follows: high-capacity, ownership-based and poorly regulated mechanization may reinforce capital dominance, whereas appropriately scaled machinery combined with accountable collective ownership may broaden access to productive assets.

The available evidence supports three main conclusions. First, labor substitution is concentrated in operations, especially harvesting, threshing and selected postharvest activities, rather than across the entire agricultural production process. Second, the concentration of surplus depends on the scale and indivisibility of the machine, the number of users and the organization of service provision. Third, class effects are shaped not only by the machine itself but also by ownership, credit, governance and labor-market conditions. Therefore, the statement that “mechanization reinforces capital dominance” should be satisfied: high-capacity, ownership-based and poorly regulated mechanization may reinforce capital dominance, whereas appropriately scaled machinery combined with accountable collective ownership may broaden access to productive assets. The literature does not yet establish whether small-scale machinery produces more inclusive outcomes than large-capacity equipment does, whether postharvest mechanization has stronger gender effects than land preparation does, or whether collective ownership produces more durable benefits than private custom hiring does. Future research should disaggregate mechanization by machine type, agricultural operation, ownership model and affected labor group. This approach moves the analysis beyond whether mechanization is beneficial and examines which type of

mechanization benefits whom, under what institutional conditions and through which mechanisms of value distribution.

Evidence Establishing and Remaining Knowledge Gaps

The reviewed literature establishes several relatively consistent findings, as summarized in Table 3. First, mechanization can improve the timeliness of agricultural operations, reduce physical drudgery and increase technical efficiency, particularly in land preparation, harvesting, threshing and selected postharvest activities (9, 31, 32). Second, mechanization can reduce demand for particular forms of manual labor, although the magnitude of displacement varies by crop, operation, region and gender (9, 23–25, 27, 28). Third, farmers with greater access to land, credit, machinery and institutional networks are generally better positioned to adopt or control mechanized assets (7, 8, 13, 21). Fourth, custom hiring, farmer groups, cooperatives and UPJA can

expand access for nonowners, but their distributional effects depend on pricing, scheduling, governance and accountability (8, 9, 26–29).

These findings indicate broad agreement on the technical benefits of mechanization and on the importance of institutional access. However, the literature is less conclusive regarding the distribution and durability of those benefits. The existing studies rarely distinguish clearly between machinery ownership, private rental, custom hiring and collective ownership. As a result, it remains unclear whether smallholders gain greater autonomy through mechanization or merely obtain temporary access to machines controlled by other actors. The literature also provides limited direct measurements of the amount of farm surplus transferred through service fees, the effect of machinery queues and seasonal delays on smallholder income and the extent to which machinery ownership changes rural class mobility.

Table 3: Established Evidence and Remaining Knowledge Gaps

Analytical Domain	What the Literature Currently Establishes	Knowledge that Remains Insufficient	Research Priority
Productivity and Efficiency	Mechanization can improve timeliness, labor productivity and selected production outcomes (9, 31, 32)	Long-term effects on profitability, resilience and net household welfare	Longitudinal and operation-specific studies
Labor Displacement	Some mechanized operations reduce demand for manual labor (9, 23–25)	Whether displaced workers obtain alternative employment or experience persistent income loss	Gender- and labor-group-disaggregated research
Gender Relations	Women may lose access to traditional agricultural tasks, particularly in rice and postharvest activities (9, 27, 28)	Whether women gain access to machinery ownership, training, or better nonfarm work	Gender-sensitive impact assessment
Ownership and Rental	Larger farmers and machine owners are better positioned to control mechanized assets (7, 8, 13, 21)	The actual extent of surplus transfer through service fees and rental dependency	Measurement of ownership, prices, delays and bargaining power
Custom Hiring	Rental services can broaden access for smallholders (8, 12, 16)	Whether custom hiring produces inclusion or long-term dependency	Comparative analysis of private, cooperative and UPJA services
Collective Ownership	Farmer groups and cooperatives may reduce individual acquisition costs (9, 26–29)	Whether collective models achieve durable and democratic control	Governance, transparency and elite-capture studies
Rural Class Formation	Machinery access may differentiate owners, service providers, renters and laborers	Direct evidence of class mobility and semi-proletarianization	Mixed-method and household-panel research

Regional Comparison	Mechanization levels and pathways differ across Southeast Asia (9, 31, 32)	Indicators are not fully harmonized across countries, years and operations	Standardized regional comparison
Policy Transfer	China offers lessons concerning subsidies, domestic production and service systems (12, 38)	The transferability of China's model to Indonesia's fragmented and archipelagic context	Comparative institutional research

As shown in Table 3, the most important knowledge deficits concern the distributional mechanisms of mechanization rather than the technical capacity of machinery. The literature provides substantial information on adoption and productivity but weaker evidence on who captures benefits, who bears costs and how mechanization changes class relations over time. The Marxian concepts of rural bourgeoisie, semi proletarianization and the rural proletariat remain useful analytical categories, but their empirical boundaries have not yet been systematically established.

Important gaps also remain concerning different types of machinery. The evidence is stronger for the labor-saving effects of tractors, threshers and combine harvesters than for mechanical seeders, transplanters, sprayers, dryers and other technologies. The long-term effects of postharvest mechanization on women's work, household processing and local employment are particularly underexamined. Similarly, few studies have compared whether small-scale machinery produces more inclusive outcomes than does large-capacity equipment. Future studies should therefore measure mechanization not only as a technology-adoption variable but also as a differentiated institutional process involving machine type, ownership, operation, labor group and service arrangement.

The Engine of Inequality: A Marxian Economic Sociology of Agricultural Mechanization in Rural Indonesia

From a Marxian perspective, agricultural mechanization changes the balance between machinery as "constant capital" and human labor as "variable capital." Indonesian evidence shows that rising real wages have increased the advantage of relatively large farms because they possess greater capacity to purchase machinery, rent additional land and replace increasingly expensive hired labor (7, 8, 13, 21). This finding is consistent with Hypothesis 1, which proposes that the benefits of mechanization are more accessible to actors with greater landholding rights,

purchasing power and control over productive assets (21, 23). However, the evidence should be interpreted as support for an unequal-access mechanism rather than as proof that all machine owners intentionally extract surplus value. The extent of accumulation depends on farm size, machinery utilization, credit access, service prices and local labor-market conditions.

There is broad agreement that mechanization can improve technical efficiency while reducing demand for forms of manual labor. Research in Indonesia shows that tractors, threshers and harvesting machinery have altered rice production and reduced labor requirements, with important consequences for women's participation in agricultural work (9, 39). However, the evidence is not uniform. In some settings, workers may move into machinery operation, transport, maintenance, or nonfarm employment, whereas in others, they may experience declining employment without viable alternatives. Comparative studies from Bangladesh, Ethiopia, Sri Lanka and other agricultural economies similarly indicate that mechanization can generate both productivity gains and labor displacement (34). Thus, the literature agrees on the potential for labor reorganization but remains less conclusive regarding the long-term welfare outcomes of displaced workers.

A Marxian lens moves the analysis beyond a technocratic focus on productivity. Mechanization is not simply an improvement in productive forces; it can also transform the relations of production by changing who controls the labor process, productive assets and surplus. In Indonesia, machinery represents fixed capital that can substitute for human labor and generate income through direct production or machinery services. As rural wages rise, the economic incentive for capital-intensive agriculture increases, creating a growing advantage for larger farms that can combine land access with machinery and hired services (5, 7, 8, 13). This advantage is reinforced by the indivisible nature of tractors and combine harvesters, whose operating costs may be

lower when they are used across larger areas (13, 22).

From this perspective, the expansion of machinery may facilitate the accumulation of capital among an emerging rural elite. These actors may include affluent landowners, traders, former civil servants, or farmers with strong institutional connections who possess the purchasing power required to acquire productive assets (23, 40). Although mechanization may contribute to increased rice production (9), ownership of the machines that generate these gains may remain concentrated among better-capitalized farmers (13, 34). The Marxian M-C-M' formulation provides a useful interpretive framework: money is invested in machinery not only for its use value but also for its capacity to produce additional income through lower production costs and service fees. Nevertheless, the available evidence does not yet measure this cycle directly. Claims concerning surplus extraction should therefore be treated as theoretically informed interpretations rather than fully demonstrated causal findings.

Custom hiring represents a major area of disagreement. Development-oriented studies regard rental services as a scale-neutral mechanism because they allow smallholders to access expensive machinery without purchasing it directly (8, 13). A Marxian interpretation emphasizes that renters do not obtain the same control as owners do. Smallholders may face service delays during peak seasons, higher prices when demand increases and limited influence over the timing of land preparation or harvesting (12, 16). These risks may contribute to service-scale displacement, especially when machinery owners prioritize their own land or more profitable contracts. Nevertheless, rental markets should not automatically be described as exploitative. Their effects depend on competition among providers, transparent pricing, collective bargaining and the effectiveness of farmer groups.

The impact of mechanization also extends beyond economic dependency. In Java and Sumatra, rice hullers, tractors and other machines have contributed to changes in labor organization, with manual and female workers among those most affected (9). Mechanization may reduce women's participation in land preparation and postharvest processing, while some women are redirected toward low-income gleaning or unstable nonfarm

employment (9, 24, 25). These outcomes are consistent with Marxian concepts of alienation and the reserve army of labor, but the evidence remains incomplete. It is still unclear when displaced workers are absorbed into machinery-related occupations and when they experience persistent labor-market exclusion. Longitudinal research is needed to distinguish temporary occupational change from long-term proletarianization.

Mechanization may also reshape village institutions and social relations. Communal labor arrangements can be replaced by individualized and market-based transactions, whereas authority may shift from lineage elders toward actors who control financial resources and machinery (23, 40, 41). State-supported programs distributed through farmer groups and UPJA may broaden access, but they may also create opportunities for elite capture when educated and well-connected farmers dominate bureaucratic procedures, machinery management and subsidy allocation (34, 42). The state should therefore not be described automatically as either an inclusive provider or a direct instrument of class domination. Its distributional effects depend on eligibility rules, local governance, monitoring and the extent to which users participate in decision-making. The main area of agreement is that mechanization creates productivity gains and reorganizes labor. The main disagreement concerns whether rental markets and state programs convert technological access into empowerment or dependency. The most important unanswered questions concern the magnitude of surplus transfer, the long-term effects on wages and land retention and the regional and gender-specific consequences of different machines. Mechanization may therefore function as an engine of inequality when high-capacity assets are concentrated among a small group, but it may support more equitable rural development when ownership, credit, services and training are organized collectively and transparently.

Several questions remain unresolved. Existing studies provide limited systematic evidence on how much surplus is transferred through machinery-service payments, whether mechanization raises or lowers rural wages over time and how outcomes differ across Java, Sumatra and other regions. The long-term effects on women's

employment, landless laborers and smallholder land retention are also insufficiently documented. These unanswered questions suggest that the central issue is not whether mechanization increases productivity but under what conditions productivity gains are converted into broadly shared welfare rather than concentrated accumulation.

The Institutional Superstructure and the Centralization of the Means of Production

Institutional arrangements strongly influence who can access and control agricultural machinery. Land tenure, credit systems, extension services, farmer groups and machinery-service organizations mediate the relationship between rural producers and the means of production. Smallholders frequently face difficulties in obtaining formal credit because lenders require land titles or other collateral that they may not possess (13, 43). In Indonesia, participation in farmer groups and UPJA can increase access to government-supported machinery and technical assistance (9, 26, 27). Extension contacts also improve the likelihood of technology adoption by providing information and operational knowledge (26, 27, 37).

From a Marxian perspective, the relations of production include laws, property rights and institutional arrangements that determine how individuals and classes engage with productive assets. Mechanization is therefore shaped by an institutional superstructure that determines who can access, control and benefit from machinery. Land-tenure policies, credit markets, extension systems and farmer organizations can operate as gatekeepers. They may reduce barriers for smallholders, but they may also reproduce existing advantages when access depends on land titles, education, social networks, or political connections (25, 33). The literature agrees that institutions affect adoption; it disagrees about whether they primarily democratize access or reproduce unequal control.

Land tenure is the material foundation of mechanization. Small and fragmented holdings in Java, Sumatra and other agricultural regions may be technically incompatible with large-capacity machinery (9, 12). Land consolidation and corporate agriculture may improve machine utilization, but they may also encourage the

individualization and commodification of land. In parallel with Myanmar, transferable land-use certificates can convert land into collateral and accelerate machinery acquisition for farmers with formal titles (13, 43). For smallholders without secure or high-value titles, this legal framework may become a barrier to asset ownership and push them toward rental dependency (9).

The evidence on land institutions is therefore mixed. Land consolidation may generate economies of scale and improve access to machinery services, but it may also increase the risk of dispossession if land transfers are poorly regulated. Similarly, formal titles may improve access to credit while exposing vulnerable households to debt and land loss. The unresolved question is not whether land formalization is beneficial in general, but under what conditions it improves smallholder security without concentrating land-management rights among wealthier actors.

Credit is another major institutional mechanism. Farmers with land titles, higher education levels and stronger social networks are more likely to obtain financing for tractors, combine harvesters and other high-value equipment (7, 27, 34). Smallholders, poor households and female-headed households may instead depend on personal savings, remittances, informal loans, or custom hiring (9, 21, 26, 44, 45). This pattern is consistent with a Marxian interpretation in which unequal access to credit increases unequal control over fixed capital. However, it remains unclear whether credit programs such as KUR (People's Business Credit, an Indonesian government-backed microcredit program) produce durable machinery ownership for smallholders or expand the service capacity of already-capitalized farmers.

Extension services and technical training represent another form of institutional power. Machinery requires knowledge of operation, maintenance, repair and scheduling. Evidence from Indonesia and South Asia suggests that extension and training are often more accessible to men and individuals with higher levels of formal education (9, 33, 39). This can create an "information elite" that controls not only the physical equipment but also the knowledge required to use it effectively (27, 37, 44). Although extension contacts are positively associated with technology adoption (27, 44, 46), the literature

provides limited evidence on whether training enables women and marginalized farmers to become machine owners or merely allows them to remain users of services controlled by others.

Farmer groups and UPJA illustrate the contradictory role of collective institutions. In principle, these organizations reduce acquisition costs, coordinate machinery use and create a scale-neutral pathway to mechanization (9, 26, 27). Cooperative membership may increase the adoption of tractors and combine harvesters. In practice, however, better-connected members may control machinery schedules, subsidy access and financial decisions (8, 9, 34, 42). Elite capture is therefore possible, but it should not be treated as an automatic characteristic of all collective organizations. Some groups may distribute machinery services fairly, whereas others may transform collective assets into privately controlled service businesses.

The state's role must consequently be examined with empirical caution. Marxian theory treats the state as part of the institutional superstructure that regulates property, credit and technological access. However, Indonesian machinery programs may produce mixed outcomes rather than simply serving rural elites. Government assistance can increase productivity and reduce labor constraints, but its distributional effects depend on eligibility rules, monitoring, gender inclusion, transparency and accountability. The key unanswered question is whether public

intervention produces collective control over productive assets or merely temporary access to machinery owned and managed by local intermediaries.

Future research should compare different UPJA and farmer-group models, identify who receives machinery and credit and measure whether public programs lead to ownership, rental dependency, or durable class mobility. Institutional studies should also examine how gender, land tenure, education and local political networks shape access. Such evidence would allow the review to move beyond the general claim that institutions matter and identify which institutional arrangements promote inclusive mechanization.

The Means of Production and the Making of Rural Classes

Tables 4 and 5 summarize the class mechanisms identified across the reviewed literature. Table 4 links the forces of production, division of labor, machinery ownership, rental access and surplus distribution to different rural class positions. Table 5 identifies the main rural actors involved in mechanization and summarizes their potential benefits, mechanisms of value capture and analytical class positions. These classifications should be understood as analytical interpretations rather than direct measurements of class identity. They describe potential relationships with machinery, land, labor and surplus.

Table 4: Marxian Analysis of Agricultural Mechanization in Indonesia

Marxist Analytical Dimension	Socio-Economic Class Position	Relationship to Machinery	Source of Power	Impact on Surplus Value	Structural Implications for Indonesian Smallholders	References
Forces of Production (Machinery)	Agrarian Elites/Rural Capitalists	Owners of high-capacity assets (tractors, combine harvesters); machinery as <i>fixed capital</i>	Machine power (fuel-based, capital-intensive technology)	High accumulation; extract surplus via rental markets and service fees	Concentration of technological advantage; reinforces capital dominance and widens rural inequality	(7, 13, 21, 22, 26)
Forces of Production (Machinery)	Smallholder Proletariat	Nonowners; dependent on hiring mechanized services	Residual human labor + hired machine access	Low accumulation; surplus partially appropriated by machine owners	"Technology gap" persists; dependency on rental markets deepens vulnerability	(8, 9, 12, 13, 16)
Division of Labor (Specialization)	Machinery Operators / Service Providers	Specialized providers of plowing, planting,	Control over timing, scale and	Capture value through service coordination	Emergence of service-based stratification; fragmentation of	(8, 12, 16, 33)

Division of Labor (Specialization)	(often elite-aligned) Middle-Tier Farmers	harvesting services Partial owners or cooperative members	logistics of operations Mixed power (machine + hired labor)	and seasonal price leverage Moderate surplus; sensitive to fuel prices and credit structures	peasantry into operators vs. renters Semi-proletarianization risk under volatile markets	(8, 26–29)
Class Differentiation (Ownership vs. Rental)	Smallholder Proletariat	Hirers; zero ownership of mechanized means	Limited bargaining power; dependent on availability	Surplus value transferred upward through rental dependency	Loss of autonomy over planting/harvesting schedules (<i>service-scale displacement</i>)	(8, 12, 16, 33)
Class Differentiation (Ownership vs. Rental)	Landless Laborers	Displaced by mechanization; excluded from asset access	Human labor (declining demand)	Surplus labor rendered redundant; no accumulation	Rural labor displacement; increased migration to urban/industrial sectors	(9, 23–25, 27, 28, 34)

Table 4 indicates that machinery ownership and temporary access through rental services do not provide equivalent forms of economic power. Larger farmers may obtain greater control over production because they possess the capital required to purchase machinery or hire services (5). Smallholders may benefit from

reduced physical drudgery and improved production timing, but their dependence on hired machinery can limit autonomy. Machinery operators and service providers occupy an intermediate position because they coordinate access to equipment and may obtain income through service provision.

Table 5: Distribution and Class Dynamics of Agricultural Mechanization in Rural Areas

Rural Actor	Nature of Impacts/ Primary Benefits	Mechanism of Value Capture	Marxist Class Categorization
Large Landowners/Landholding Elites / Machine Owners	Economies of scale; high technical efficiency; accumulation of surplus through capital intensification and control of machinery assets.	Extraction of surplus value via rental markets, rent-seeking behavior and ownership of machinery as <i>fixed capital</i> (“dead labor”).	Rural Bourgeoisie (Agrarian Capitalists)
“Lead Farmers”/Wealthy Peasantry	Increased productivity and preferential access to subsidies, state programs and mechanization grants; intermediary role between state and village economy.	Elite capture of public resources; semicapitalist accumulation through partial ownership and service provision.	Petit Bourgeoisie (Rural Petty Capitalists)
Machinery Rental Agents/Service Providers	Income generation through machinery hiring services; monetization of technological access.	Service-fee extraction and commodification of mechanized labor power; transformation of technology into circulating capital.	Emerging Rural Service Class (Fraction of Petty Bourgeoisie)
Smallholder/Subsistence Farmers	Reduced physical drudgery; limited productivity gains; short-term subsistence stability.	Dependence on rental markets; partial surplus loss through service payments; erosion of production autonomy.	Peasantry (Semi-Proletarian/Disguised Proletariat)
Landless Laborers	“Release” of labor from agricultural employment; limited opportunities in mechanized farms.	Displacement of living labor by machinery; forced proletarianization and precarious migration to urban wage labor markets.	Rural Proletariat

The actor-specific synthesis presented in Table 5 complements Table 4 by showing how land-owners, lead farmers, machinery-service

providers, smallholders and landless laborers may experience and participate in mechanization differently. Large landowners and machine owners

may benefit from economies of scale, reduced production costs and service income. “Lead farmers” may act as intermediaries between government programs and village producers, although their position may facilitate either inclusive coordination or the concentration of public resources. Machinery-service providers generate income through fees that may reflect capital, fuel, maintenance and labor costs; therefore, service income should not automatically be classified as exploitative rent. Smallholders may obtain temporary access to machinery but remain exposed to rental-price fluctuations and scheduling problems. Landless laborers may experience declining demand for selected manual tasks, whereas women may be particularly affected when mechanized operations replace activities traditionally performed by them (9, 11, 15).

Large landowners and machine owners may benefit from economies of scale, reduced production costs and service income. However, their actual position depends on machinery utilization, fuel and maintenance costs, credit conditions and local demand. “Lead farmers” may act as intermediaries between government programs and village producers. Their position may facilitate inclusive coordination, but it may also create opportunities for the concentration of public resources. Machinery-service providers generate income through fees that may reflect capital investment, fuel, depreciation, maintenance and labor. Service income should therefore not automatically be classified as exploitative rent.

Smallholders may obtain temporary access to machinery but remain exposed to rental-price fluctuations and scheduling problems. Landless laborers may experience declining demand for selected manual tasks, whereas women may be particularly affected when mechanized operations replace activities traditionally performed by them (9, 11, 15). The evidence from Afghanistan and South Asia suggests that ownership of productive assets can improve technical efficiency (46, 47), whereas other studies emphasize the benefits of custom hiring for fragmented farms (12, 43, 45). These findings are not necessarily contradictory; they may reflect differences in land size, crop type, machinery scale, institutional arrangements and service-market conditions.

The major area of disagreement concerns whether rental markets represent inclusion or dependency. Custom hiring can allow smallholders to use expensive equipment without purchasing it. Moreover, renters may lack control over production schedules, face higher prices during peak seasons and experience delays when owners prioritize their own land or larger contracts (8, 12, 16). The same service arrangement can therefore support smallholder production in one locality and increase vulnerability in another.

Collective ownership offers a possible alternative to both individual ownership concentration and private rental dependency. Group business models, cooperatives, farmer groups and UPJA can pool capital and distribute maintenance costs (28, 29). Nevertheless, collective ownership does not automatically eliminate class differentiation. Better-connected members may control machinery schedules, finances and access to government programs, creating the possibility of elite capture (8, 9, 21, 23, 35).

The evidence is strongest in showing that machinery access differentiates rural actors. It is weaker in showing how long these class positions persist and whether smallholders can move from rental access to ownership. Future research should measure ownership changes, service fees, labor transitions, land retention and the distribution of machinery-related income. Without such evidence, Marxian class categories should retain analytical positions rather than fixed empirical identities.

Regional Comparison within Southeast Asia

In comparison with Vietnam, Thailand, Malaysia and the Philippines. Indonesia’s mechanization trajectory is placed within a broader regional context. Available evidence suggests that Indonesia occupies an intermediate position: its reported mechanization level reached approximately 1.68 hp/ha in 2018, which is higher than the levels reported for Vietnam and the Philippines but lower than those reported for Thailand and Malaysia (9). These figures should be interpreted cautiously because national indicators may differ in measurement year, machinery type, agricultural operation and distinction between ownership and hiring. Higher machinery intensity does not necessarily indicate more equitable access or greater smallholder autonomy.

Thailand and Malaysia provide useful benchmarks for mechanization, commercial agriculture and service infrastructure. Thailand has developed relatively extensive machinery use and a combination of machinery ownership and custom-hiring services, particularly in commercially oriented production zones (48). Malaysia also records higher machinery intensity than Indonesia does in regional comparisons (9). These experiences suggest that greater mechanization may be associated with stronger infrastructure, commercial production, rural income and more developed machinery-service markets. Nevertheless, they should not be treated as direct models for smallholder inclusion. National averages may reflect commercial or plantation-based agriculture and conceal differences between large farms and smallholders.

The policy lesson from Thailand and Malaysia is therefore conditional. Indonesia can learn from its machinery-service infrastructure, maintenance systems and commercial coordination, but it should not pursue higher machinery intensity without examining ownership concentration and distributional outcomes. The Indonesian concern is that large-capacity machinery may be introduced into fragmented farming systems without sufficient mechanisms for collective ownership or affordable access.

Vietnam offers a more comparable smallholder-oriented case. Its mechanization trajectory has been nonlinear, with substantial variation across regions and farm sizes and an increasing role for private machinery suppliers and hiring services (49). Recent evidence from rice-producing areas indicates high mechanization in land preparation, irrigation, fertilization and harvesting, whereas transplanting, sowing, transportation and other operations remain less mechanized (31). This pattern demonstrates that mechanization should be assessed by operation and production stages rather than through a single national index.

Vietnam's experience also shows that service markets can expand access when smallholders cannot purchase equipment directly. However, service markets do not automatically guarantee equal benefits. Their distributional effects depend on service prices, provider competition, scheduling and the ability of farmers to organize collectively. For Indonesia, the relevant policy lesson is to support region-specific services,

improve coordination between harvesting and transportation and ensure that private providers remain accountable to smallholder users.

The Philippines presents a contrasting case of uneven and operation-specific mechanization. Evidence from maize-producing provinces shows that engine-powered machinery is used substantially for land preparation and shelling, whereas planting, crop care and drying remain more dependent on manual labor and draft animals (32). Only a small proportion of farmers own four-wheel tractors or maize shellers, although some owners provide custom services to other farmers (32). This pattern resembles the Indonesian problem of access without ownership. The Philippine experience highlights the importance of operation-specific programs, postharvest infrastructure, training and cooperative machinery services.

The comparison reveals several areas of agreement. Across Indonesia, Vietnam, Thailand, Malaysia and the Philippines, mechanization is generally associated with greater labor productivity, reduced physical drudgery and improved timeliness. The countries also demonstrate that ownership is not the only pathway for access; custom hiring, cooperatives and machinery-service providers can reduce the financial burden of purchasing expensive equipment. However, the evidence also reveals disagreement. Higher mechanization intensity does not necessarily produce greater smallholder autonomy and service-based access may either support production or deepen dependency depending on pricing, scheduling, governance and competition.

The comparison identifies several specific concerns for Indonesia. First, Indonesia should not pursue machinery-intensity targets without measuring ownership concentration, service affordability, regional access and effects on women and landless laborers. Second, machinery assistance should be combined with credit that does not depend exclusively on high-value land collateral, technical training, maintenance infrastructure and transparent service management. Third, Indonesia needs a balanced institutional model that combines Vietnam's service-market development, Thailand's machinery infrastructure, the Philippines' operation specific approach and Malaysia's

commercial capacity while protecting smallholder land rights.

The major knowledge gap is the lack of harmonized, operation specific and distribution-sensitive regional data. Current comparisons reveal differences in national machinery levels but provide insufficient evidence on who owns machinery, who rents it, who captures service income and how labor outcomes differ across countries. This limitation should be made explicit because national mechanization rankings alone cannot explain rural inequality.

A Historical Materialist Roadmap: Charting Indonesia's Mechanization Path through China's Evolutionary Stages

China provides a useful comparative case because its mechanization process developed through gradual stages involving domestic machinery production, institutional reform, targeted subsidies and the expansion of agricultural service systems (12, 38). The literature agrees that Indonesia should avoid treating mechanization as a simple technological import. Machinery must be compatible with land size, labor availability, local crops and the institutional capacity to operate and maintain it. China's experience also suggests that state intervention can accelerate mechanization when it supports farmers, cooperatives, machinery manufacturers and service providers rather than only private entrepreneurs (12).

However, the transferability of the Chinese model remains contested. China's state capacity, domestic manufacturing base, land-rights reforms and administrative infrastructure differ substantially from Indonesia's archipelagic geography, fragmented landholdings and uneven regional institutions. China should therefore be treated as a comparative reference rather than a universal blueprint. The relevant question is not whether Indonesia can copy China's historical sequence, but which institutional mechanisms can be adapted without reproducing land concentration or machinery-based class inequality.

The first lesson concerns domestic productive capacity. During China's early mechanization stage, the state prioritized the development of a domestic agricultural machinery industry despite initial difficulties with unsuitable imported models (12). From a Marxian perspective, this represented

an effort to build national constant capital and reduce dependence on external suppliers. Indonesia's reliance on imported machinery and its relatively modest increase in mechanization power from 1.17 hp/ha in 1968 to 1.68 hp/ha in 2018 highlight the importance of domestic manufacturing, repair and maintenance capacity (9, 12). A stronger domestic machinery industry could reduce costs and improve compatibility with Indonesian crops, farm sizes and ecological conditions.

Nevertheless, domestic production alone would not guarantee inclusive mechanization. If locally produced machinery is designed primarily for large farms or commercial estates, it may reinforce rather than reduce inequality. Indonesia therefore needs a machinery industry that produces equipment appropriate for small and fragmented holdings. The relevant policy priority is not simply self-reliance but context-sensitive self-reliance.

The second lesson concerns technological appropriateness. China's household responsibility system created a landscape of small and fragmented plots and institutional responses encouraged machinery suited to smallholder conditions (9, 12). For Indonesia, this suggests prioritizing cost-efficient hand tractors, small-scale tillers, appropriate planting equipment and flexible harvesting services rather than relying exclusively on heavy machinery designed for consolidated farms. The wrong scale of machinery may be economically inefficient and may marginalize smallholders by making ownership impossible or by forcing them into dependence on external service providers.

The third lesson concerns subsidies and market institutions. During China's market-oriented and agricultural-subsidy stages, direct subsidies were provided not only to machinery dealers but also to farmers, cooperatives and financial institutions (12). Such measures helped reduce financial barriers to machinery acquisition and expanded the market for agricultural services. For Indonesia, this suggests that subsidies should not stop at the distribution of machines to farmer groups. They should also support machinery maintenance, operator training, affordable credit and transparent service management.

Moreover, subsidies can produce elite capture if access is concentrated among farmers with land, education and political connections.

The distribution of machinery through Indonesian farmer groups and UPJA may improve access, but it does not necessarily produce widespread ownership. The unresolved issue is whether subsidies should prioritize individual ownership, collective ownership, or accountable service provision. These models may have different effects on class formation and smallholder autonomy.

The fourth lesson concerns scale management and land governance. China addressed the tension between fragmented plots and large machinery through reforms that differentiated ownership, contract and management rights (12). Regulated land transfers enable machinery to be used across larger operational areas, whereas service-scale management allows smallholders to retain land ownership and benefit from mechanization services. This provides a possible model for achieving economies of scale without forcing smallholders to abandon their land in Indonesia. However, land consolidation can also generate dispossession if land rights are weakly protected or if land transfers are driven by unequal bargaining power.

The final lesson concerns human capital and institutional knowledge. Mechanization requires trained operators, mechanics, extension officers and maintenance systems. China's institutional infrastructure integrated training and after-sales services into the mechanization process (12). Indonesia's shortage of agricultural mechanization experts constrains its effective adoption and may increase its dependence on machine owners and service providers (9). Therefore, extension reform should include women, young workers, smallholders and landless laborers rather than focusing only on male lead farmers or large producers.

The literature agrees that Indonesia needs gradual, appropriate and institutionally supported mechanization. This approach disagrees about the appropriate balance between land consolidation, small-scale machinery, private hiring and collective ownership. The main unanswered question is whether Indonesia can increase machinery use while preventing the concentration of land, technical knowledge and surplus among a small group of rural actors. China's experience offers possible policy instruments, but their effectiveness in Indonesia requires comparative and longitudinal evaluation.

Overall, the historical-materialist comparison indicates that mechanization should be pursued as an institutional and social transformation rather than as the rapid acquisition of machinery. Indonesia's future pathway will depend on whether the state can develop appropriate technologies, broaden access to credit and knowledge, regulate service markets and protect land and labor rights. Addressing these conditions is essential if agricultural modernization becomes an instrument of inclusive rural development rather than an additional mechanism of class differentiation (12, 35).

Conclusion

This scoping review shows that agricultural mechanization in rural Indonesia is not merely a technical pathway to higher productivity. It also transforms ownership structures, labor relations, access to productive assets and the distribution of rural surplus. The findings are consistent with the hypothesis that rising wages and capital-intensive technologies may strengthen the position of larger farmers and rural elites who possess land, credit and machinery-access advantages. However, this conclusion should be interpreted as a structural tendency rather than as evidence that all machinery owners intentionally exploit smallholders.

Mechanization produces differentiated outcomes according to machine type, scale, agricultural operation and mode of access. Small-scale machinery and custom hailing services can reduce physical drudgery and expand access for farmers who cannot purchase equipment. Nevertheless, renters may remain dependent on service prices, machinery availability and scheduling decisions controlled by machine owners. High-capacity machinery, particularly tractors and combine harvesters, may generate stronger economies of scale and increase the bargaining power of capitalized farmers and service providers. Mechanization also has gendered consequences, especially when harvesting and postharvest technologies replace tasks traditionally performed by women without providing equivalent access to training, ownership, or alternative employment. State-led programs and farmer organizations, including the UPJA, have the potential to reduce these inequalities by expanding access to machinery and coordinating services. However,

their outcomes depend on governance, transparency, service affordability and the participation of marginalized farmers. Without effective accountability, collective programs may be affected by elite capture and may provide temporary access without creating meaningful ownership or control. Indonesia should therefore strengthen the UPJA by transforming it from a machinery-distribution mechanism into an accountable rural service institution that guarantees timely, affordable and gender-inclusive access. This should be supported by asset-agnostic credit, technical training, transparent service schedules and structured collective-ownership models.

The lessons from China suggest that Indonesia should combine appropriate-scale machinery, domestic manufacturing and maintenance capacity, farmer-oriented subsidies and stronger coordination between land, credit and mechanization policies. However, China's experience should not be copied mechanically because Indonesia has different land-tenure conditions, regional inequalities, institutional capacities and archipelagic geography. Mechanization policies should therefore prioritize technologies suitable for small and fragmented farms while protecting land rights and preventing the concentration of machinery and service income among a limited group of rural actors.

The conclusions of this review must be interpreted in light of limitations in the existing literature. First, the Scopus-based and English-language selection strategy may generate publication and language bias, because studies with statistically significant or policy-relevant findings may be more likely to be published and indexed than studies reporting limited or negative effects. Second, the available evidence appears to be regionally concentrated, particularly in Java and Sumatra and in rice-based production systems. Consequently, the experiences of eastern Indonesia, nonrice commodities, remote areas and highly diverse agroecological zones remain insufficiently documented. Third, the reviewed studies use heterogeneous research designs, indicators, machinery classifications and outcome measures. Differences between cross-sectional surveys, case studies, policy evaluations and qualitative research prevented direct statistical comparisons and limited the possibility of conducting a meta-

analysis. The findings should therefore be understood as a structured narrative synthesis rather than as definitive estimates of causal effects. Future research should address these limitations through longitudinal and comparative studies that distinguish machinery type, agricultural operation, ownership model and affected labor group. Particular attention should be given to the measurement of service fees, seasonal delays, machinery ownership, women's employment, land retention and the transition of displaced workers into alternative livelihoods. More evidence is also needed on whether UPJA, cooperatives and group business models produce genuine collective control or merely redistribute access to machinery without changing underlying class relations.

Agricultural mechanization can contribute to rural revitalization, but its social consequences depend on how the means of production are owned, governed and distributed. Without inclusive credit, accountable collective ownership, appropriate technologies, gender-responsive training and secure land rights, mechanization may consolidate the advantages of the rural bourgeoisie and deepen rental dependency among smallholders. With these institutional safeguards, however, mechanization may improve productivity while also supporting more equitable and resilient rural development.

Implications

This review indicates that agricultural mechanization in rural Indonesia is not merely a technical transition from human and animal labor to machinery. It also transforms the relations of production by reshaping ownership, labor organization, bargaining power and surplus distribution. High-capacity machinery, including four-wheel tractors and combine harvesters, tends to favor larger farmers and capitalized service providers because its economic benefits depend on sufficient land, credit and utilization rates. Although mechanization has contributed to increased productivity and rice production, its benefits should not be assumed to be evenly distributed or caused by machinery alone. Custom-hiring services can expand access for smallholders, but may also expose them to service delays, price fluctuations and rental dependency.

The policy implications are therefore institutional rather than purely technological. The UPJA and farmer organizations should be strengthened as

accountable service institutions rather than functioning only as machinery-distribution channels. Their responsibilities should include transparent pricing, timely service scheduling, inclusive membership, public reporting and mechanisms to prevent elite capture. Asset-agnostic credit is also needed to reduce the dependence of machinery ownership on land titles and collateral. Structured collective ownership, cooperative management and affordable maintenance services could allow smallholders to obtain greater control over productive assets. Mechanization policies should also be operation-specific and gender-responsive. Technologies that reduce women's physical burden should be accompanied by training, ownership opportunities and alternative income pathways so that labor-saving innovation does not become labor exclusion. Indonesia should further promote machinery suitable for fragmented farms, domestic manufacturing and regionally adapted service systems, while protecting land rights and displaced workers. Overall, mechanization can support equitable rural development only when productivity gains are combined with democratic access, accountable institutions and safeguards against the concentration of machinery, land and surplus among a small rural elite.

Abbreviations

CHS: Custom-Hiring Services, HRS: Household Responsibility System, GBM: Group Business Models, hp/ha: Horsepower per hectare, M-C-M': Money-Commodity-Money, TE: Technical Efficiency.

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Author Contributions

Komang Ariyanto: Conceptualization, Methodology, Literature Search, Data Curation, Formal Analysis, Writing – Original Draft, Saharuddin: Supervision, Conceptualization, Validation, Writing – Review and Editing, Rilus A Kinseng: Methodology Support, Validation, Writing – Review and Editing, Language Refinement.

Conflict of Interest

The authors declare that they have no conflicts of interest. All the authors have read and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study are derived from publicly available sources. All the articles and documents included in the scoping review were obtained from academic databases and published literature, as cited in the reference list. No new primary data were generated. Additional details regarding the search strategy and selection criteria are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

The authors declare that they did not use generative AI or AI-assisted technologies in the writing process of this manuscript. The manuscript was prepared entirely by the authors and they take full responsibility for the content of the work.

Ethics Approval

This study is based on a scoping review of previously published literature and does not involve human participants, animals, or primary data collection. Therefore, ethical approval from an institutional review board or ethics committee was not needed. All sources included in the review were properly cited and the study was conducted in accordance with academic integrity and ethical standards for secondary data analysis.

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