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Muslim Women-Led Agriculture: Strengthen Families and Climate for SDGs in East Java, Indonesia

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Abstract

Objective: This study analyzes the contribution of Muslim women-led agriculture in Bondowoso Regency to the reduction of household carbon emissions as well as the strengthening of ecological and economic resilience based on tengka values, supporting local SDGs targets. This study also formulates a synergy model for households, Islamic boarding schools, and village governments as a form of women's empowerment aligned with global SDGs objectives. **Theoretical framework:** This research is based on the integration of sustainable agriculture, women's empowerment, and Islamic ecology based on local wisdom. Tengka values serve as a framework for cultural empowerment that connects low-carbon practices with women's social agency. **Literature review:** Literature review shows that studies on low-carbon agriculture, women's leadership, and the role of local values are still rarely integrated simultaneously. This research fills this gap through an integrated cultural and institutional approach. **Methods:** This study uses a qualitative approach with a case study design in Karanganyar Village, East Java. Data was obtained through interviews, observations, and document analysis. **Results:** The results showed that the production of local bhug-bhug feed from kitchen waste resulted in lower carbon emissions than industrial feed. This practice is able to reduce feed costs by up to 80% and strengthen household economic resilience. **Implications:** These findings confirm that climate change mitigation can be achieved through gender-equitable and culturally sensitive household farming practices. The synergy model of households–pesantren–village governments has the potential to become a reference for low-carbon village policies. **Novelty**: The novelty of this research lies in the formulation of a tengka-based women's empowerment model that integrates low-carbon agricultural practices and local institutional synergy. This study places local wisdom and religious institutions as the foundation of sustainable ecological transformation (sdgs).

Keywords: local wisdom, carbon emission, community empowerment, sdgs, islamic economics.

INTRODUCTION

Climate change has emerged as one of the most urgent global challenges, with carbon emissions from household activities, agriculture, and waste management contributing substantially to environmental degradation and undermining SDGs goals. In rural regions of Indonesia, particularly East Java, the interplay between family livelihoods, agricultural practices, and ecological pressures creates a complex landscape in which climate vulnerability is deepening [1]. Bondowoso, an agrarian district with high levels of organic waste and dependence on industrial livestock feed, reflects this challenge. The National Waste Management Information System (SIPSN, 2024) reports that Bondowoso produces 315 tons of waste daily, 68 percent of which is organic and highly prone to methane (CH_4) formation. Yet within this ecological pressure, local women-led agricultural initiatives are emerging as powerful climate actors, supporting local SDGs targets [2].

Muslim women in Bondowoso, especially in villages such as Karanganyar, have historically played central roles in household agriculture, livestock care, and waste management [3]. Their contributions are not only economic but also environmental, particularly through practices such as converting kitchen waste and coarse rice bran into bhug-bhug, a low-emission alternative livestock feed aligned with SDGs objectives. Recent findings show that industrial feed production generates compounds such as C, CO, CO_2, CH_4, and CaO due to energy-intensive milling, chemical decomposition, and long-distance transportation. In contrast, bhug-bhug generates only minimal CO_2 and CH_4, demonstrating a significantly smaller carbon footprint [4].

Table 1. Composition of Waste Type in Bondowoso 2024

Waste Type	Percentage	Daily Volume (tons/day)	Annual Volume (tons/year)
Food Waste	35.04 percent	110.38	40,293.35
Wood/Branches	16.97 percent	53.60	19,564.61
Paper/Cardboard	16.79 percent	52.90	19,329.72
Plastic	19.44 percent	61.31	22,353.83
Metal	0.50 percent	1.58	575.25
Fabric/Textile	2.44 percent	7.69	2,808.20
Rubber/Leather	0.80 percent	2.52	920.40
Glass	2.77 percent	8.73	3,186.86
Others	5.25 percent	16.54	6,016.77
Total	**100 percent**	**315.00**	**115,049.00**
Source: SIPSN, 2024			

The waste composition data from Bondowoso Regency (SIPSN, 2024) reveals that the region produces 315 tons of waste per day, or 115,049 tons annually, with more than 68 percent consisting of organic materials such as food waste, wood and branches, and paper. The dominance of organic waste, especially food waste, which accounts for 35.04 percent of the total, directly relates to the theme of Muslim women–led agriculture in East Java, as it highlights the abundance of biodegradable materials that can either contribute to methane emissions if left unmanaged or become a valuable ecological resource when processed through local knowledge [5]. In Bondowoso, Muslim women have long utilized kitchen waste as part of livestock feed, transforming what would otherwise decompose and release methane into an environmentally friendly input known as *bhug-bhug*. This practice not only reduces the household carbon footprint but also demonstrates how women's everyday domestic activities are deeply intertwined with climate mitigation efforts.

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The high organic waste volume also underscores the strategic role women play in shaping sustainable agricultural practices within the household, as they are often responsible for food preparation, waste sorting, and livestock feeding. Their ability to convert abundant organic waste into low-cost, low-emission animal feed strengthens family economic resilience while reducing dependence on industrial feed that produces multiple carbon compounds throughout its production and distribution chain. Meanwhile, the significant presence of plastic waste, 19.44 percent of the total, shows that broader systemic collaboration is necessary, supporting the study's emphasis on synergy between households, pesantren, and government institutions [6]. Pesantren can integrate environmental ethics and waste reduction into Islamic education, while local government can facilitate waste-management infrastructure and community training to optimize the use of organic waste and reduce inorganic pollution.

Thus, the waste data not only highlights the environmental pressures faced by Bondowoso but also illustrates the immense potential of women-led agricultural innovation to respond to climate challenges. By situating organic waste as both a climate threat and a resource, the data support the argument that Muslim women's ecological agency, rooted in local wisdom and the Madurese principle of *tengka*, is essential for strengthening family resilience and advancing sustainable, low-carbon rural development. With 315 tons of waste produced daily, or approximately 115,049 tons per year, the potential for greenhouse gas emissions, particularly methane (CH_4) and carbon dioxide (CO_2), produced during the decomposition of organic waste, is a serious issue that local authorities and society must consider [7].

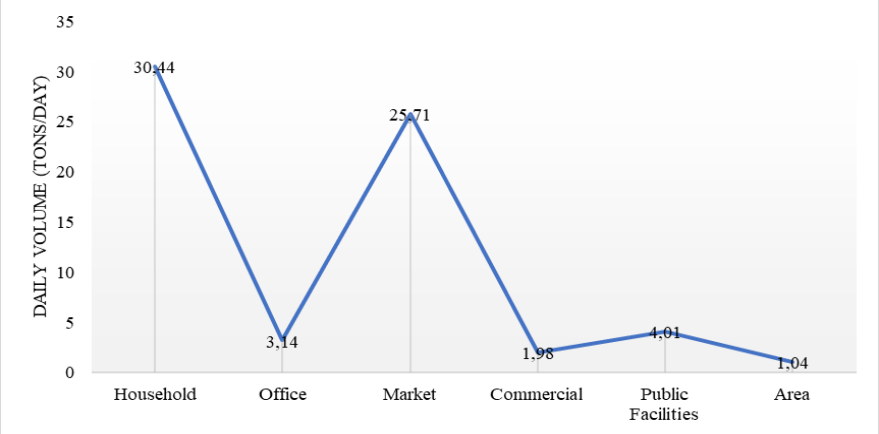

Figure 1. Daily Waste TYPE by Source in Bondowoso in 2024

The figure illustrates the daily waste volume generated by different sources in Bondowoso in 2024. Households are shown as the largest contributor, producing 30.44 tons of waste per day, followed by markets with 25.71 tons per day. Meanwhile, public facilities produce 4.01 tons, commercial areas generate 1.98 tons, offices contribute 3.14 tons, and dense/settled areas produce 1.04 tons per day. The chart reveals a clear pattern: most waste in Bondowoso originates from everyday domestic and market activities rather than from institutions or commercial sectors [8]. This distribution has a direct connection to carbon emissions. Household and market waste consists largely of organic materials such as food scraps, which, when disposed of in landfills, decompose anaerobically and produce methane (CH_4), a greenhouse gas with a global warming potential 25 times greater than carbon dioxide. Therefore, the two largest waste sources in the figure represent the most significant contributors to methane emissions in the region. This means that the environmental burden of waste-related carbon emissions in Bondowoso is heavily driven by daily domestic consumption and traditional market activities [9].

In the context of Muslim women-led agriculture in Bondowoso, these data highlight the importance of women's roles in managing household waste. Since households and market

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spaces where women are commonly involved in food preparation, purchasing, and waste handling produce the majority of waste, women have strategic potential to reduce carbon emissions through waste-based innovations [10]. Practices such as converting kitchen waste into *bhug-bhug* (local livestock feed) directly interrupt the methane-producing cycle by diverting organic waste away from landfills. This not only reduces the household's carbon footprint but also transforms waste into a productive, low-emission resource for agriculture.

Kitchen waste, which is normally discarded, is now a valuable resource in local livestock production. Vegetable scraps, stale rice, fruit peels, and even rice wash water are easily processed into suitable feed for livestock, especially cows, goats, and chickens. The bran produced by the rice mill is also optimally utilized by the community. Once considered worthless, it has now become a key ingredient in alternative animal feed. This local knowledge is not static but evolves. Through trial and error and the transmission of knowledge between generations, communities develop feed production patterns that are not only effective but also easily replicable. At a small scale but comprehensive at the family level, the environmental impact becomes significant when implemented on a mass scale. The use of organic waste as animal feed also reduces the amount of waste in landfills. This directly reduces methane emissions from the decomposition of waste outdoors. Furthermore, the reduced purchase of feed whose production process uses fossil energy also reduces the carbon footprint of the household sector [11].

The family, as the smallest economic unit, directly benefits from this innovation. Expenditure on feed purchases can be drastically reduced or, in some cases, even eliminated. Funds previously earmarked for feed purchases can be used for other, more productive purposes or saved for long-term needs [12]. In the context of economic resilience, this innovation reflects a survival strategy that is of great importance for rural communities vulnerable to market price fluctuations. If the price of concentrated feed increases, the Bondowoso community can continue to pursue its livestock farming uninterrupted, thanks to the use of locally available resources [13].

This waste-based feed management also reinforces the value of independence within the family. Each household becomes both a producer and consumer of animal feed, independent of external markets. This independence strengthens the family's position in economic crises, which can occur at any time, especially in a situation of global uncertainty. Furthermore, this practice is not isolated. It is supported by social values embedded in the culture of the Bondowoso community, such as cooperation, consideration, and social solidarity. Feed production is often done communally, or raw materials are shared among neighbors. This strengthens the social network, which is important in dealing with economic and environmental stresses. From an environmental standpoint, this practice plays an important role in lowering CO_2 emissions. The carbon footprint of livestock production is shaped not only by gases released by the animals themselves, but also by the energy-heavy processes involved in manufacturing and transporting commercial feed. By substituting industrial feed with locally produced alternatives, communities actively help diminish these emission sources.

The positive impact of reducing CO_2 extends from the local to the global level. Locally, it contributes to a cleaner and healthier environment. Globally, the cumulative effect of small-scale household actions becomes meaningful for climate stability. This reflects a tangible contribution from rural communities to broader sustainable development efforts. Beyond environmental and economic advantages, this practice also functions as an environmental learning tool. Children who participate in preparing livestock feed develop an early understanding of waste cycles, efficient resource use, and ecological responsibility. Nevertheless, the long-term sustainability of local feed production depends on recognition, promotion, and capacity-building support. Without institutional backing, this tradition may be overshadowed by modernization trends and increased reliance on commercial products. Conceptually, this local knowledge illustrates the integration of social, economic, and

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ecological dimensions into a unified practice aligned with sustainable development principles that emphasize balance among these domains.

Bondowoso's agrarian context provides fertile ground for strengthening livestock practices rooted in local wisdom. The abundance of raw feed materials, particularly agricultural by-products and household waste, serves as a key advantage. Additionally, strong social ties among community members support the rapid sharing of information and resources. In essence, Bondowoso's tradition of creating livestock feed from kitchen waste and coarse bran stands as a concrete example of a community-driven solution that enhances family economic resilience while lowering carbon emissions. This approach represents a valuable model for shaping sustainable development policies grounded in local cultural values.

LITERATURE REVIEW

Recent scholarship on sustainable livestock and waste management highlights the potential of using organic waste from domestic and agricultural sources as alternative livestock feed or as material for waste treatment, which can significantly reduce greenhouse gas (GHG) emissions and improve ecological resilience. A 2024 study by Mahajoeno et al. demonstrated that the use of fermented straw as animal feed, derived from agricultural residues, has an indirect positive effect on lowering GHG emissions: by diverting agricultural waste from open dumping or landfill, methane emissions from decomposition are mitigated [14]. Similarly, a broader review of organic waste utilization underlines that converting agricultural and household residues into livestock feed reduces environmental burdens associated with waste disposal while offering a sustainable feed source [15]. The environmental footprint of the livestock sector in Indonesia has been carefully documented. A recent comprehensive study by Ismiraj (2025) quantifies greenhouse gases emitted from livestock across the country, including CO_2, methane (CH_4), and nitrous oxide (N_2O), and calls for mitigation strategies within livestock management [16].

The analysis is consistent with global assessments such as the seminal report Livestock's Long Shadow, which estimates that livestock contribute up to 18% of total anthropogenic greenhouse gas emissions (when accounting for feed production, land use change, enteric fermentation, manure management, and transport). Given this high baseline of emissions associated with conventional livestock farming, interventions such as alternative feed from waste can play a critical role in reducing the carbon intensity of small-scale, rural livestock systems. As the literature underscores, feed production (including cultivation of feed crops, fertilizer use, feed processing, and transport) and manure/enteric fermentation are major emission sources. Replacing conventional feed with local, waste-based feed directly targets the feed-production component of this footprint [17].

Beyond direct feed substitution, literature from waste management studies demonstrates that the accumulation of organic waste in landfills contributes substantially to methane emissions. For instance, research on using larvae of the black soldier fly (BSF) shows that these insects can convert organic waste into biomass protein, reducing the volume of organic waste and hence the potential methane emissions from landfill decomposition. In addition to livestock feed, organic-matter management in agricultural soils has been studied for its dual role in productivity and emission mitigation. For example, research on rice cultivation in rainfed paddies found that applying appropriate organic matter (e.g., compost) can increase yield while managing methane emissions, depending on the decomposition and carbon/nitrogen balance of the organic amendment [18].

The reviewed literature provides a robust empirical and theoretical foundation for the local phenomena observed in Bondowoso. Specifically: 1) Converting organic household or agricultural waste into livestock feed (as documented in Mahajoeno et al., and waste-to-feed reviews) is empirically shown to reduce GHG emissions. This supports the environmental rationale of local innovations like *bhug-bhug*. 2) The quantified

environmental footprint of Indonesia's livestock sector highlights how feed production, enteric fermentation, and manure management contribute heavily to national emissions, underscoring the strategic importance of local, low-carbon feed alternatives for smallholders. 3) Circular-economy approaches, e.g., using waste as feed or bioconverting with BSF larvae, align with sustainable development goals and can help reduce waste, pollution, and greenhouse-gas output while supporting rural livelihoods. 4) To ensure sustainability and scalability, institutional support (policy, education, capacity building) is critical; this aligns with your research's emphasis on synergy among households, pesantren, and government. In sum, the literature confirms that waste-based feed systems and community-level, circular management of organic waste are not only viable but essential for mitigating climate impacts in rural livestock-intensive areas. These provide scientific legitimacy and global context for the women-led agricultural practices in Bondowoso, and justify analyzing them as part of a broader low-carbon, sustainable development model rooted in local wisdom (such as *tengka*) [19].

METHODOLOGY

This study employs a qualitative case study design to explore how Muslim women-led agricultural practices in Bondowoso contribute to reducing household carbon emissions, strengthening family resilience, and promoting empowerment based on the local Madurese value of tengka. The case study approach is appropriate because the phenomenon under investigation is context-dependent, culturally embedded, and requires an in-depth understanding of social practices within a specific community.

Data were collected through multiple qualitative methods to ensure triangulation and capture diverse perspectives. First, semi-structured interviews were conducted with women practitioners, household members, local government officers, and Islamic boarding school educators. These interviews focused on daily agricultural practices, waste management strategies, decision-making processes, and the perceived social and environmental impacts of the activities. Second, participant observation was carried out to document the process of bhug-bhug preparation, including ingredient selection, mixing, cooking, and feeding routines. Observational notes highlighted how cultural values such as tengka guided resourcefulness, effortfulness, and resilience in practice. Third, relevant documents, including community guidelines, government policies, and pesantren curricula, were analyzed to understand institutional support and regulatory frameworks that facilitate sustainable practices aligned with SDGs.

Data analysis followed thematic coding procedures, combining inductive and deductive approaches. Initial coding identified emergent patterns related to empowerment, environmental sustainability, and social norms. Deductive coding aligned observed practices with global sustainability frameworks, particularly SDGs targets concerning climate action, responsible consumption, and gender equality. Themes were continuously refined through iterative comparisons across data sources, ensuring credibility, dependability, and transferability. Ethical considerations were strictly observed, including informed consent, confidentiality, and respect for cultural norms. The study's qualitative approach allows for a nuanced understanding of how localized, women-led agricultural innovations can simultaneously foster household resilience, community cohesion, and environmental sustainability, contributing meaningfully to global SDGs efforts while remaining deeply grounded in Madurese cultural values.

RESULTS AND DISCUSSION

Footprint of Carbon Emissions in Karanyanyar, Bondowoso

Karanganyar Village in Bondowoso Regency exhibits a household-centered pattern of carbon emissions, driven primarily by organic waste generation and small-scale livestock

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farming. Based on regional waste data from SIPSN (2024), households contribute the largest share of daily waste in Bondowoso, producing 30.44 tons/day, followed closely by markets at 25.71 tons/day. Given that over 68 percent of this waste consists of biodegradable materials, especially food scraps, wood, and paper, the potential for methane (CH_4) emissions is substantial. Methane, which is produced when organic waste decomposes anaerobically in landfills, has a global warming potential approximately 25 times higher than carbon dioxide (CO_2), making household waste patterns a critical determinant of local emissions [20]. In Karanganyar specifically, the village's agrarian lifestyle intensifies the carbon footprint through livestock-related activities. Conventional livestock feed typically purchased from industrial suppliers carries a significant embodied carbon cost due to energy-intensive production, milling, packaging, and transportation processes. Scientific studies on the livestock sector in Indonesia show that emissions arise not only from animals' enteric fermentation but also from the upstream processes of feed manufacturing. This aligns with observations in Karanganyar, where households that depend on commercial feed indirectly contribute to CO_2, CH_4, and N_2O emissions embedded within the agricultural value chain [21].

However, the carbon profile of Karanganyar is unique because many households, especially those led by Muslim women, practice alternative feed production using kitchen waste and coarse bran. This local feed, known as bhug-bhug, significantly disrupts the conventional emission cycle. By diverting food scraps and organic residues away from disposal sites, the community reduces methane emissions that would otherwise arise from decomposition. Additionally, replacing industrial feed with waste-based feed lowers indirect CO_2 emissions associated with commercial feed production and transportation. Thus, the village's carbon footprint is shaped by the interplay between traditional household waste patterns and women-led ecological innovation [22]. The synergistic role of pesantren and community groups further influences emission patterns in Karanganyar. Islamic boarding schools often promote environmental stewardship as part of religious education, encouraging waste sorting, composting, and sustainable feed practices. These initiatives amplify community engagement in reducing carbon emissions, demonstrating how local institutions can mediate behavior at the household level. Government programs, especially through the Environmental Agency (DLH), support these efforts by providing data, training, and waste-management infrastructure that improve the efficiency of organic-waste utilization [23].

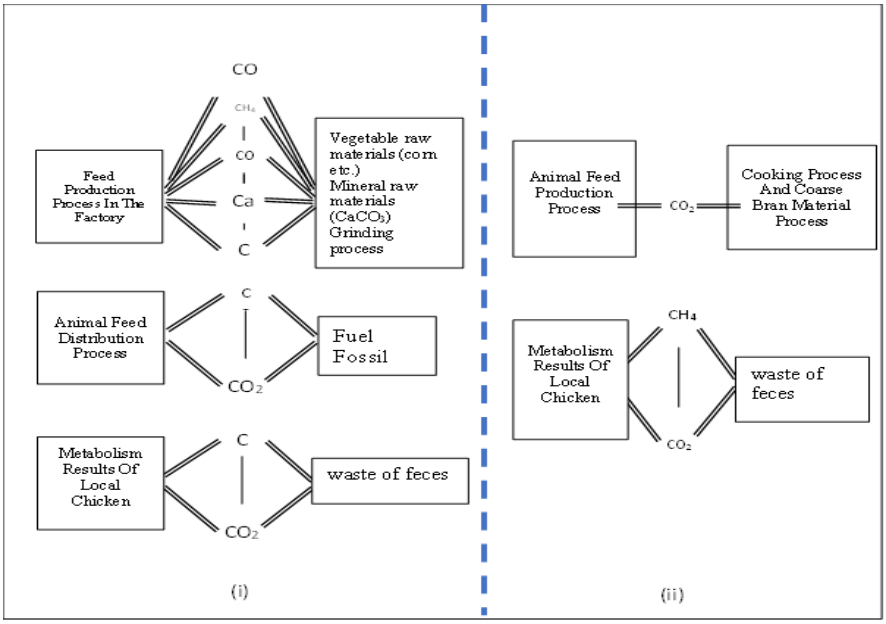

Figure 2. The Comparison of Carbon Emission Footprint in Industrial Animal Feed Versus Local Feed in Karanyanyar Bondowoso

The left side of the diagram (i) provides a detailed illustration of the industrial feed system, revealing how each stage in the production, distribution, and consumption of factory-made chicken feed contributes to a substantial carbon footprint. This system represents a linear, resource-intensive chain in which emissions accumulate long before the feed reaches the chickens in rural households [24]. The first stage depicted is the feed production process in the factory, where various raw materials, most commonly corn, soy, and mineral additives such as calcium carbonate ($CaCO_3$), undergo mechanized processing. Industrial feed manufacturing typically involves grinding, heating, pelleting, and drying, all of which require large amounts of energy generated through fossil fuels. The diagram highlights that these activities release multiple types of emissions, including carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2), elemental carbon (C), and mineral dust (e.g., Ca). These emissions result not only from the combustion of fuel powering heavy machinery but also from the chemical decomposition of minerals during grinding and mixing [25]. This means that even at the earliest stage, the industrial system produces both greenhouse gases and particulate pollutants that directly increase the environmental burden.

After production, the feed enters the distribution process, represented in the middle box on the left side. Distribution involves transporting large quantities of feed from factories often located in industrial zones or urban centers to rural villages like those in Bondowoso. These distribution routes typically rely on diesel-powered trucks and transportation fleets, adding another layer of carbon emissions [26]. The left side of the diagram shows that fossil fuel use during distribution emits CO_2 and carbon particulates (C), making this stage a major contributor to the overall carbon footprint of industrial feed. Transportation emissions are further intensified by long distances, poor road infrastructure, and repeated supply cycles, meaning households are indirectly tied to a continuous stream of emissions through their dependency on factory-made feed. This dependency creates an ongoing carbon cost that accumulates daily, even though the households themselves contribute only marginally to the emissions coming from this phase [27].

The final stage shown is the metabolic process of chickens, which follows after the feed reaches the local households. Chickens naturally produce metabolic waste, including CO_2 and fecal matter, which releases methane as it decomposes. In the industrial system, however, these natural emissions are added to the upstream emissions produced during feed production and transportation, resulting in a much higher total carbon impact [28]. The diagram emphasizes that while chicken metabolism itself is unavoidable and common across all feeding systems, the industrial model amplifies its environmental impact through the significant emissions generated earlier. Thus, the industrial feed cycle forms a multilayered emission chain: heavy factory emissions, transportation emissions from fossil fuels, and metabolic emissions from the animals.

Collectively, the left side of the diagram demonstrates how industrial feed systems embed carbon emissions into every phase of the livestock-food chain. From the extraction and chemical processing of raw materials to the fuel-intensive distribution process and the natural metabolic outputs of chickens, the cumulative carbon footprint is extensive. This depiction underscores why reliance on factory-made feed is environmentally costly, especially when compared to local, waste-based feed systems [29]. It also clarifies that the environmental burden of industrial feed extends beyond the visible household level. Households using industrial feed participate indirectly in a global supply chain that contributes significantly to greenhouse gas emissions, air pollution, and ecological degradation. The right side of the diagram (ii) presents a contrasting model to the industrial feed system: a local waste-based feed system that is circular, low-emission, and deeply rooted in household practices, especially those led by women in rural Bondowoso. This system illustrates how daily organic waste, such as vegetable scraps, leftover rice, fruit peels, and coarse bran (*katul kasar*), can be transformed into a sustainable feed source with minimal environmental impact. Unlike industrial feed, which requires factory-level energy and long-distance transportation, the local system operates entirely within the household

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and village environment, generating only a fraction of the emissions seen in the industrial model [30].

The first component highlighted on the right side is the animal feed production process, which in this local model relies on simple, low-energy methods. Households prepare kitchen waste by boiling, chopping, or mixing it with coarse bran [31]. These steps require basic cooking tools and small amounts of heat energy, producing only minimal CO_2 emissions. Crucially, there are no chemical additives, no large machinery, and no extraction of minerals such as $CaCO_3$. This drastically reduces the carbon footprint because the process does not involve industrial-scale grinding, steaming, or pelletizing. The diagram shows that the emission from this stage is limited primarily to CO_2 generated during cooking, an emission that would occur regardless, since household cooking is a daily necessity. In this sense, the feed-making process piggybacks on existing household energy use rather than creating new, additional emissions [32].

Adjacent to this is the coarse bran and cooking process, which represents the other primary input to local feed production. Coarse bran is an agricultural by-product generated during rice milling, a common activity in rural Bondowoso. Its production requires minimal energy because it naturally results from separating rice grains from husks, rather than being produced through high-energy transformation. Integrating kitchen waste with coarse bran, therefore, not only repurposes unavoidable household organic waste but also utilizes a local feedstock with an extremely low emission profile. This is fundamentally different from industrial feed inputs, which require cultivation, chemical treatment, and mechanized processing. The simplicity of local feed inputs produced naturally and processed minimally ensures the system remains low-carbon from the outset [33].

The diagram then moves to the next stage: the metabolic results of local chickens fed with waste-based feed. As with any livestock system, chickens naturally produce metabolic gases such as CO_2 and CH_4 and generate fecal waste. The diagram depicts these outputs clearly, but the key point is that these emissions represent the only significant carbon output in the entire local feed cycle. There are no upstream emissions from factories, transportation, or mineral processing. In other words, the metabolic emissions are “net” emissions only from the biological processes of the chickens themselves. This makes the local feed system substantially more climate-friendly because it eliminates all industrial and distribution emissions seen on the left side of the diagram. The local system also creates a circular cycle in which waste becomes a resource. Chicken feces, instead of being treated as mere waste, can be reintegrated into agricultural systems as organic fertilizer. When used correctly, the manure enhances soil fertility, increases agricultural productivity, and reduces dependency on chemical fertilizer products that also carry high carbon footprints due to industrial manufacturing. In this way, the system supports a regenerative loop: kitchen waste feeds chickens; chickens produce manure; manure enriches the soil; and the soil produces crops that eventually return to the household kitchen. This is a foundational characteristic of circular, low-carbon agriculture.

Overall, the right side of the diagram illustrates that the local waste-based feed system dramatically reduces carbon emissions by eliminating industrial processes and long-distance distribution. It depends entirely on resources already available within the household, requiring only minimal additional energy. This system aligns with traditional practices led primarily by women, who manage household organic waste and livestock feeding. As a result, their role becomes central not only to family nutrition and economic resilience but also to climate mitigation [34]. The local feed model in Bondowoso is therefore not just a cost-saving practice; it is a strategic environmental intervention grounded in community knowledge and cultural values. Concerning the economy, the costs of high carbon emissions are very high in the long term, especially in connection with infrastructure damage, reduced agricultural products, and an increased frequency of natural disasters. The costs borne by developing countries tend to be higher due to the limited adaptation and technology [35].

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Studies in the area of public health show that high carbon emissions are not only due to climate change, but also through increased air pollution, which worsens cardiovascular and respiratory diseases and increases premature mortality. A study by Maciejczyk, Chen, and Thurston (2021) showed that long-term exposure to PM2.5, namely microscopic particles, which are made from the combustion of fossil fuels, is closely associated with increased cases of lung cancer and neurodegenerative diseases. Other studies also show that the social effects of long-term CO_2 emissions extend to political instability and social conflicts. An increase in global temperature is closely related to increased violent cases between groups and agricultural conflicts. If the natural resources are too few due to the deterioration in the environment, social competition becomes harder, and people who have no access to climate adaptation are most susceptible to experiencing social transfers and climate change.

Synergizing Women-led Agriculture, The Government, and The Islamic Boarding School in Reducing Carbon Emissions

Synergizing women-led agriculture, the government, and Islamic boarding schools (*pesantren*) in Bondowoso represents a deeply interlinked environmental governance model that is not only effective in reducing carbon emissions but also culturally embedded, socially inclusive, and economically empowering. This synergy creates a three-pillar system: household innovation, institutional guidance, and policy support that collectively transform how rural communities produce, consume, and manage organic resources [36]. In the context of climate change and rural vulnerability, such a model demonstrates how localized, low-cost, and culturally relevant approaches can achieve meaningful reductions in greenhouse gases, especially methane (CH_4) and carbon dioxide (CO_2), which are heavily produced by agricultural and waste-management activities.

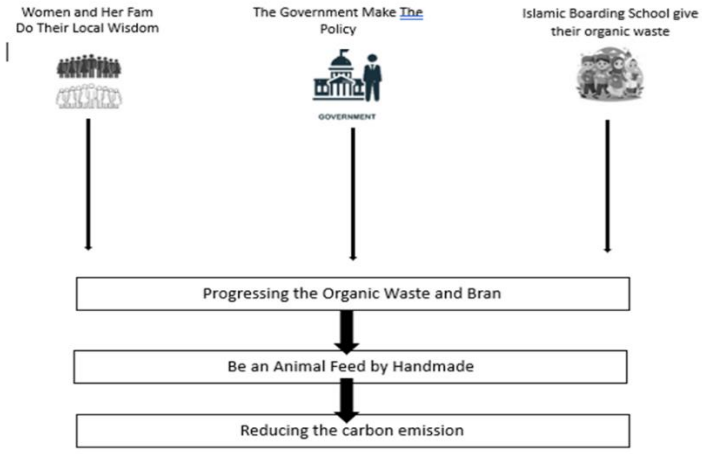

Figure 3. Community-Based Organic Waste Management for Animal Feed and Carbon Reduction

At the heart of this synergy is women-led agriculture, which functions as the operational pillar of low-carbon transformation. In villages like Karanganyar, women play central roles in cooking, waste sorting, livestock feeding, and managing household resources. Their daily routines give them continuous access to organic waste, vegetable scraps, fruit peels, leftover rice, papaya stems, and other biodegradable materials that would otherwise be discarded into landfills, where anaerobic decomposition releases methane, a greenhouse gas with a global warming potential far greater than CO_2. Instead of discarding these materials, women transform them into *bhug-bhug*, a nutrient-rich chicken feed combined with coarse bran. By repurposing organic waste into feed, women not only prevent methane emissions but also eliminate the need for industrial feed, which carries a large carbon footprint due to energy-intensive production and fossil-fuel transportation [37]. Women also act as

knowledge transmitters within the family, teaching children and other household members how to value waste as a resource and how to maintain low-emission agricultural systems. Their environmental role is deeply intertwined with the Madurese cultural value of *tengka*, which emphasizes effort, responsibility, trustworthiness, and resourcefulness qualities that naturally align with sustainable waste management and low-carbon practices.

The government forms the structural and regulatory support system that amplifies these household-level innovations. Through agencies such as the Environmental Office (DLH), the Agriculture Office, and village-level institutions, the government provides essential data, training, monitoring, and policy frameworks that enable community practices to operate more effectively. For example, DLH's waste data, which shows that Bondowoso produces 315 tons of waste per day, 68 percent of which is organic, helps justify and guide the need for community waste-management innovations [38]. The government also conducts training programs on composting, organic feed production, sustainable farming methods, and circular economy approaches. Additionally, village governments often allocate resources through Village Funds (*Dana Desa*) to support environmental programs. By endorsing women-led waste-based feed production, the government not only strengthens economic resilience but also embeds these practices into local regulations, ensuring that they last beyond short-term initiatives. This institutional support is crucial for scaling up innovations from household-level practices to community-wide systems that significantly reduce carbon emissions across multiple villages.

Meanwhile, Islamic boarding schools (*pesantren*) serve as the moral, educational, and cultural backbone of this synergy. Pesantren influences how communities perceive environmental responsibility by framing it within Islamic teachings. Concepts such as *khalifah fil-ardh* (humans as guardians of the Earth), *amana* (trust), *ihsan* (excellence in doing good), and *maslahah* (public good) reinforce the importance of preserving the environment and managing resources wisely. In many pesantren across Bondowoso, environmental education is integrated into religious learning, where students participate in activities such as composting, organic farming, and livestock management. By institutionalizing ecological ethics, pesantren strengthen collective awareness about waste reduction, resource efficiency, and low-emission agricultural practices. Importantly, pesantren also bridges the gap between technical knowledge and cultural acceptance. When religious leaders endorse waste-based feed production or environmental stewardship, community members are more likely to adopt and sustain these practices because they are supported by spiritual motivation and social legitimacy [39].

When women-led practices, government support, and pesantren guidance converge, they create a multi-level climate action system that operates from the household to the institutional scale. Women's practical innovations reduce methane emissions by diverting organic waste from landfills; government policy structures provide the infrastructure and training needed to expand these practices; and pesantren cultivate a moral-ethical foundation that makes environmental care a shared community responsibility [40]. This synergy is critical in rural areas like Bondowoso, where formal environmental infrastructure may be limited, but social cohesion and cultural identity are strong. Together, they create a circular system in which waste is continuously transformed into value, emissions are minimized, and economic resilience is strengthened.

In effect, this three-way collaboration offers a replicable model for low-carbon rural development that is grounded not in expensive technologies but in cultural values, religious ethics, and women's everyday knowledge. It shows that carbon-emission reduction can be achieved through simple, community-based interventions when supported by coherent governance and moral frameworks. The synergy between women-led agriculture, government institutions, and Islamic boarding schools thus represents a powerful blueprint for sustainable, culturally rooted climate action in Bondowoso and beyond.

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Bhug-Bhug: A Local Wisdom as an Empowering Family Institution

Bhug-bhug, the traditional practice of converting kitchen waste and coarse bran into livestock feed, stands as one of the most significant manifestations of local wisdom in Bondowoso, both as an ecological innovation and as a family-strengthening institution. More than a simple feeding technique, *bhug-bhug* represents an intergenerational knowledge system that embodies practical skills, cultural values, gendered roles, and ecological ethics passed down through families, especially through women. This practice has transformed household waste, traditionally seen as a burden, into a valuable asset that supports food security, economic resilience, and environmental protection. As such, *bhug-bhug* functions not only as a resource-management strategy but also as an empowering institution that reinforces the stability and agency of rural families [41].

At the household level, *bhug-bhug* empowers women by positioning them as central actors in managing both waste and livestock nutrition. Women possess intimate knowledge of daily kitchen activities, which allows them to identify, sort, and reuse biodegradable waste effectively. Their ability to convert leftovers, vegetable scraps, and overripe fruit into feed reflects a complex form of skill-based intelligence combining observational insight, practical experience, and a deep understanding of local livestock behavior. Through this practice, women gain economic leverage, as *bhug-bhug* drastically reduces the financial burden of purchasing industrial feed. Interview data reveal that feed costs can fall from IDR14,500 per kilogram (using commercial feed) to as low as IDR1,000 per kilogram when households adopt *bhug-bhug*. This cost reduction substantially increases household savings, allowing families to reallocate resources toward education, health, and other essential needs, thereby improving overall family well-being.

Ecologically, *bhug-bhug* embodies a circular-economy principle by reintroducing organic waste into the food cycle instead of allowing it to decompose in landfills, where it would otherwise release methane, a greenhouse gas far more potent than CO_2. The integration of waste into animal feed eliminates almost all upstream emissions associated with the industrial feed chain, such as energy-intensive factory processing, packaging, and fuel-based transportation. This low-emission cycle makes *bhug-bhug* a vital community-level climate mitigation strategy [42]. The environmental impact is significant because it addresses two major emission sources simultaneously: waste decomposition and industrial feed production. Through everyday household actions, women in Bondowoso contribute meaningfully to reducing carbon emissions and enhancing local environmental health.

Culturally, *bhug-bhug* reflects the Madurese value of *angka*, which emphasizes responsibility, effortfulness, trustworthiness, and self-reliance. It teaches discipline in resource management, communal sharing of knowledge, and the importance of contributing to family stability. The practice often involves cooperation between family members: children help collect leaves or vegetable scraps, husbands assist in preparing bran or managing livestock, and elders transmit knowledge about mixture proportions or nutritional balance. In this way, *bhug-bhug* becomes an institution of family bonding, where each generation participates in sustaining both the practice and the values embedded within it. The shared labor reinforces family cohesion, enhances social resilience, and fosters a collective sense of pride in maintaining local traditions [43].

Moreover, *bhug-bhug* helps strengthen the position of women within the household. Their expertise in feed production grants them decision-making power over livestock management and household budgeting. As primary drivers of this knowledge system, women become educators within the family and the wider community, often guiding neighbors and relatives in adopting similar practices. This elevates their social status and recognition within the village, aligning with broader goals of women's empowerment and gender-responsive development. The practice also nurtures children's environmental awareness, serving as an informal education platform where young family members learn about the waste cycle, animal care, and the importance of sustainability.

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In broader community terms, *bhug-bhug* acts as a grassroots institution that supports local economic systems. Villages that widely adopt this practice reduce dependence on external markets and become more resilient to fluctuations in feed prices or shortages. *Bhug-bhug* fosters a sense of local autonomy, allowing families to produce their own resources independently of industrial supply chains. This autonomy strengthens community solidarity because individuals often share tips, organic materials, or bran supplies, reinforcing social networks and mutual assistance, key cultural traits in rural Madurese society [44].

After all ingredients are mixed and cooked evenly, the feed mixture is removed from the stove and cooled before it is handed over to the local chickens in the cage. Feeding takes place routinely three times a day, namely in the morning, in the afternoon, and in the evening. The advantage of this type of food is its good durability, which can last up to one or two days. In addition, the cooking process mixes all the ingredients perfectly, and the texture is easier for the chicken to consume. If the food is not cooked, rough rice bran usually tends to clump and is difficult to eat, and has the potential to quickly cause slimy feed. Involving feed is rejected by chickens because it causes unpleasant smells and lowers their appetite of the chickens.

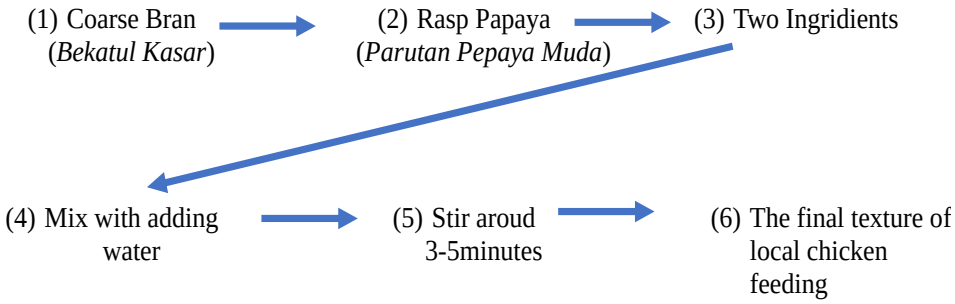

Figure 4. System Dynamics and Feedback Loops Illustrating Interactions Among Components in a Network

However, the process of manufacturing *bhug-bhug* is still traditional and has not been touched by technological innovations. The community has not used modern tools that can increase the productivity and efficiency of feed processing, such as a mill or a helicopter that can cut and smooth the material quickly and evenly. Therefore, there is a synergy between the community, government, and other stakeholders to strengthen the development of green and circular economy and to promote sustainable reduction in carbon emissions. The sequence of images illustrates the traditional process of preparing *bhug-bhug*, a local chicken feed created by rural women in Bondowoso using simple, low-cost, and environmentally friendly materials. The process begins with the use of coarse bran (*bekatul kasar*), a by-product of rice milling that is abundant in agrarian communities. This coarse bran serves as the primary dry ingredient, providing essential carbohydrates and fibrous content for local chickens. Alongside the branch, women prepare grated young papaya (*parutan pepaya muda*), which is shown being scraped manually from a fresh papaya using a traditional tool. Young papaya is chosen not only because it is readily available, but also because it contains natural enzymes such as papain, which support digestive health in poultry [45].

The third image shows the two main ingredients, coarse bran and grated papaya, placed side by side in separate containers. This visual emphasizes the simplicity and accessibility of the materials needed, reflecting a feeding system grounded entirely in household resources rather than industrial inputs. Once the ingredients are ready, they are combined in a large cooking pan. Water is added gradually to soften the mixture, creating a moist consistency that allows the bran to absorb the liquid and blend smoothly with the papaya fibers. This mixture is then stirred continuously for three to five minutes. The short cooking

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duration indicates that the process requires minimal energy, which contributes to the overall low-carbon nature of this traditional feed preparation.

As the mixture thickens, the grated papaya begins releasing its natural moisture and enzymes, helping to bind the bran and improve the nutritional value of the feed. The final image displays the completed *bhug-bhug*, a soft, grainy-textured blend with a mildly sweet aroma. This texture is especially suitable for local chickens, making it easier for them to digest compared to dry commercial feed. The feed's warm, moist consistency also encourages quick consumption, reducing food waste. In addition, the most dominant waste types are based on the data composition of waste in Bondowoso Regency. The biggest contribution to this waste generation comes from households and traditional markets. Against this background, this research underlines the importance of cooperation between the government and the community for the use of the potential of organic waste in environmentally friendly livestock feed. Such initiatives not only contribute to family food and economic security but also strengthen agricultural practices and sustainable cattle at the local level.

The process depicted is not only a practical demonstration of how *bhug-bhug* is made but also a living embodiment of the Madurese cultural value known as *tengka*. *Tengka* represents a set of interwoven principles of effortfulness, responsibility, resilience, resourcefulness, and mutual trust that guide how individuals contribute to their families and communities. Every step in the preparation of *bhug-bhug* reflects these values in action, showing how local wisdom becomes a mechanism for empowerment and environmental stewardship.

The selection and preparation of ingredients, beginning with coarse bran and grated young papaya, demonstrate the *tengka* principle of resourcefulness. Women do not rely on external, factory-produced materials but instead make use of what is already available in their homes or nearby fields. This reflects an intrinsic ability to turn limited resources into something valuable and productive. Rather than viewing kitchen waste or agricultural by-products as disposable, the concept of *tengka* encourages individuals to repurpose and maximize the usefulness of every item, avoiding waste and reducing dependency on external markets. The process of mixing and cooking the ingredients also reveals the *tengka* value of perseverance and diligent effort. Creating *bhug-bhug* requires time, attention, and physical labor, particularly in stirring the mixture until it reaches the right consistency. This continuous effort, though modest, represents the everyday resilience that women exercise in maintaining household stability. Their labor, though often unseen, sustains the economic and ecological well-being of the family. The short cooking time, three to five minutes, demonstrates another aspect of *tengka*: adaptive efficiency. Women know how to balance effort with practicality, minimizing the use of fuel and time while still producing high-quality feed.

Furthermore, the final product, the soft, nutrient-rich *bhug-bhug*, represents the *tengka* principle of responsibility toward the family's livelihood. By preparing their own feed, women ensure that their chickens grow healthily and continue to provide eggs, meat, or income for the household. This practice strengthens family economies by reducing costs and increasing self-sufficiency. The knowledge of how to prepare *bhug-bhug* is often passed down through generations, reinforcing the cultural transmission of *tengka* from mothers to daughters and sustaining a cycle of empowerment rooted in tradition. On a broader level, *bhug-bhug* encourages social cooperation and community trust, core components of *tengka*. The ingredients, techniques, and experiences involved in preparing the feed are commonly shared among neighbors and relatives. Women discuss proportions, troubleshoot challenges, and exchange ingredients when necessary, creating a network of mutual aid that extends beyond the household. This reinforces social cohesion and strengthens community resilience, allowing families to support one another in times of economic or environmental stress.

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Finally, *bhug-bhug* embodies the *tengka* ethic of ecological care. By converting kitchen waste into feed, women prevent methane-producing organic matter from entering landfills. This aligns with the value of maintaining balance within the environment, a key aspect of *tengka*, which implicitly teaches individuals to respect natural resources and avoid unnecessary exploitation. Through this practice, women demonstrate that environmental responsibility is not separate from daily life but is embedded in routine activities that sustain the household. In essence, the images show more than the technical production of local chicken feed; they portray a cultural system where *tengka* guides how families interact with their environment, utilize resources, build resilience, and care for one another. *Bhug-bhug* is therefore not only a feeding technique but a cultural expression of empowerment, responsibility, and sustainability deeply rooted in Madurese identity.

CONCLUSION

The integration of women-led agriculture, local wisdom, and community-based institutions in Bondowoso demonstrates a powerful and culturally grounded pathway toward sustainable development and carbon-emission reduction, contributing to SDGs. Through the practice of bhug-bhug, the transformation of kitchen waste and coarse bran into nutrient-rich chicken feed, rural women play a central role in reshaping household economies, strengthening food security, and minimizing environmental impact, aligning with SDGs targets. This practice significantly reduces reliance on industrial feed, thereby cutting emissions associated with factory production, packaging, and fossil-fuel transportation. At the same time, the repurposing of organic waste directly reduces methane emissions that would have been generated in landfills, contributing meaningfully to climate mitigation at the local scale, supporting global SDGs efforts. More importantly, the preparation of bhug-bhug represents the lived expression of tengka, a core Madurese cultural value grounded in effortfulness, responsibility, resilience, and resourcefulness. Every step of the process, from ingredient selection to cooking, shows how cultural ethics shape sustainable behavior. Women embody tengka by maximizing available resources, reducing waste, and ensuring the economic stability of their families. This cultural dimension strengthens the social legitimacy of environmentally friendly practices, ensuring that they are not only technically effective but also emotionally meaningful and widely accepted within the community. The synergy between households, government institutions, and Islamic boarding schools further reinforces this sustainable system. Government support provides structure, policy, and training that amplify household innovations, while pesantren embed environmental responsibility within religious and moral teachings, cultivating a shared understanding of ecological stewardship. Together, these three actors create a multi-level governance model that transforms everyday practices into collective climate action. Overall, the Bondowoso experience demonstrates that sustainable development does not need to depend on advanced technology or large-scale interventions. Instead, it can emerge organically from local knowledge, cultural values, and gendered roles that have long shaped community life. By recognizing and strengthening practices like bhug-bhug, policymakers and development practitioners can support a bottom-up model of climate resilience, one that empowers families, protects the environment, and preserves the cultural identity of rural communities.

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Author Contribution

Dianidza Arodha conceptualized the study; Maya Panorama and Moh. Syawaludin conducted fieldwork and collected data; Bahrina Almas, Imamul Arifin, and Hilmy Baihaqy Yussof contributed to methodology, data analysis, and manuscript writing. All authors reviewed and approved the final version, ensuring academic quality.

Conflicts of Interest

All authors declare no conflict of interest.

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