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Building Socio-Ecological Resilience of Riparian Communities Through A Circular Economy: A Case Study of The Tersuara Program by PT Pertamina Patra Niaga Fuel Terminal Sei Siak

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TERSUARA Program; circular economy; corporate social responsibility; community empowerment; riparian conservation

Abstract
This research analyzed the implementation of the TERSUARA Program (Ternak Sumber Sari Sejahtera) as a circular economy-based social innovation initiated by PT Pertamina Patra Niaga Fuel Terminal Sei Siak in Tanjung Rhu Village, Pekanbaru. The program integrated riparian ecosystem conservation with a community-based integrated livestock system to generate simultaneous economic, social, and environmental value for vulnerable communities experiencing socio-ecological challenges. This research employed a qualitative descriptive case study design based on secondary data from academic literature and company internal documents, including social mapping reports, program implementation records, and community group financial statements. Data credibility was ensured through triangulation between theoretical frameworks and internal company evaluation findings. The TERSUARA Program successfully integrated vetiver grass-based ecological mitigation with an integrated circular livestock farming system consisting of goat farming, KUB native chicken farming, Black Soldier Fly (BSF) larvae cultivation, and the production of compost and liquid organic fertilizer. The program outcomes indicated that average participant income increased by 35%, group collective income increased by 25% between semesters, greenhouse gas (GHG) emissions were reduced by 1.648 tCO_2-eq per year, and 100% of office organic waste (3,546 kg/year) was diverted from landfills and utilized as BSF larvae substrate. The findings were limited to the first year of implementation; therefore, future longitudinal studies over a 3–5-year period are recommended to evaluate long-term sustainability and impacts. This study provides empirical evidence of a circular corporate social responsibility (CSR) model that integrates ecological restoration with the economic empowerment of marginalized communities, demonstrating its potential for replication in other riparian areas across Indonesia as an integrated approach to achieving environmental sustainability and inclusive community development.

INTRODUCTION

Rapid urbanization and urban expansion have become major challenges to environmental sustainability, socio-ecological resilience, and community well-being across many developing countries (Sasana et al., 2019). Uncontrolled and poorly planned urban growth has contributed to

environmental degradation, the loss of green open spaces, declining ecological carrying capacity, and increasing socio-economic vulnerability among communities living in marginal areas (Abdullah et al., 2022; Geissdoerfer et al., 2017; United Nations, 2023). These challenges have become increasingly complex as environmental pressures coincide with persistent poverty, limited access to formal employment, and declining productivity of local natural resources on which communities depend for their livelihoods (Sasana et al., 2019).

In Indonesia, rural-to-urban migration has accelerated considerably over the past several decades. Urban economic centers continue to attract migrants seeking improved employment opportunities, education, and public services. This phenomenon is particularly evident in Pekanbaru City, Riau Province, especially within the riparian areas of the Siak River. Continuous urban development and land-use conversion have transformed natural green spaces into densely populated residential areas. Consequently, the ecological functions of riverbanks have deteriorated, increasing the risk of riverbank erosion while reducing the environment's natural capacity to mitigate flooding (Sandhyavitri et al., 2015). These environmental pressures are further exacerbated by the predominance of peatland ecosystems in Pekanbaru. Because peat soils are highly vulnerable to hydrological disturbances, local communities face increasing exposure to environmental degradation and declining living conditions (Mubekti, 2011).

Environmental degradation along riverbanks has not only damaged local ecosystems but has also threatened the livelihoods of communities that depend heavily on the Siak River, particularly those residing in Tanjung Rhu Urban Village, Limapuluh District, Pekanbaru City. The river serves as an important economic resource supporting local livelihoods. According to the 2025 social mapping assessment, many residents rely on riverine and wetland ecosystems for income-generating activities, including floating net-cage aquaculture, the harvesting of natural grasses for livestock feed, and the collection of Tubifex worms. Consequently, further degradation of the Siak River would directly affect household income sources and weaken the economic resilience of local families (Hadi et al., 2025; Ramadhana et al., 2024; Wong & Abdullah, 2021).

One of the most pressing environmental issues in this area is the continuous erosion of the Siak River's riparian zone, where approximately one meter of riverbank is lost annually. This progressive land degradation threatens residential areas while reducing the riverbank's natural function as a flood-buffering ecosystem. The loss of erosion-control vegetation has increased flood susceptibility, accelerated sediment accumulation within the river, and degraded aquatic habitats (Gacu et al., 2025; Juan-Diego et al., 2025; Pavlova-Traykova et al., 2026). According to the 2025 Social Mapping Report of PT Pertamina Fuel Terminal Sei Siak, these impacts became particularly evident during the major flood that inundated Tanjung Rhu Urban Village in early 2025, directly affecting approximately 550 households. As argued by Hamim and Usman (2020), densely populated settlements established along riverbanks without adequate conservation of infiltration vegetation substantially increase hydrological overflow, disrupting the socio-economic activities of vulnerable communities.

These ecological challenges have also directly affected the productivity of local livestock farming. Demographic data and the 2025 social mapping assessment indicate that small-scale

household livestock production and the collection of natural wetland forage serve as important livelihood safety nets for low-income households in Tanjung Rhu Urban Village. However, degradation of the riparian ecosystem has significantly reduced the availability of nutritious and sustainable forage resources (Changwony et al., 2015; Maestas et al., 2023; Xiang et al., 2016). Despite previous assistance programs, livestock farmers continue to experience shortages of high-quality animal feed. Furthermore, conventional livestock management practices have resulted in suboptimal productivity, increased livestock morbidity, and inefficient manure management. Animal waste is commonly disposed of directly onto the ground without treatment, generating unpleasant odors, degrading environmental sanitation, and limiting opportunities to convert organic waste into economically valuable products. Chen et al. (2026) argued that conventional livestock systems operating in densely populated urban environments without effective waste management practices exacerbate environmental sanitation problems and increase public health risks. Collectively, these conditions demonstrate that environmental degradation and economic hardship in Tanjung Rhu Urban Village are closely interconnected, forming a socio-ecological vulnerability cycle (Adger, 2006). Drawing upon social innovation theory (Mulgan et al., 2007) and circular economy principles (Geissdoerfer et al., 2017), addressing this interconnected vulnerability requires integrated interventions capable of transforming environmental challenges and waste streams into productive resources with economic value.

In response to these challenges, PT Pertamina Patra Niaga Fuel Terminal (FT) Sei Siak initiated the SEJAMBA (Siak Jaga Alam, Masyarakat Berdaya) program, which includes the TERSUARA (Ternak Sumber Sari Sejahtera) production sub-program as its primary social innovation initiative. The program integrates ecological disaster mitigation with community-based circular economy practices by utilizing vetiver grass (Chrysopogon zizanioides) as both erosion-control vegetation and an alternative forage source for ruminant livestock. The integrated livestock production system is further supported by an adaptive livestock housing design that separates solid and liquid manure, enabling a zero-waste management approach through efficient resource recovery and reuse (El Mahdi, 2024).

The TERSUARA Program represents an innovative governance model that integrates multiple environmental and socio-economic challenges into mutually reinforcing solutions. Riverbank erosion and conventional sanitation problems, which initially posed significant environmental threats, have been transformed into opportunities for generating economic value through circular resource utilization. This approach reflects the principle of addressing one problem by utilizing it to solve another within the social innovation framework, whereby the ecological vulnerability of the Siak River riparian zone is converted into productive green resources that reduce livestock production costs among vulnerable households. Consequently, the multidimensional challenges experienced by communities in Tanjung Rhu Urban Village can be addressed through a community-driven and regenerative closed-loop circular system facilitated by corporate intervention.

The development of the TERSUARA integrated livestock farming model also represents a corporate empowerment initiative grounded in circular economy principles to foster social

innovation among marginalized urban communities, particularly vulnerable groups and persons with disabilities residing along the Siak River riparian area. Accordingly, this article examined the design, implementation, and utilization of the TERSUARA Program from the perspectives of social innovation and circular economy. Specifically, the study analyzed how circular interventions generated economic value while simultaneously promoting social inclusion and ecological restoration for beneficiary communities in Tanjung Rhu Urban Village.

Research on the integration of circular economy principles into community empowerment and CSR programs has shown that implementation at the community level can generate multidimensional value, including social inclusion and environmental restoration (Geissdoerfer et al., 2017). Effective social innovation must also provide solutions that are more efficient, sustainable, and equitable than existing alternatives (Mulgan et al., 2007). In Indonesia, studies of community-based empowerment programs have identified that uncontrolled urbanization contributes to environmental degradation and socio-economic vulnerability among marginalized communities (Sasana et al., 2019), while densely populated settlements along riverbanks without conservation vegetation increase flood risks (Hamim & Usman, 2020). However, research on integrating circular economy principles into CSR programs in riparian communities remains limited, while studies of community-based livestock systems in Indonesia have primarily focused on production efficiency with limited attention to waste valorization and environmental risk reduction.

Despite the growing body of literature on circular economy, social innovation, and community empowerment, several gaps remain. First, existing research has predominantly examined ecological conservation or economic empowerment separately, with limited studies addressing integrated approaches that simultaneously consider both dimensions. Second, studies on CSR programs in Indonesia have primarily evaluated program outputs and outcomes, with limited attention to the mechanisms through which circular economy principles are implemented at the community level. Third, research on community-based livestock systems has mainly focused on production efficiency, with limited consideration of waste valorization and its contribution to household income diversification. Fourth, studies on riparian community resilience have primarily emphasized flood risk reduction, with limited attention to integrating ecological restoration with livelihood diversification strategies. Therefore, this research addressed these gaps by analyzing the TERSUARA Program as an integrated circular economy model that simultaneously promotes ecological restoration, economic empowerment, and social inclusion in riparian communities.

This study was based on two interrelated theoretical frameworks: social innovation theory and circular economy principles. Social innovation theory, developed by Mulgan et al. (2007), emphasizes that effective social innovations provide solutions that are more efficient, sustainable, and equitable than existing alternatives while creating value that primarily benefits society. The circular economy framework, as articulated by Geissdoerfer et al. (2017), emphasizes closing material and energy loops, extending resource utilization, and minimizing waste generation. The integration of these frameworks provides an analytical foundation for examining how the TERSUARA Program operationalizes circular economy principles as a social innovation strategy.

This study aimed to analyze the implementation of the TERSUARA Program as a social intervention based on circular economy principles. Specifically, the study investigated how the integration of riparian ecological conservation and community-based livestock production generated simultaneous economic, social, and environmental value for vulnerable communities experiencing socio-ecological vulnerability. The significance of this research lies in providing empirical evidence of a circular CSR model that integrates ecological restoration with economic empowerment, demonstrating its potential for replication in other riparian areas across Indonesia as an integrated approach to achieving environmental sustainability and inclusive community development.

METHOD

This research employed a qualitative research design using a descriptive case study approach. The approach was selected to obtain an in-depth understanding of the implementation of the TERSUARA (Ternak Sumber Sari Sejahtera) Program and its contribution to community empowerment and circular economy practices. The study was conducted in Tanjung Rhu Urban Village, Pekanbaru City, the operational area of PT Pertamina Patra Niaga Fuel Terminal Sei Siak, during the first half of 2025.

The research adopted a document-based case study approach by examining the implementation process and documented outcomes of the TERSUARA Program. The program focused on vulnerable communities residing along the Siak River riparian area, with the TERSUARA community group serving as the primary beneficiary. The analysis utilized documented records related to program implementation, community engagement, and beneficiary outcomes available in the company's internal documentation.

Data collection relied on secondary data obtained from academic literature and company documents. The literature review was conducted to establish the theoretical foundation of social innovation and circular economy concepts and to support the analytical framework of the study (Neuman, 2014). Company documents, including social mapping reports, program implementation records, monitoring and evaluation reports, and beneficiary financial records, were used as the primary sources for analyzing program implementation and assessing documented outcomes.

The collected data were analyzed using thematic analysis. The analysis examined the design and implementation of circular innovation interventions and evaluated their contribution to community economic improvement through value creation while supporting social inclusion and environmental restoration objectives in Tanjung Rhu Urban Village. To ensure the credibility of the findings, data validity was established through secondary data triangulation by comparing theoretical perspectives with documented program achievements and company monitoring and evaluation records.

RESULTS AND DISCUSSION

Integration of an Odor-Free Circular Livestock Farming System

The TERSUARA (Ternak Sumber Sari Sejahtera) Program is a production sub-program under the SEJAMBA (Siak Jaga Alam, Masyarakat Berdaya) initiative developed by PT Pertamina Patra Niaga Fuel Terminal (FT) Sei Siak in Tanjung Rhu Urban Village, Pekanbaru City. The program was designed as a closed-loop circular production system integrating four mutually reinforcing production chains: goat farming, KUB native chicken farming, Black Soldier Fly (BSF) larvae cultivation, and the production of compost and liquid organic fertilizer. Within this integrated system, by-products generated from one production activity serve as inputs for subsequent processes, thereby minimizing anaerobic waste disposal and maximizing resource utilization. This design reflects the fundamental principles of the circular economy by extending the productive value of materials and energy throughout the production cycle.

Design of the Integrated Production System

The TERSUARA Program was established as an integrated production system that closes material and waste loops across all production stages. As illustrated in Figure 1, the circular production flow consists of five interconnected components: (1) vetiver grass cultivated along the Siak River riparian zone as the primary forage source for goats and KUB native chickens; (2) livestock manure processed into compost and liquid organic fertilizer; (3) office organic waste generated by PT Pertamina Patra Niaga Fuel Terminal Sei Siak utilized as feed substrate for BSF larvae cultivation; (4) dried BSF larvae used as a high-protein supplementary feed for catfish and poultry; and (5) nutrient-rich biofloc pond water reused for irrigating hydroponic vegetable cultivation.

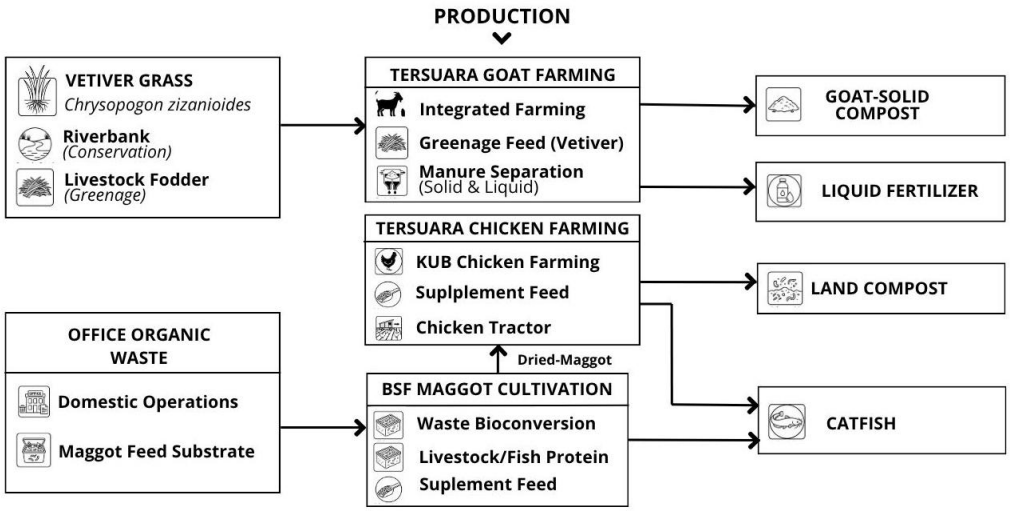

Figure 1. The circular economy flow diagram of the TERSUARA program: TERSUARA Goat Farming, TERSUARA Poultry Farming, and BSF Maggot Cultivation
Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025), Program Implementation Report

The TERSUARA production system integrates three core components: goat farming, KUB native chicken farming, and BSF larvae cultivation. Its distinctive feature lies in its ability to simultaneously address three major contextual challenges faced by communities in Tanjung Rhu Urban Village: recurrent flooding, environmental sanitation problems associated with livestock waste, and the high operational costs of conventional livestock farming.

First, flood risk is mitigated through the construction of elevated livestock housing. Given that Tanjung Rhu is characterized by flood-prone peatland with limited drainage capacity, both goat and poultry houses were constructed on elevated platforms. This structural design ensures the continuity of livestock production during flood events while protecting productive assets from flood-related damage, thereby enhancing the resilience of community-based livestock enterprises.

Second, the program introduced an odor-free goat housing system. Unlike conventional livestock systems, where manure is directly deposited onto the ground and generates unpleasant odors that may increase disease risks, the TERSUARA goat housing system incorporates an automatic separation mechanism for solid and liquid manure. Solid manure is processed into organic compost, producing approximately 127.8 kg of compost annually, while liquid manure (urine) is collected and processed into 547.5 liters of liquid organic fertilizer per year, which is marketed to local fruit farmers. Beyond eliminating odor pollution within surrounding residential areas, this waste management system transforms livestock waste into two additional income streams for the beneficiary group.

Third, the program applies a chicken tractor system in KUB native chicken farming. This innovation utilizes the chickens' natural scratching behavior to facilitate in situ decomposition of manure. As chickens continuously disturb and aerate the soil, organic waste is naturally incorporated into the substrate, producing approximately 4.59 tons of compost annually without requiring manual cleaning. Consequently, members of the TERSUARA group no longer need to allocate additional labor for manure management, as compost is produced naturally and is immediately available for agricultural application following each production cycle.

Fourth, both livestock houses are equipped with an automatic temperature sensing and control system that adaptively regulates ventilation according to ambient environmental conditions. The sensor-based ventilation system improves energy efficiency by reducing electricity consumption by approximately 8–20% compared with conventional manual operation. Within the TERSUARA facilities, this innovation is estimated to save approximately 350.4 kWh of electricity per year, equivalent to an operational cost reduction of IDR 390,696 annually, while simultaneously reducing greenhouse gas emissions by approximately 0.287 tCO_2-eq per year. These improvements contribute not only to lower production costs but also to a reduced operational carbon footprint.

Collectively, these four design innovations operate as an integrated system. The elevated housing enhances production resilience against flooding; the odor-free manure management system and chicken tractor approach convert livestock waste into economically valuable products; and the automated temperature control system improves operational efficiency while reducing energy consumption. Together, these complementary innovations enable the TERSUARA

Program to outperform conventional livestock farming systems, which generally emphasize production efficiency while paying limited attention to waste valorization and resilience to environmental risks.

Figure 2. TERSUARA Goat and Chicken Farming Structures
Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025)

Within the integrated production system, Black Soldier Fly (BSF) (Hermetia illucens) larvae cultivation functions as a circular intermediary that connects two material streams previously treated as independent systems: organic office waste generated by PT Pertamina Patra Niaga Fuel Terminal Sei Siak and the demand for high-protein feed within the TERSUARA group's poultry and catfish farming operations. Prior to the implementation of the TERSUARA Program, approximately 295.5 kg of organic office waste per month (equivalent to 3,546 kg annually), primarily consisting of food scraps and grass clippings generated from the terminal's operational activities, was transferred to the Pekanbaru Environmental and Sanitation Agency without undergoing any resource recovery or treatment. This practice not only resulted in the loss of potentially valuable organic materials but also contributed to landfill capacity pressures and methane (CH_4) emissions associated with anaerobic decomposition. Following the implementation of the program, 100% of the organic waste stream has been diverted and utilized as feed substrate for BSF larvae, effectively achieving zero organic waste disposal to landfill from the office operations of Fuel Terminal Sei Siak.

BSF larvae possess a highly competitive nutritional profile as an alternative protein source, containing approximately 41–42% crude protein, 31–35% ether extract (lipids), 14–15% ash, 4.18–5.10% calcium, and 0.60–0.63% phosphorus on a dry matter basis (Sanjaya et al., 2024). This nutritional composition enables BSF larvae to serve as an effective feed supplement, reducing the group's dependence on commercial feed while lowering production costs for both poultry and catfish farming. From a technical perspective, BSF larvae are capable of biodegrading a wide range of organic substrates, including food waste and vegetable residues generated from office operations. The cultivation process is relatively straightforward, requiring rearing containers to be maintained under moist but non-compacted conditions with controlled humidity. BSF larvae were initially sourced from experienced practitioners, while the cultivation facility was strategically co-located with the poultry house to improve material flow efficiency within the integrated production

system. Harvested larvae are processed into dried BSF meal as a high-protein feed supplement for KUB native chickens and catfish, whereas the residual frass (BSF larval excreta) is further utilized as an organic fertilizer, reinforcing the program's closed-loop circular production system.

Figure 3. BSF Maggot Cultivation by the TERSUARA Community
Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025)

Capacity Building of the TERSUARA Group

To strengthen the technical capacity of program beneficiaries, the TERSUARA Program delivered three specialized training modules facilitated by experienced practitioners in their respective fields: (1) odor-free goat farming systems; (2) KUB native chicken farming based on the chicken tractor approach; and (3) Black Soldier Fly (BSF) larvae cultivation using organic waste substrates. Each training session was attended by all active members of the TERSUARA Group and incorporated pre-test and post-test assessments to evaluate participants' knowledge acquisition before and after the intervention. A summary of the assessment results is presented in Table 1.

Table 1. Summary of average pre-test and post-test results of the TERSUARA Group training

Training Type	Average Pre-Test	Average Post-Test	Improvement
Goat Farming	51,55	73,89	43,0%
KUB Chicken Farming	53,39	83,34	56,1%
BSF Maggot Cultivation	45,55	87,22	91,5%
Average	50,20	81,48	62,3%

Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025)

The three training modules demonstrated consistent improvements in participants' knowledge across all intervention areas. The combined average pre-test score of 50.20 increased to 81.48 in the post-test, representing an average knowledge gain of 62.3% across all training programs. These findings indicate that the technical capacity-building interventions effectively enhanced participants' understanding of integrated circular livestock farming practices.

Beyond formal training, capacity development was further reinforced through a knowledge-sharing mechanism facilitated by the program's local champion. As an experienced goat farmer responsible for the routine monitoring of vetiver grass cultivation and livestock housing, the local

champion regularly provided practical guidance to group members on goat husbandry and livestock management. This included recommendations on appropriate breed selection to improve herd genetics and maintain livestock productivity. The continuity of knowledge transfer has been further strengthened through a local champion succession mechanism, ensuring that practical expertise is continuously passed on to subsequent members with strong commitment to overseeing the daily management of both goat and poultry farming activities.

Impact Assessment of the TERSUARA Program

Economic Impact on the TERSUARA Group

The economic impact of the TERSUARA Program was assessed by comparing the income levels of group members before and after program implementation using the group's financial records and Income Improvement Certificates issued by the Tanjung Rhu Urban Village Office up to September 2025. Prior to joining the TERSUARA Group, none of the participants had permanent employment and relied primarily on irregular informal work, with monthly incomes ranging from IDR 780,000 to IDR 2,650,000. Following the implementation of the program, all members experienced income growth. The group's average monthly income increased from IDR 1,482,143 to IDR 1,942,143, representing an average increase of IDR 460,000 per month, equivalent to approximately 35% per participant.

The largest proportional increase (59%) was recorded among participants with the lowest baseline income (IDR 780,000 per month), whereas the smallest increase (17%) occurred among those with the highest initial income (IDR 2,650,000 per month). This pattern suggests that the program generated proportionally greater economic benefits for participants experiencing the highest levels of economic vulnerability, thereby contributing to a more inclusive distribution of program outcomes. Although the post-intervention average monthly income remained below the 2025 Riau Provincial Minimum Wage (IDR 3,508,776), all participants had incomes above the 2025 Pekanbaru City poverty line of IDR 767,408 per capita per month (BPS, 2025). In addition to improvements in individual earnings, the TERSUARA Group also demonstrated positive growth in collective income during its first year of operation, as presented in Table 2.

Table 2. TERSUARA Community Income per Semester (2025)

Period	Income Realization	Source of Income
January – July 2025	IDR 7.200.000	Sale of goats, chickens, solid compost, and liquid fertilizer
August – December 2025	IDR 9.000.000	Sale of goats, chickens, solid compost, and liquid fertilizer
Total 2025	**IDR 16.200.0000**	

Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025), Community Group Financial Records

The group's collective income increased from IDR 7,200,000 in the first semester to IDR 9,000,000 in the second semester, representing a 25% semester-on-semester growth. This increase was primarily attributable to the full-scale operation of the KUB native chicken farming system

during the second semester, alongside the regular commercialization of value-added by-products, including organic compost and liquid organic fertilizer, to local fruit farmers.

Overall, the group's income is generated through four complementary revenue streams: (1) the sale of live goats and their value-added by-products, including 127.8 kg of organic compost and 547.5 L of liquid organic fertilizer annually; (2) the sale of KUB native chickens, with an average production of approximately 400 kg of meat per production cycle; (3) the sale of dried Black Soldier Fly (BSF) larvae to catfish farmers; and (4) a profit-sharing mechanism through which group revenues are distributed equitably among all members.

The diversification of these four revenue streams has reduced the group's dependence on a single commodity, thereby enhancing its economic resilience against price fluctuations and production failures affecting individual livestock enterprises. Based on documented financial records, the direct measurable economic value generated by the implementation of the odor-free livestock housing innovation was estimated at IDR 3,220,000, representing the difference between the group's average income before and after the adoption of the innovation. Nevertheless, this estimate does not yet reflect the program's full economic potential, as the study captures only the first year of implementation, during which the four integrated production components of the TERSUARA system had not yet reached full operational capacity.

Environmental Impact

Beyond its economic benefits, the TERSUARA Program has generated significant environmental outcomes through integrated livestock waste management, energy-efficient technologies, and the diversion of organic office waste from landfill disposal. All environmental impact estimates were calculated using the 2006 IPCC Guidelines in conjunction with the program's 2025 operational data, as summarized in Table 3.

Table 3. Environmental Impact Results of the TERSUARA Program

Parameter	**Baseline Condition**	**TERSUARA Achievements**
Avoided GHG	-	1.648 tons CO2-eq/year
1. GHG emissions from livestock manure	Unmanaged CH4 + N2O	1.361 tons CO2-eq/year
2. Barn energy savings	12 hours/day × 2 units (manual fans)	350.4 kWh/year (0.287 tons CO2-eq/year & IDR 390,696/year)
Livestock manure waste generation	±14.05 tons/year unmanaged	5.71 tons/year
Office organic waste	295.5 kg/month (3,546 kg/year) to Muara Fajar Landfill	100% diverted as maggot feed
Chicken compost product *(chicken tractor)*	-	4.59 tons of compost/year
Goat liquid fertilizer product	-	547.5 liters/year for local fruit farmers

Source: PT Pertamina Patra Niaga Fuel Terminal Sei Siak (2025), Program Implementation Report & 2006 IPCC Guidelines

As presented in Table 3, the program achieved a total avoided greenhouse gas (GHG) emission of 1.648 tCO_2-eq per year, derived from two principal intervention pathways. First, the conversion of livestock manure into organic compost and liquid fertilizer avoided approximately 1.361 tCO_2-eq annually, comprising 0.191 tCO_2-eq of avoided methane (CH_4) emissions and 1.170 tCO_2-eq of avoided nitrous oxide (N_2O) emissions. Second, the installation of an automated temperature-control system reduced electricity consumption by approximately 350.4 kWh per year, corresponding to an additional reduction of 0.287 tCO_2-eq annually.

Without the TERSUARA intervention, the entire volume of livestock manure approximately 14.05 tons per year would have undergone unmanaged anaerobic decomposition, resulting in uncontrolled methane emissions to the atmosphere. By contrast, the aerobic waste treatment system implemented through the program substantially reduced these emissions. According to the 2006 IPCC Guidelines, every metric ton of livestock manure treated under aerobic conditions can prevent the formation of approximately 2.68 tCO_2-eq of methane emissions (IPCC, 2006).

From the perspective of waste reduction, the integrated livestock system generated approximately 14.05 tons of manure annually, consisting of 13.14 tons of poultry manure and 0.913 tons of goat manure. Through the implementation of the chicken tractor approach and the automatic separation of solid and liquid manure, unmanaged wet manure generation was reduced by approximately 5.71 tons per year. The remaining manure that was not directly converted into marketable products was recycled back into the production system, ensuring that no untreated livestock waste was discharged directly into the surrounding environment.

With respect to office waste management, approximately 295.5 kg of organic waste per month (equivalent to 3,546 kg annually) generated from the operational activities of Fuel Terminal Sei Siak, which had previously been transferred to the Pekanbaru Environmental and Sanitation Agency, is now entirely utilized as feed substrate for Black Soldier Fly (BSF) larvae. This intervention has enabled the facility to achieve zero organic waste to landfill from its office operations while simultaneously producing high-protein BSF biomass that serves as a valuable production input for the integrated poultry and catfish farming system within the TERSUARA circular economy model.

Social Impact and Institutional Sustainability

From a social perspective, the TERSUARA Program successfully mobilized seven core group members (six active participants and one local champion), all of whom were drawn from socio-economically vulnerable communities. These participants were characterized by the absence of permanent employment or reliance on irregular informal work, while several were registered beneficiaries of Indonesia's Family Hope Program (Program Keluarga Harapan/PKH), a national conditional cash transfer scheme targeting low-income households.

Gender inclusion was also incorporated into the participant selection process. Women were intentionally included as program beneficiaries because goat husbandry was considered an activity that could be effectively undertaken regardless of physical strength, thereby providing equitable opportunities for both men and women to participate in productive livelihood activities.

From the perspective of social inclusion, the program reached 30 of the 36 individuals (83%) identified through the 2025 social mapping assessment as poor and elderly residents living within the company's Ring 1 operational area. The issuance of the Decree of the Tanjung Rhu Urban Village Office No. A.100/Kel.TR/2025 concerning the Establishment of the TERSUARA Group for the 2025–2030 period provides formal institutional recognition and strengthens the group's legitimacy within the local governance system.

The establishment of the TERSUARA Group was facilitated through a participatory policy advocacy process involving multiple key stakeholders, including the Acting Head of Tanjung Rhu Urban Village, the Pekanbaru City Agriculture and Fisheries Office, academic institutions, and PT Pertamina Patra Niaga Fuel Terminal Sei Siak. Furthermore, a formal cooperation agreement between the Pekanbaru City Agriculture and Fisheries Office and PT Pertamina Patra Niaga Fuel Terminal Sei Siak concerning the use of a 7,000 m² municipal government land asset provides a long-term legal basis for the program's production activities. This institutional arrangement reflects the principles of multi-stakeholder governance, which are widely recognized as fundamental to the long-term sustainability and scalability of social innovation initiatives.

The findings demonstrate that the TERSUARA Program successfully operationalized a social innovation model grounded in circular economy principles. Its primary strength lies in integrating two interventions that are frequently implemented in isolation: ecological restoration through the cultivation of vetiver grass for riparian conservation and economic empowerment through an integrated community-based livestock production system. These findings support the argument of Geissdoerfer et al. (2017) that the application of circular economy principles at the community level can generate multidimensional value extending beyond improvements in economic efficiency alone.

More specifically, the odor-free livestock housing system, which automatically separates solid and liquid manure, represents a form of reverse innovation within the context of marginalized urban communities. Rather than relying on expensive externally developed technologies, the TERSUARA Group developed a simple, locally appropriate, and low-cost technical solution that can be independently replicated by other smallholder livestock farmers. This characteristic aligns with the conceptualization of social innovation proposed by Deiglmeier et al. (2008), who argue that effective social innovations provide solutions that are more efficient, sustainable, and equitable than existing alternatives while creating value that primarily benefits society as a whole rather than individual private actors.

The 35% increase in average participant income during the first year of implementation represents a substantial achievement within the context of community-based livestock empowerment. This improvement can be directly attributed to the program's ability to create additional economic value through its circular production model. Unlike conventional livestock systems, which typically rely solely on the sale of live animals or meat products, the TERSUARA Program diversified household income through the commercialization of value added by products derived from waste utilization, including organic compost, liquid organic fertilizer, and dried Black Soldier Fly (BSF) meal.

Nevertheless, these economic achievements should be interpreted within a broader socio-economic context. Despite the substantial increase in income, the participants' average monthly earnings (IDR 1,942,143) remained below the 2025 Riau Provincial Minimum Wage (IDR 3,508,776). This gap reflects the structural nature of poverty, which cannot be fully addressed through a single intervention within a relatively short implementation period. As suggested by Adger (2006) in the theory of socio-ecological vulnerability, the transition from vulnerability to long-term resilience requires the gradual accumulation of social, physical, and financial capital. Consequently, the strategic contribution of the TERSUARA Program should be understood as laying the foundation for long-term socio-economic transformation rather than providing an immediate solution to structural poverty.

One of the study's principal theoretical contributions is its demonstration that circularity can function as a dual risk mitigation strategy, simultaneously addressing ecological risks including riverbank erosion, flooding, and livestock waste pollution and economic risks, such as high feed costs, unstable household income, and dependence on a single source of livelihood. By positioning vetiver grass as both an ecological restoration mechanism and a productive input for livestock feed, while simultaneously converting livestock manure into marketable organic fertilizer, the TERSUARA Program creates two complementary resilience buffers that reinforce both environmental and economic sustainability.

This finding is consistent with the concept of eco-efficiency proposed by the World Business Council for Sustainable Development (2019), which emphasizes generating greater value while reducing environmental impacts. In the case of TERSUARA, the system simultaneously produces multiple value-added outputs including livestock products, organic compost, liquid organic fertilizer, and BSF biomass while avoiding approximately 1.648 tCO_2-eq of greenhouse gas emissions annually, reducing 5.71 tons of unmanaged livestock waste per year, and achieving zero organic waste to landfill from office operations. Collectively, these outcomes indicate a favorable eco-efficiency profile that is likely to improve further as production capacity expands.

Another noteworthy aspect of the program is the utilization of office organic waste as feed substrate for BSF larvae. This practice exemplifies what McDonough and Braungart (2002) describe as biological nutrient cycling, whereby organic materials are continuously returned to biological production systems rather than being disposed of in landfills. The application of this concept within a Corporate Social Responsibility (CSR) initiative remains relatively uncommon in Indonesia, positioning the TERSUARA Program as a promising example of circular CSR with considerable potential for replication in other riparian communities.

The substantial increase in knowledge observed following the BSF cultivation training (+91.5%) compared with the other training modules also provides important implications for the design of future community empowerment programs. The findings suggest that participants demonstrate a high capacity for knowledge acquisition when training content introduces genuinely new knowledge that is directly relevant to the practical challenges they encounter in their daily livelihoods. This observation is consistent with the principles of andragogy, which posit that adult

learning is most effective when educational content is immediately applicable to real-world problems.

Furthermore, the local champion mechanism established by PT Pertamina Patra Niaga Fuel Terminal Sei Siak represents an endogenous and sustainable approach to capacity development. By positioning the local champion as both a spokesperson during media engagements and a facilitator of internal knowledge-sharing activities, the company has effectively embedded a community-based knowledge management system within the beneficiary group. As a result, technical knowledge remains within the community even after external facilitation concludes, having been institutionalized through the competencies of the local champion and increasingly capable group members. The succession mechanism for local champions further strengthens the long-term continuity of technical leadership, thereby enhancing the institutional sustainability of the program.

CONCLUSION

This study concluded that the TERSUARA (Ternak Sumber Sari Sejahtera) Program, initiated by PT Pertamina Patra Niaga Fuel Terminal Sei Siak, demonstrated that a circular economy approach could be effectively operationalized as a social innovation strategy to strengthen the socio-ecological resilience of marginalized communities residing in riparian areas. By integrating vetiver-based ecological engineering with an integrated zero-waste livestock production system, the program not only mitigated environmental risks, such as riverbank erosion and livestock waste pollution, but also improved the economic resilience of vulnerable households. Furthermore, the adoption of appropriate technologies, including elevated odor-reducing livestock housing and the conversion of office organic waste into feed substrates for Black Soldier Fly (BSF) larvae, illustrated how ecological efficiency and biological nutrient cycling could be successfully implemented at the community level.

From an economic perspective, the circular production system generated additional value by transforming waste into marketable by-products, resulting in a 35% increase in participants' average income while producing redistributive benefits that primarily supported economically vulnerable households. Environmentally, the program contributed to measurable reductions in operational carbon emissions, decreased unmanaged livestock waste generation, and achieved the diversion of 100% of office organic waste from landfill disposal. These outcomes were further strengthened by improved social cohesion and institutional sustainability through the local champion mechanism, which embedded technical knowledge and leadership capacity within the community. This mechanism supported the continued transfer, adaptation, and independent development of appropriate technologies beyond the external facilitation period.

The findings contribute to the growing literature on social innovation, circular economy, and community-based resilience by providing empirical evidence that integrated circular interventions can simultaneously generate economic, environmental, and social value. Accordingly, the TERSUARA Program provides a practical and potentially scalable model that can be adapted for other riparian communities experiencing similar socio-ecological challenges**.**

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