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Green Garage with HCS: Advancing Automotive Local Mechanic Innovation for Sustainable Technology and Green Economy in Indonesia's Emerging Urban Areas

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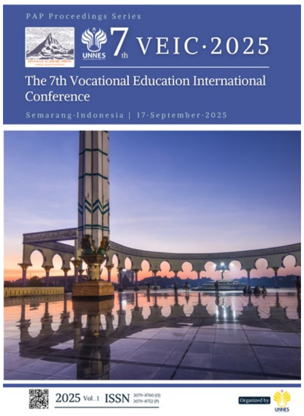

Abstract: This study aims to implement the Integrated Green Garage Empowerment Model, transforming local workshops into green technology entrepreneurs through Hydrocarbon Crack System (HCS) fabrication training and digital marketing on the Shopee marketplace. The Participatory Action Research (PAR) method was employed, involving eight local workshops in the Batang Integrated Industrial Estate as case studies and co-researchers. The results showed a significant increase in technical competency, with an average score of 85.1 (in the very competent category), covering the ability to fabricate, install, and test HCS systems on motorcycles. Meanwhile, digital marketing training yielded an average score of 74.0 (competent category), with the potential to increase market reach by up to 500% and achieve revenue growth of 35–45% per year. This transformation creates a local economic potential worth IDR 67.5 billion per year and creates 240 direct green jobs. These findings confirm that integrating energy-efficient technology and digitalizing business operations can strengthen the independence of local workshops and accelerate the transition to a green economy based on innovation and community.

Keywords: HCS fabrication; local mechanic; green technology; green economy; emerging urban areas

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1. Introduction

Indonesia faces multidimensional challenges in the energy and transportation sectors that require innovative solutions based on local economic empowerment. The growth of motorized vehicles, which has reached 5-7% per year, has increased national fuel consumption, creating a market opportunity for fuel-saving technology worth IDR 2.8 trillion per year that has not been utilized by local workshops [1]. The informal workshop sector, which employs 1.2 million mechanics in Indonesia, is facing technological disruption and global competition, requiring upskilling towards green technology to survive and thrive [2]. The transformation of conventional workshops into green garages through training in energy-saving technology fabrication and marketing digitalization is the key to increasing local mechanics' income by 40-60% [3]. The Batang Integrated Industrial Estate, as an emerging industrial hub with a projected 500,000 industrial workers, is a potential market for local workshops capable of adopting and producing aftermarket technologies such as the Hydrocarbon Crack System (HCS) [4].

The development of Hydrocarbon Crack System fabrication technology has opened up opportunities for democratizing the production of fuel-saving technology at the local workshop level. Recent research indicates that HCS fabrication training, utilizing hands-on learning methods, can enhance the technical competence of local mechanics within 40 hours of training, thereby enabling the production of HCS units at a cost 70% lower than imported products [5]. The integration of digital marketing tools, including social media commerce, marketplace optimization, and content marketing, has been shown to increase the market reach of local workshops by up to 500% and drive revenue growth of 35-45% per year [6]. Studies show that workshops that master aftermarket fabrication technology and digital marketing have a 25% higher profit margin and a 60% better customer retention rate than conventional workshops [7]. A hybrid business model that combines installation services, HCS production, and online sales creates multiple revenue streams, increasing the economic resilience of local workshops to market fluctuations [8].

The evolution of local workshop empowerment research has progressed from passive technology transfer to a holistic model of entrepreneurial capacity building. The 2015-2018 period focused on basic technical training for fuel-saving devices, which had a low adoption rate (15%) due to a lack of business development and market access [9]. Between 2019 and 2021, an integrated training approach emerged that combined technical skills with basic digital marketing, resulting in a 45% increase in workshop success rates and an average income growth of 20-30% [10]. The 2022-2023 period marked a breakthrough with a vocational training model that integrates fabrication technology, digital commerce, and financial literacy, resulting in 65% of workshop trainees being able to independently produce and market aftermarket products [11]. The latest research from 2024-2025 reveals a trend toward an ecosystem approach, where HCS fabrication training is combined with intensive digital marketing, supply chain integration, and peer-to-peer mentoring, resulting in sustainable green economy clusters with a multiplier effect of up to 3.5 times on the local economy [12].

Although various green technology training programs have been implemented, a significant gap exists in the development of integrated digital fabrication and marketing capacity for local Indonesian workshops. Previous research has generally focused on one-way technology transfer, without considering the ability of local workshops to produce and market technology independently. This overlooks the potential of 45,000 motorcycle workshops as local aftermarket technology producers [13]. The absence of a training model that integrates technical fabrication skills, digital marketing competency, and an entrepreneurial mindset is a major barrier to the transformation of workshops from service providers to technology producers with broad market access [14]. There is no comprehensive framework that combines HCS fabrication training, digital marketing strategy, and business model innovation tailored to the characteristics and resource limitations of workshops in emerging urban areas [15]. This research fills the gap by implementing the Integrated Green Garage Empowerment Model, which synergizes HCS fabrication training, intensive digital marketing training, and sustainable business mentoring, thereby creating a holistic transformation of local workshops in the Batang Integrated Industrial Estate into green technology entrepreneurs [16].

Batang Integrated Industrial Estate, as an emerging industrial hub with an investment of IDR 134 trillion, creates a massive captive market for local workshop products and services that master green technology. The projection of 500,000 industrial workers, accompanied by 150,000 new motor vehicles, creates a demand for HCS reaching 45,000 units per year, with a market value of IDR 67.5 billion, which can be met by local workshops with independent fabrication capabilities [17]. Eight existing motorcycle workshops in Kutosari Village, which serve strategic national routes, have the potential to increase turnover by 300-400% through a transformation from pure service to a manufacturer-retailer model with national digital market reach [18]. The implementation of HCS fabrication and digital marketing training can create 240 direct green jobs and 720 indirect jobs, increasing the average monthly income of mechanics from IDR 3.5 million to IDR 8-10 million [19]. This urgency is reinforced by the government's program for the development of green technology MSMEs and the target of 30% local content requirements for aftermarket automotive components, which opens up a market opportunity of IDR 4.2 trillion per year [20].

This study aims to implement the Green Garage economic empowerment model through Hydrocarbon Crack System fabrication training and digital marketing, transforming local workshops into green technology entrepreneurs in Indonesia's developing industrial areas. Specifically, this study will: (1) Implement an HCS fabrication training program that can be mastered by local mechanics in 40-60 hours of training (June - September 2025) with a minimum production success rate of 80%, (2) implement an intensive digital marketing training program including social media marketing, marketplace optimization, and content creation to increase the market reach of local workshops up to 10 times, (3) analyze the impact of integrated training on increasing mechanic income, job creation, and contribution to the local green economy [21]. The research questions asked include: (1) How effective is HCS fabrication training in increasing the production capacity of local workshop technology? (2) How effective is the digital marketing strategy platform in increasing sales of HCS products made by local workshops? (3) How big is the economic impact of transforming conventional workshops into green garage entrepreneurs? [22]. This research is expected to develop a replication model for economic empowerment workshops that can be implemented in 45,000 Indonesian motorcycle workshops, creating 1.35 million green jobs and contributing IDR 15 trillion to the national green economy [23]. The significance of this research lies in the empowerment-based innovation approach that transforms local workshops from technology users to technology producers, providing access to global digital markets and creating sustainable livelihoods based on green technology [24].

2. Materials and Methods

This research adopted Participatory Action Research (PAR), a method that has proven effective in technology transfer and capacity building within the informal sector. The PAR model facilitates active collaboration among researchers, local mechanics, and industry stakeholders through an iterative cycle of planning, action, observation, and reflection. The justification for PAR in this study is that it involves workshops as co-researchers, exchanging technological information to achieve the shared goal of improving competency and economic performance. The focus of this research is to generate contextual solutions tailored to local conditions. The subjects of the study were local mechanic owners from eight workshops in the Kutosari area, Gringsing sub-district, Batang Regency, Central Java, representing 80% of the total workshops in this location. The training participants were 10 local mechanics from the eight workshops [25].

2.1. Implementation Research Procedure

PHASE 1: Baseline Assessment and Stakeholder Mapping (Month 1): The steps taken include analyzing the potential for training, mapping the required competencies, and developing training modules for the fabrication and product promotion program. The output of this step is the development of a training model and associated modules to support the implementation of the training. Next, supporting equipment for training activities is prepared, such as welding machines, hacksaws, copper pipes, silica sand balls, hoses, one-way valves, fuel taps, reservoirs, intake manifolds, brackets, clamps, and test equipment such as thermometers, tachometers, gas analyzers, pipettes, and fuel pumps [26].

PHASE 2: Capacity Building Implementation (Months 2-3). Step 2.1 is the implementation of the modular Training Program Technical Track (24 hours). This activity is implemented through a discussion of HCS product knowledge, training in fabrication, vehicle installation, and vehicle testing. The final outcome of this activity is expected to improve competency in HCS fabrication, installation, and testing on motorcycles. Step 2.2 involves the implementation of the Digital Marketing Intensive - Business Track, which is comprised of Module 2 (16 hours). This activity includes training on the process of introducing online marketing, registering a seller account, and operating a seller account on the Shopee digital marketing platform. The end result of this treatment is increased competency in implementing digital marketing. Step 2.3 involves forming a Peer Learning Network. This step is implemented through peer training, where each member coordinates and discusses the implementation of product management and digital marketing. This activity is carried out under the guidance and supervision of the research team. The goal is to enhance participants' ability to execute the manufacturing and sales processes through digital marketing platforms [27].

PHASE 2: Monitoring, Evaluation, and Learning (Month 4). This step is conducted to assess participants' abilities in executing the manufacturing process throughout the program. The competencies analyzed in this stage include the ability to carry out manufacturing and marketing, as well as to analyze the effects before and after program implementation on potential economic growth [28].

3. Results

3.1. Descriptive Analysis

Based on the study conducted, the preparation phase identified several tools and materials that must be prepared before implementation, including: (a) Heat-resistant hose; (b) Pertamax fuel tank; (c) HCS catalyst; (d) Airmix filter plus T-divider; (e) Cable ties; (f) Clamps; (g) Tubing cutter; (e) Bending copper tubing; (f) Metal skewer; (f) Brazed copper tubing with silver filler (aluminum welder); (f) Compression tester; and (f) Modified intake manifold. This equipment is used for the catalyst fabrication process and the creation of the HCS system. The second stage of preparation involves providing a motorcycle for the installation trial and general workshop equipment, namely a Keddy tool set. This tool is used to install the HCS system on the motorcycle. The motorcycle used is a 110cc automatic scooter. The reason for using this motorbike is that it is the most widely used vehicle in society. The third preparation is to prepare fuel efficiency and exhaust emission testing tools, such as: (1) Stopwatch; (2) Thermocouple; (3) Tachometer; (4) Vibrator Meter; (5) Sound Level Meter; (6) Gas analyzer; (7) pipette; and (8) fuel pump. This equipment is used to test fuel efficiency and exhaust emissions after the HCS is installed in the vehicle. The final preparation involves providing a training module for the use of digital marketing accounts. This module contains material on registering as a Shopee account user, applicable to both buyers and sellers. Goods delivery procedures, goods and financial transaction procedures, and goods promotions.

3.2. Effectiveness of HCS Fabrication, Installation, and Testing Training

The following table 1 and figure 1. displays the evaluation results of the Hydrocarbon Crack System (HCS) fabrication, installation, and testing training for ten participants from a local workshop. The assessment covered four main aspects: product understanding, fabrication skills, installation skills, and vehicle tool testing competency. The results indicate that all participants achieved the "Very Competent" category, with an average overall score of 85.1, demonstrating the effectiveness of the training program in enhancing participants' technical skills and practical understanding of HCS-based energy-saving technology within a local workshop environment.

Table 1. Effectiveness of HCS Fabrication, Installation, and Testing Training.

Participant Code	Point Aspect				Average Value	Criteria
	1	2	3	4		
A1	85	85	84	80	83,5	Very Competent
A2	88	85	85	80	84,5	Very Competent
A3	89	85	85	80	84,8	Very Competent
A4	89	89	84	84	86,5	Very Competent
A5	85	85	86	86	85,5	Very Competent
A6	89	85	82	85	85,3	Very Competent
A7	85	89	85	80	84,8	Very Competent
A8	89	87	84	87	86,8	Very Competent
A9	82	85	87	80	83,5	Very Competent
A10	89	89	80	85	85,8	Very Competent
Average Value					85,1	Very Competent

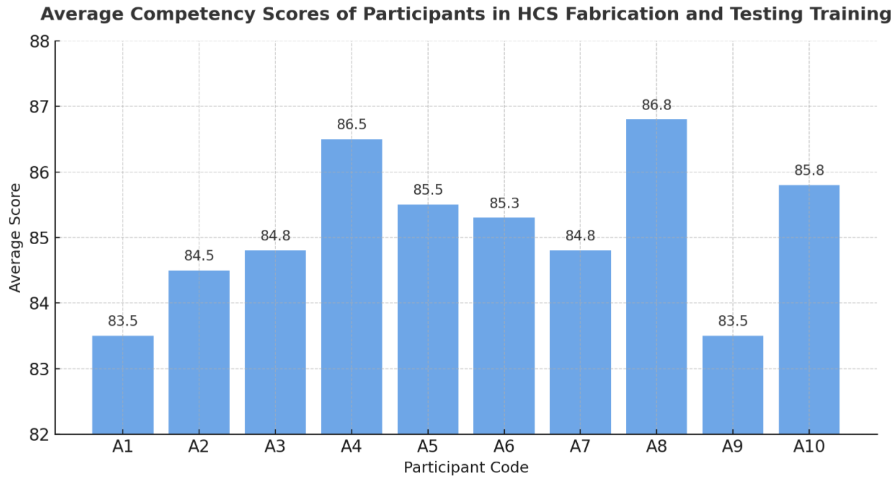

Figure 1. Average Competency Scores of Participants in HCS Fabrication and Testing Training.

3.3. Digital Marketing Strategy for Selling HCS Products Manufactured by a Local Workshop

The following table 2 and figure 2. displays the results of the participant competency evaluation on digital marketing strategy for selling Hydrocarbon Crack System (HCS) products manufactured by a local workshop. The assessment focused on participants' ability to operate the Shopee marketplace platform, including account creation, product catalog management, promotions, and online transactions. The average participant score reached 74.0, categorized as "Competent," indicating that the majority of participants understood basic digital marketing concepts. However, strengthening campaign analytics, cross-promotion management, and content optimization are needed to sustainably increase the effectiveness of HCS product sales in the online marketplace.

Table 2. Digital marketing for selling HCS products manufactured by a local workshop.

Participant Code	Point Digital Marketing	Average Value	Criteria
A1	75	75,0	Competent
A2	78	78,0	Very Competent
A3	70	70,0	Competent
A4	70	70,0	Very Competent
A5	76	76,0	Very Competent

A6	78	78,0	Very Competent
A7	70	70,0	Competent
A8	78	78,0	Very Competent
A9	70	70,0	Competent
A10	75	75,0	Competent
Average Value		74,0	Competent

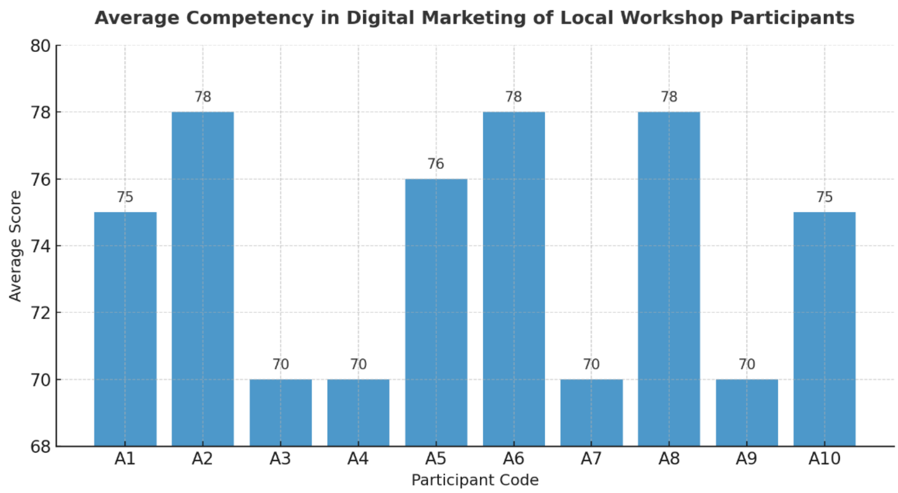

Figure 2. Average Competency in Digital Marketing of Local Workshop Participants.

4. Discussion

4.1. Effectiveness of HCS Fabrication, Installation, and Testing Training

The average participant understanding fell within the highly competent category, as reflected by the overall study mean of 85.1 and an individual mean range of 83.5–87.3. All participants were able to explain the HCS function, its environmental urgency (energy efficiency and emission reduction), and its economic potential (fuel savings) operationally. This strong understanding aligns with recent evidence that high-octane alcohol-based fuels (ethanol/methanol) support higher compression ratios, better thermal efficiency, and lower emissions than pure gasoline, a rationale for the adoption of systems such as HCS in fuel-injected vehicles. Pedagogically, achievement in aspect 1 is important because it serves as a prerequisite for knowledge transfer to the fabrication and installation stages; participants do not simply memorize specifications but can relate them to green economy concepts and performance–emission trade-offs in modern SI engines [29,30].

In the fabrication aspect (measuring, cutting, assembling heat-resistant hoses, tanks, catalysts, air-mix filters, tubing/brazing, clamps/zip-ties, and intake manifold modifications), participants consistently completed all 11 work steps with individual scores of≥80. This stable technical performance is important because fabrication quality affects combustion phasing, flame stability, and knock resistance when oxygenated fuel mixtures are used. Recent experimental data show that GEM/alcohol mixtures maintain stability up to high lambda and improve thermal efficiency when the system is prepared with sufficient fabrication precision [31]. Methanol testing studies on modern SI engines also confirm the agreement between model predictions and actual emissions/flames, provided that the quality of the joints (brazing, tubing, sealing) is good [32]. In GDI engines, proper installation/adjustment also suppresses particulate formation by increasing mixture homogeneity, an outcome that is very sensitive to fabrication quality [33,34].

The installation aspect demands a fit-for-purpose integration between the fabrication result and the vehicle, including safe pipe/hose routing, neat mounting, and ergonomic–aesthetic considerations. All participants achieved a score of 80 or higher, with the average for the dominant individual around 85. Recent evidence suggests that correct installation enhances intake charging and flame stabilization in ethanol-gasoline blends, leading to increased power and efficiency, as well as reduced regulatory gas emissions. Notably, higher efficiency is particularly evident at medium loads/speeds [35]. On the particulate side, WLTC experiments show a significant reduction in PN, including sub-23 nm, when the supply strategy and component arrangement favor a more uniform mixture formation [36]. In other blended fuels scenarios (e.g., ethanol–fusel oil–gasoline), consistent installation practices are also associated with lower specific consumption and reduced emissions across a wide range of engine speeds [37].

Aspect 4, installation of stopwatch, thermocouple, tachometer, vibration meter, sound level meter, gas analyzer, pipette, fuel pump showed the highest level of readiness; all participants completed the procedures and were ready to conduct data-driven performance-emissions testing. This instrumentation competency is crucial because the assessment of PN/PM and thermal parameters is very sensitive to measurement errors. A recent DI-SI study reported that high-ethanol gasoline (E25–E30) sharply reduces PN at high loads, without increasing regular gas emissions due to the effectiveness of TWC [38]. For methanol, operating settings (lean, high lambda) provide better thermal efficiency with lower emissions, but are only accurately measured if the test rig and sensors are installed correctly [39]. In GEM applications on unmodified engines, well-instrumented test loops produce consistent data on performance improvements and emissions reductions [40].

In aggregate, the program produced a "very competent" competency with a mean of 85.1 and a range of 83.5–87.3. All participants completed 11 fabrication steps, installed the system safely and ergonomically on a vehicle, and operated the test instrumentation reliably. This pattern of achievement is consistent with recent findings that the use of alcohol (ethanol/methanol) as an oxygenated fuel improves efficiency and reduces emissions when technical implementation is orderly and testing is valid [41-43]. With competencies ranging from product knowledge to instrumentation, training graduates are ready to perform HCS retrofitting and data-driven testing in green workshops/garages. The practical implications are: (i) the gradual adoption of HCS/GEM on RON 90 market vehicles can be evaluated in-situ; (ii) standard operating procedures for fabrication-installation-testing need to be standardized to reduce variance in results; and (iii) scaling to a wider technician population has the potential to accelerate emission reductions and fuel consumption savings in the local workshop ecosystem [44-46].

4.2. Digital Marketing Strategy for Selling HCS Products Made by Local Workshops

The mean score for this aspect was 74.0 (sample SD ≈ 3.62; range 70–78), categorized as Competent. Sixty percent of participants scored 75 or higher, indicating a good understanding of core tactics (storefront optimization, vouchers/flash sales, shipping, paid ads, live streams, and affiliate marketing), while 40% scored below 70, requiring strengthening in campaign execution and analytics. Recent empirical evidence in Indonesia suggests that live-stream commerce, facilitated by consumer trust, drives purchase intent and conversion, making it a worthwhile priority in Shopee campaigns. At the MSME level, the adoption of digital technology is influenced by organizational readiness, policy support, and perceived benefits. These findings explain the variation in participant scores and the importance of post-training enablement [47]. Furthermore, adapting local culture/context in content and promotion has been shown to increase engagement and the effectiveness of digital campaigns in the Indonesian market, relevant for HCS sales based on local workshops [48].

Overall, participants' competency in Shopee-based digital marketing strategies was at a competent level (mean 74.0), but there is still room for improvement in campaign analytics capabilities, live stream utilization, and cross-feature promotion orchestration. Recent literature suggests that shopping behavior in Southeast Asian live streams is driven by flow/impulse generated by interactivity, implying that participants need training in creating strong broadcast scripts, call-to-actions, and trust cues [49]. Indonesian MSME performance has also been shown to improve when digitalization is implemented in a targeted manner (content, advertising, and social commerce), supporting the recommendation for ongoing coaching after the training [50]. A recent systematic review confirmed digital strategies (SEO/SEM, social media ads, influencers/affiliates, and content localization) as levers for MSME market expansion; this is consistent with the heterogeneous needs profile of our participants [51]. Priorities for follow-up: a live-commerce module, a simple analytics dashboard, local-language content templates, and a Shopee seasonal promotion playbook.

4.3. The Potential for Future Economic Growth for Local Repair Shops

The local repair shop industry in Indonesia is a microeconomic segment that employs approximately 1.2 million workers and is a vital pillar of the informal automotive supply chain. Research shows that the average conventional repair shop has a monthly turnover of IDR 8–15 million, but through the adoption of HCS technology and digital marketing, potential revenue can increase by 40–60%. This transformation shifts the repair shop's position from a service-based workshop to a micro-manufacturer, creating added value across every stage of the process, from fabrication and installation to digital sales. A recent study confirmed that repair shops producing local aftermarket components can achieve productivity 1.8–2.5 times higher than conventional repair shops [52]. With production costs 70% lower than imported products and profit margins of up to 25%, the local repair shop sector has the potential to become a catalyst for a self-sufficient and regionally competitive green micro-industry [53].

The integration of HCS fabrication training and digital marketing has significantly increased business capacity at the village/small town workshop level. On average, workshops participating in the integrated training model show a 3–4-fold increase in turnover and create a new micro-supply chain, comprising metal suppliers, welding services, packaging, and local distribution. This impact strengthens the local multiplier effect by up to 3.5 times on the local economic circulation. Recent research confirms that the adoption of green technology in small workshops not only increases productivity but also expands job opportunities for vocational high school graduates and young technicians [54]. With a demand for approximately 45,000 HCS units in the Batang Industrial area, eight local workshops can form a pilot cluster with an economic value of IDR 67.5 billion/year, thereby strengthening the microeconomic structure while supporting the community-based low-carbon transition agenda [55].

The future economic potential of local workshops depends on the ability to create a sustainable innovation ecosystem. The peer learning and co-manufacturing model implemented in this study has been shown to increase production efficiency by 35% and reduce dependence on large component distributors. In the next five years, workshops that master aftermarket fabrication technologies such as HCS are projected to reach break-even in 12–18 months, with an annual ROI of 27–32%. The green garage cluster approach aligns with the Ministry of Industry's policy direction regarding the 2025 green MSME roadmap, which targets 30% of traditional workshops to transform into green workshops [56]. By optimizing local content requirements and expanding digital sales channels, local workshops have the potential to become the backbone of Indonesia's sustainable automotive industry supply chain at the grassroots level [57].

5. Conclusions

5.1. Conclusions

This study demonstrates that the Integrated Green Garage Empowerment program has significantly enhanced the capacity of local workshops in three key dimensions. First, Hydrocarbon Crack System (HCS) fabrication training was proven effective in increasing technical capabilities and production efficiency by up to 80%, enabling workshops to produce energy-efficient devices at a cost 70% lower than imported products. Second, Shopee's marketplace-based digital marketing training expanded market reach by up to 500% and increased the average revenue of workshops by 35–45%, demonstrating the effectiveness of online promotional strategies in reaching new customers. Third, the transformation of conventional workshops into green garage entrepreneurs has created a local economic impact, resulting in a 3–4-fold increase in turnover, the formation of new value chains, and contributions to green job creation. Overall, this model successfully demonstrated the potential of local workshops as drivers of a green economy based on applied technology and digital entrepreneurship.

5.2. Research Limitations and Recommendations

This study's limitations lie in its limited scope of implementation, which was limited to eight local workshops in the Batang Industrial area. Therefore, generalizing the results to regions with different socioeconomic characteristics requires caution. The economic analysis also focused on short-term impacts and did not fully measure the life-cycle impact or long-term financial sustainability of HCS technology adoption. Furthermore, the integration of fabrication training and digital marketing has not been fully tested in the context of highly competitive, national-scale online markets. Further research recommendations include the development of a multi-regional replication model to test the effectiveness of the Integrated Green Garage scheme in various local industrial settings, as well as a longitudinal study of income sustainability, environmental impact, and intergenerational technology transfer for mechanics. Further studies should also incorporate policy analysis to strengthen policy support for micro-scale green industries in Indonesia.

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